Wireless LAN Revolution: from Silicon to Systems

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Abstract: Advances in silicon technology have brought forth the tremendous success of the modern-day wireless industry, demonstrating a 40% yearly growth in the cellphone industry. The wireless local area network (wireless LAN) has also expanded its deployment in recent years. To increase the performance and to serve various usage models, the wireless LAN industry has proposed a few standards. These approaches, however, are only a small step forward in comparison to what is achievable with current-day CMOS technology, not to mention what will be possible with next-generation processes. The new era of wireless LAN will be built on a combination of breakthroughs in wireless signal processing and the ever more powerful CMOS processes to deliver a ubiquitous wireless fabric, allowing connectivity of a multitude of computation and consumer devices incorporating a variety of data rates and quality of service.

I. INTRODUCTION

Wireless LANs in business applications enable mobile computing devices to communicate with one another and access information sources on a continuous basis without being tethered to network cables. In the home, the demand for wireless networks is also growing as multi-computer homes look for ways to communicate among computers and share resources such as broadband internet connections. The home LAN is beginning to stretch the traditional notion of the LAN as primarily a means of connecting computers. Consumer electronics devices are being added to home wireless LANs. Thus enters the concept of the multi-service home network, which supports a broad variety of media and computing devices as part of the same network.

Over the past decade, three major developments happened in the wireless world: wireless capacity expansion through advanced signal processing, continued scaling of CMOS technology for high GHz operation, and the newly opened 5-GHz spectrum by FCC. We now have the tools to design low-cost, high-speed wireless communications devices to satisfy the requirements of future wireless LANs.

By leveraging advanced digital signal processing techniques, the design of RF front-end circuitry could be greatly simplified, and the loss of signal strength due to multi-paths and less aggressive technology could be more than compensated for by coding and enhanced diversity. Through an integrated design approach, low cost, high performance and robustness of the overall system can be achieved at the same time.

II. CMOS TRANCEIVER DESIGN

We address the wireless communication problem from the device, circuit and system perspectives simultaneously. At the architectural level, we recognize that the continued performance improvements of digital CMOS technology promote a system design philosophy that shifts the burden to the digital domain as much as possible. The design ability to integrate all of the RF circuitry with the digital processing presents the unique opportunity to maximize performance by joint design of the two domains, while simultaneously reducing cost and power consumption.

This combination of signal processing and RF functional blocks enables fully integrated, 5-GHz wireless LAN devices to be implemented in the standard CMOS technology. One of our designs achieved a data rate exceeding 100 Mbps. The use of the standard CMOS technology means a significant reduction in the cost of future wireless systems. And the continual scaling of the CMOS processes can further enhance the cost and performance benefits of this approach.

As an example, Figure 1 illustrates the design of a wireless LAN chipset compliant with the IEEE 802.11a standard (which is to be discussed in the next section). The chipset contains an analog transceiver and a digital baseband processing chip that work together to deliver a wireless LAN system.

The analog transceiver operates in the 5-GHz UNII band (5.15-5.35 GHz), implemented in a standard 0.25um CMOS process. The circuit includes all active RF and baseband analog circuits on a single-chip, including the synthesizer and the power amplifier. The only off-chip components required to implement a wireless LAN system are an antenna, RF band select filter, a Tx/Rx switch, two baluns, a reference clock, resistors, inductors, and capacitors. No special Ceramic or SAW IF filters are required, nor are off-chip resonating elements for VCOs. The transmit path has a single mixing stage that converts the baseband signal to RF. Programmable gain amplifiers in the transmit path allow transmit power control. The synthesizer

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generates the three local-oscillation frequencies required. A serial interface is used to control the circuit, including several levels of power saving and digitally controlled gain settings. The receive path uses two stages of mixing to convert the input signal from RF to the baseband. Programmable gain amplifiers in the baseband have their gain and offset controlled from the digital chip.

The baseband processing chip is also implemented in 0.25um CMOS. It contains a transmitter and a receiver. The transmitter first powers up the analog chip gracefully before generating the packet. Data bits are first scrambled by a scrambling sequence, then convolutionally encoded with puncture codes, padded with zeros at the end, followed by an interleaver before mapped to a constellation. The digital receiver performs reception and detection of transmitted data. The reception task is composed of magnitude, timing, and frequency acquisitions of the received packet. The detection task is composed of filtering, frequency offset correction, phase and magnitude correction, FFT, constellation translation, de-interleaving, Viterbi decoding, de-scrambling, data assembling and status reporting to the media access control unit (MAC).

The 802.11 MAC [1] performs all the necessary operation for the transceiver chipset to communicate with a higher-level protocol such as TCP/IP. The IEEE 802.11 standard chose a collision-avoidance mechanism, rather than the collision-detection scheme as in the Ethernet, to increase the efficiency of wireless communication. This MAC also regulates the operation of both the analog and digital chips to guarantee a seamless data transfer between the host machine and the analog transceiver.

