WiMAX – Delivering on the Promise of Wireless Broadband

Using Xilinx FPGAs in the MAC subsystem provides a key differentiator in WiMAX product design.

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Much of the current excitement surrounding WiMAX is driven by both technological and commercial reasons. The industry is facing tremendous pressure to reduce cellular network costs, which is possible by achieving greater efficiency of the wireless spectrum than is currently feasible with today's mobile networks. This efficiency can be achieved by using a mixture of advanced technologies that allow very quick changes to user traffic modulation and coding schemes, in conjunction with advanced error correction and traffic scheduling schemes.

WiMAX builds on a network equipment design philosophy, similar to Ethernet and WLAN specifications, that has significantly reduced costs and enables increased efficiency within the enterprise environment. Its challenge is to prove that such benefits can scale and can be applied to wider public networks.

A Closer Look at the Specification

The IEEE 802.16 standard specifies a system comprising two core components: the subscriber station (SS) or customer premises equipment (CPE), and the base station (BS). A BS and one or more SS can form a cell with a point-to-multipoint (P2MP) structure. On air, the BS controls activity within the cell, including access to the medium by any SS, allocations to achieve QoS, and admission to the network based on network security mechanisms.

Multiple BSs can be configured to form a cellular wireless network. When using OFDM, the cell radius can reach as far as 30 miles; however, this requires a favorable channel environment and only the lowest data rate is achievable. Practical cell sizes usually have a small radius of around 5 miles or less. Note that the WiMAX standard also can be used in a point-to-point (P2P) or mesh topology, using pairs of directional antennas to increase the effective range of the system relative to that possible with P2MP.

The 802.16 MAC protocol is designed specifically for the P2MP wireless access environment. It supports transport protocols such as ATM, Ethernet, and Internet Protocol (IP), and can accommodate future developments using the specific convergence layer (Figure 1). The MAC also accommodates very high data throughput through the physical layer while delivering ATM-compatible quality of service (QoS), such as UGS, rtPS, nrtPS, and Best Effort (BE) (Figure 2).

The 802.16 frame structure enables terminals to be dynamically assigned uplink and downlink burst profiles according to the link conditions. This allows for a trade-off to occur – in real time – between capacity and robustness. It also provides, on average, a 2x increase in capacity when compared to non-adaptive systems.

The 802.16 MAC uses a variable-length protocol data unit (PDU) and other innovative concepts to greatly increase efficiency. Multiple MAC PDUs, for example, may be concatenated into a single burst to save PHY overhead. Multiple service data units (SDUs) may also be concatenated into a single MAC PDU, saving on MAC header overhead. Fragmentation allows very large SDUs to be sent across frame boundaries to guarantee the QoS. Payload header suppression can be used to reduce the overhead caused by the redundancy within the SDU headers.

The 802.16 MAC uses a self-correcting bandwidth request/grant scheme that eliminates any delay in acknowledgements, while allowing better QoS handling than traditional acknowledgement schemes. Depending on the QoS and traffic parameters of their services, terminals have a variety of options available to them for requesting bandwidth.

The 802.16 privacy layer follows the model adopted by DOCSIS. The data encryption standard (DES), in cipher block chaining (CBC) mode, is used to encrypt payload for transport and secondary man-