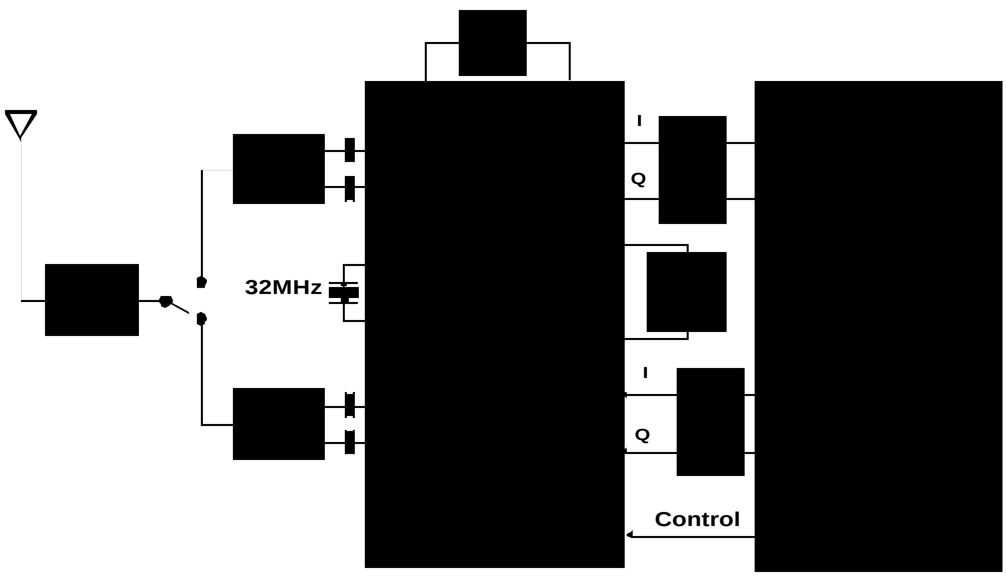

Figure 1. A CMOS wireless LAN chipset.

III. SCALABLE WIRELESS LAN DESIGN

Popular wireless networking protocols such as Bluetooth, IEEE 802.11b, and HomeRF were originally developed for the 2.4-GHz frequency band by organizations that made design tradeoffs based on values such as complexity, price, and performance. The various protocols do not easily interoperate with one another and can cause significant mutual interference when functioning in the same radio space.

Newer high-performance wireless LAN standards such as IEEE 802.11a [2] and ETSI HiperLAN2 [3] operate in the 5-GHz band and offer much higher speeds than previous wireless LAN standards, but do not yet adequately provide for unified networks that support multiple classes of devices with differing speed, performance, power, complexity, and cost requirements.

The 5-GHz Unified Protocol (5-UP™) is a proposed extension to existing 5-GHz wireless LAN standards that supports data transfer rates to over 100

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Mbps and also allows a wide variety of lower-power, lower-speed devices carrying diverse traffic types to coexist and interoperate within the same unified wireless network.

A. 5-Ghz Wireless LAN Physical Layer

The physical layers of both 802.11a and HiperLAN2 are based on Orthogonal Frequency Division Multiplexing (OFDM) [4], a modulation technique that uses multiple carriers to mitigate the effects of multi-path. OFDM distributes the data over a large number of carriers that are spaced apart at precise frequencies.

Both HiperLAN2 and 802.11a provide for OFDM with 52 carriers in a 20 MHz bandwidth; 48 carriers are for data, the rest four are for pilot signals. Each carrier is ~300 KHz wide, giving raw data rates from 125 Kbps to 1.5 Mbps depending on the modulation type employed and the amount of error-correcting code overhead. Considering the net of the 48 data carriers, a 4 us symbol duration, and the various modulations and codes, data rates from 6 Mbps to 54 Mbps are supported.

The high data rates supported by 802.11a are more than sufficient to scale to the needs of both present and future home network traffic such as multiple streaming MP3 audio, VoIP telephony, Internet access, digital TV, MPEG-2 DVD streams, and even Video-on-Demand services.

Clearly, the 5-GHz band under 802.11a and HiperLAN2 is a vast improvement over 2.4-GHz and its protocols. However, to provide a complete solution for wireless home networks, these standards need to be extended to address remaining challenges.

B. 5-GHz Unified Protocol

The 5-GHz Unified Protocol (5-UP) proposal extends the OFDM system to support multiple data rates and usage models. It is not a new standard, but an enhancement to the existing IEEE and ETSI standards that would permit cost-effective designs in which everything from cordless phones to high-definition televisions and personal computers could communicate in a single wireless multimedia network with speeds up to 108 Mbps. 5-UP achieves this by allocating the carriers within the OFDM signal on an individualized basis. In addition, 5-UP includes the ability to allocate additional carriers beyond the 52 carriers currently specified to 104 carriers. This allows the doubling of bandwidth, potentially to 108 Mbps, for nodes able to take advantage of very high capacity.