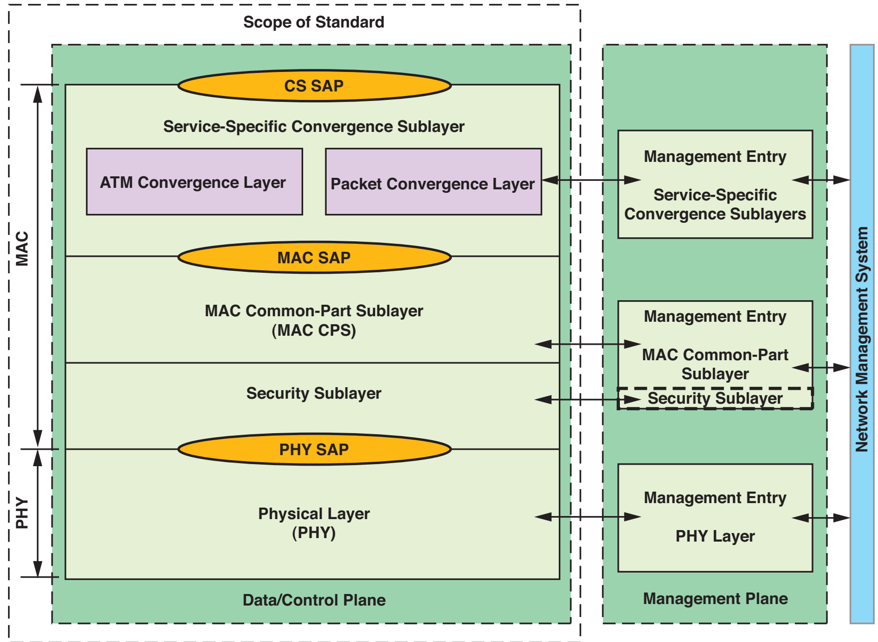

Figure 1 – The 802.16 protocol stack

Service	Definition	Applications	Mandatory QoS Parameters
UGS	Real-time data streams comprising fixed-size data packets issued at periodic intervals	T1/E1, VoIP without Silence Suppression	• Maximum Sustained Traffic Rate = Minimum Reserved Traffic Rate • Maximum Latency • Tolerant Jitter • Request/Transmission Policy
ertPS	Real-time service flows that generate variable-sized data packets on a periodic basis	VoIP with Silence Suppression	• Maximum Sustained Traffic Rate • Minimum Reserved Traffic Rate • Maximum Latency • Request/Transmission Policy
rtPS	Real-time data streams comprising variable-sized data packets that are issued at periodic intervals	MPEG Video	• Minimum Reserved Traffic Rate • Maximum Sustained Traffic Rate • Maximum Latency • Traffic Priority • Request/Transmission Policy
nrtPS	Delay-tolerant data streams comprising variable-sized data packets for which minimum data rate is required	FTP	• Minimum Reserved Traffic Rate • Maximum Sustained Traffic Rate • Traffic Priority • Request/Transmission Policy
BE	Data streams for which no minimum service level is required and therefore may be handled on a space-available basis	HTTP	• Maximum Sustained Traffic Rate • Traffic Priority • Request/Transmission Policy

Figure 2 – QoS classes of service

agement connections. The personal knowledge management (PKM) protocol provides certificate-based authorization of the SS and performs the transfer of keys between the BS and the SS using RSA public key methods and x.509 certificates.

The network entry of any device involves a set of tasks to authenticate and synchronize the BS and SS. Once the BS downlink signal is synchronized, the uplink channel descriptor (UCD) is used to get the timing parameters and the initial ranging contention slot. During the SS ranging process, the BS allocates various management messages for negotiated capabilities followed by registration. Using PKM, a secured secondary management connection is established for authorization. The system is now ready to operate through user connections using various IP protocols, by deploying various MAC services. Regular ranging and channel condition monitoring manages the channel resources.

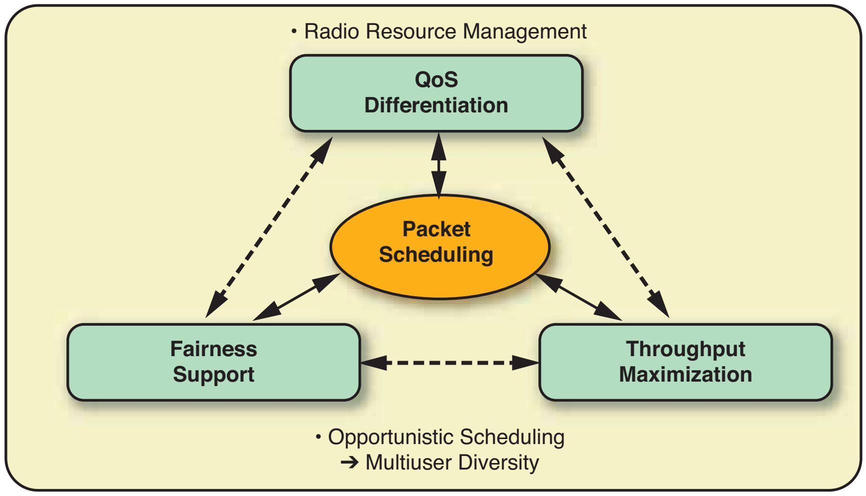

Figure 3 – Packet scheduling, as specified by 802.16, enables a maximization of resources.

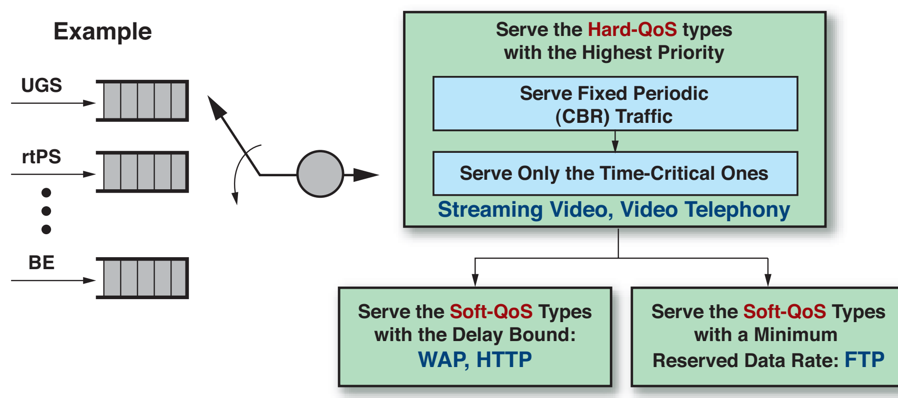

Figure 4 – The functionality of the packet scheduler entails scheduling for different classes of users.

QoS and Scheduling

A high level of QoS and scheduling support is one of the interesting features of the WiMAX standard. These service-provider features are especially valuable because of their ability to maximize air-link utilization and system throughput, as well as ensuring that service-level agreements (SLAs) are met (Figure 3).

The infrastructure to support various classes of services comes from the MAC implementation. QoS is enabled by the bandwidth request and grant mechanism between various subscriber stations and base stations. Primarily there are four buckets for the QoS (UGS, rtPS, nrtPS, and BE) to provide the service-class classification for video, audio, and data services, as they all require various levels of QoS requirements. The packet scheduler provides scheduling for different classes of services for a single user. This would mean meeting SLA requirements at the user level. Users can be classified into various priority levels, such as standard and premium (Figure 4).

Managing Mobility for IEEE 802.16-2005

Handover at high speed, and with low packet loss, is a key requirement for IEEE 802.16-2005 systems. Although much of the handover can be done at the software layer, performance requirements push a part of this functionality into the hardware level.

To identify a neighboring network and define its characteristics in relation to an associated mobile service station (MSS), base stations periodically broadcast a neighbor advertisement management message. Each MSS scans the neighbor BS and measures the signal strength. It then selects the neighbor BS and prepares for the future handover by performing ranging and association procedures.

The performance of a handover is determined by the authentication speed of a user moving from one cell to another cell. Differentiation comes from fast adaptation to changing QoS needs for mobility. The MSS can be stationary or mobile, and the QoS profile can change. The SLA may even employ a different policy for mobile and stationary use.

Sub-Channel Allocation for MAC/PHY Interaction

As the number of subscribers increase, multipath fading and path loss become more significant. OFDMA, based on OFDM, is immune to inter-symbol interference and frequency-selective fading. Achieving high transmission rates depends on the ability of the broadband wireless access (BWA) system to provide efficient and flexible resource allocation. Significant performance gains can be

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obtained if frequency hopping and adaptive modulation techniques are used in sub-carrier allocation, with channel gain in the transmitter. The optimal solution is to schedule the user with the best channel at each time. Of course, this procedure is not as simple as it sounds, because the best sub-carrier for the user may also be the best sub-carrier for another user, who has no other good sub-carrier options. The QoS requirement is defined as achieving a specified data transmission rate and bit error rate (BER) for each user in each transmission.