By creating a radio system that scales from 125 Kbps to 108 Mbps (in 125 Kbps steps), 5-UP provides scaleable communications by allowing different nodes to simultaneously use different subsets of the OFDM carriers. An example is shown in Figure 2. In this figure, the laptop, PDA, and VoIP phone are simultaneously transmitting to an access point. The laptop device generates its OFDM signal using an inverse Fast Fourier Transform (IFFT). It would be simple for this device to avoid transmitting on some of the carriers by zeroing out some of the inputs to the IFFT and using only the remaining inputs to transmit data. Low-data-rate devices can then occupy the slots that were omitted by the laptop.

At the receiving side, all carriers can be simultaneously received by the access point and recovered through its single FFT based receiver. Finally, when the access point transmits to the other nodes, it can use a single IFFT to simultaneously create all the carriers. Each of the other nodes can receive only its subset of carriers, discarding the data that comes in carriers intended for a different node.

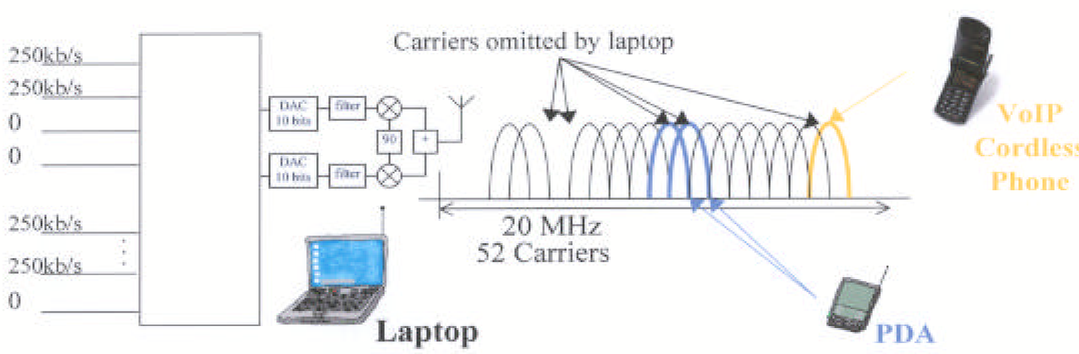

Figure 2. Scalable carrier allocation for 5-UP.

The great advantage to this approach is that both the analog and digital complexity required in the radio scales with the number of carriers that can be transmitted/received. The following table highlights the relative analog and digital complexity required to achieve a given data rate, where N is the number of carriers for each device.

Rate	N	Mod	Tx Power*	ADC	FFT Size
125 Kb/s	1	BPSK	0.8 mW	4 bits	None
750 Kb/s	1	16 QAM	0.8 mW	5 bits	None
1.5 Mb/s	4	QPSK	3.2 mW	5 bits	4
6 Mb/s	8	16 QAM	6.4 mW	6 bits	8
12 Mb/s	16	16 QAM	12.8 mW	7 bits	16
36 Mb/s	48	16 QAM	40 mW	8 bits	64
54 Mb/s	48	64 QAM	40 mW	8 bits	64

*TX power based on lower 100 MHz of US UNII band.

Along with allowing the construction of radios that are scaled down in complexity and data rate, 5-UP includes the ability to aggregate two 20-MHz channels to provide data rates up to 108 Mbps. When two 20-MHz channels are aggregated, there are a total of 104 carriers, 96 of which are used for data, and 8 of which are pilots. 802.11a allocates eight 20 MHz channels in the lower UNII band (5.15-5.35 GHz), and four more 20 MHz channels in the upper UNII band (5.725-5.825 GHz). Therefore, when aggregated, there are four 40 MHz channels available in the lower band, and two 40 MHz channels in the upper band. A total of six channels for different access points to operate on is sufficient for most environments. For comparison, the 802.11b standard that allows for 11Mbps communication gets by with only three channels. However, in dense environments such as apartment complexes, restricting operation to 20 MHz channels may be appropriate.

Once the channels are aggregated, they can be used just as a single channel would be used in the current 802.11a and HiperLAN2 standards. The 104 carriers may also be individually allocated for overlaid transmission as previously described.

5-UP enables the building of radios with a broad range of complexity, which in turn results in a range of power and price points that serve a multitude of different data rate requirements, allowing all to function simultaneously and efficiently in a high-data-rate system. The following table lists examples of the data rates and applications that can be met using various modulations and numbers of carriers.

Rate	Applications	N	Mod
125 Kb/s	Cordless phone, remote control	1	BPSK
1.5 Mb/s	High fidelity audio	2, 4	16-QAM, QPSK
12 Mb/s	MPEG2 video, DVD, satellite, xDSL, cable modem, data network	12, 16, 32	64-QAM, 16-QAM, QPSK
20 Mb/s	HDTV, future cable or VDSL modem	18, 27	64QAM, 16QAM

IV. CONCLUSIONS

By combining RF circuit design techniques, submicron CMOS technology and advanced digital signal processing, we have delivered low-cost, high-performance wireless communication devices that will change the notion of wireless connectivity in the future. Furthermore, the proposed 5-GHz Unified Protocol is a definitive step forward in the development of a scalable wireless LAN standard for home networking that will allow all wireless devices, regardless of their bandwidth requirement, to interoperate on the same network, while at the same time providing scaleable cost, power usage, and bandwidth allocation.

REFERENCES

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