Scalable OFDMA

The concept of scalability was introduced as part of the OFDMA physical layer mode of the IEEE 802.16 wireless MAN standard. A scalable PHY allows standards-based solutions to deliver optimal performance in channel bandwidths ranging from 1.25 to 20 MHz, with fixed subcarrier spacing for both fixed and portable/mobile usage models while keeping product costs low. A sub-channel structure, with variable FFT sizes per channel bandwidth, enables scalability.

The WiMAX specification also supports advanced modulation and coding (AMC) sub-channels, hybrid automatic repeat request (HARQ), high-efficiency uplink sub-channel structures, multiple-input-multiple-output (MIMO), coverage-enhancing safety channels, different sub-carrier allocations, and diversity schemes. The WiMAX MAC supports scalability using feedback from CQI and HARQ requests.

Key Implementation Challenges

Perhaps the most crucial challenge when implementing a WiMAX system is defining what should be done in the processor and what should be done in hardware, or more specifically, the FPGA-based accelerator. Key to establishing this hardware/software partition is finding the optimal trade-off between system performance and processing requirements, as compared to time-to-market needs. The way in which this trade-off is resolved will result in a variety of different CPE and base station implementations.

WiMAX CPE designs need to adopt a processor-based approach, with lower MAC functions like CRC and encryption/decryption implemented using a hardware accelerator. Base-station implementation, on the other hand, would need to evolve from a lower MAC accelerator to a slow path/fast path approach to packet processing. To achieve this in hardware, the base-station MAC implements slower management and control functions using a processor (either embedded or external to the FPGA), while implementing faster data path functions using the FPGA logic fabric for hardware acceleration.

The key to MAC implementation is to provide the support for handling the "triple play" of voice, data, and video using appropriate queuing and scheduling. Although the IEEE 802.16 standard provides an effective baseline for such functionality, differentiating between competitive solutions comes from how this feature is specifically implemented. Xilinx® FPGAs enable manufacturers to target this critical area of system design and provide a flexible platform on which new MAC functions can be targeted and developed.

The latest Virtex™-4 FX Platform FPGAs include a low-latency auxiliary processor interface (APU) that enables you to simplify the hardware/software partition by allowing customized instructions to be put into software code, which when executed are implemented in the logic fabric.

Advanced DSP functions such as high-performance FEC provide another area in which Xilinx Platform FPGAs can enable product differentiation and advanced functionality. With the release of an optimized Turbo Convolutional codec and its inclusion in a low-cost WiMAX FEC pack, Xilinx has enabled system designers to gain access to highly efficient FPGA cores that can rapidly be deployed as part of a flexible FEC solution in a WiMAX baseband design.

Of course, there are many other areas of a WiMAX base station design – beyond the scope of this article – in which Xilinx technology can add real value. Xilinx devices are now routinely used to implement advanced DSP correction algorithms in the RF card, in areas such as crest factor reduction (CFR), digital predistortion (DPD), and digital up/down conversion (DUC/DDC). By correcting the characteristics of a power amplifier (PA) digitally, you can realize large cost savings by utilizing more cost-effective analog RF circuitry, thereby significantly reducing the cost of the overall base station. For more information about this, visit *www.xilinx.com/esp/wireless*.

Conclusion

Although a great deal of debate continues to swirl around the WiMAX standard and its merits in comparison to incumbent cellular standards, current trends suggest that WiMAX is an ideal platform for the delivery of voice, data, and video over wireless. Xilinx has been involved in the early stages of the WiMAX standardization process. Our products' unique feature set enables our customers to get their WiMAX designs out into the market before the competition.

Xilinx has been working with a number of customers on accelerated traffic management solutions in wireless MAC applications. Each implementation can be customized depending on the application. If you have an opportunity, or wish to find out more, email *espteam@xilinx.com*.