Chapter 1
Introduction

1.1 Motivation

The second half of the 20th century has been a remarkable period for technological innovation, and particularly so for telecommunications. During the first half of the last century, telecommunications was almost entirely in the analog mode. Digital transmission of voice and low-speed data communications were the first ventures into digital transmission along a twisted pair telephone line. The invention of the transistor and the subsequent innovation of integrated circuits quickly led to a revolution in electronics and in communications in general. The rapid development of computer and consumer electronics, traditional telephone subscribers are ready for new services based on digital technologies. Driven by the deregulation in the telecommunications industry and the vast growth rate of internet users, world wide industry has made enormous efforts to deploy and standardize a multitude of various different access technologies ranging from media such as air, twisted-pair copper cables, coax cables and optical fibers. Applications such as video conferencing, fast internet downloads, digital television and tele-working have been made available to the public with wide coverage. With a powerful PC processing lots of information, the capability of a voice band modem becomes a limiting factor. The voice channel is limited by the 3.1 kHz band bottlenecking the achievable data-rate for integrating consumers to the evolving high-speed digital communication network. The drawback of a telephone modem can be overcome with the Digital Subscriber Line (DSL) technology. There were several key innovations such as Integrated Service Digital Network (ISDN) and High bit-rate Digital Subscriber Line (HDSL) that led to an application for a system that transmitted to the customer at a high data-rate for supporting entertainment features such as video on demand or simple download of any desired data. The emerging market ultimately led to the conception of the Asymmetric Digital Subscriber Line (ADSL). ADSL allows for simultaneous transmission of digital data and Plain-Old Telephone Service (POTS) signal on a twisted-pair wire. This fact turned out to be one of the success factors during the commercial launch of this product since it could be easily put on top of the already widely spreaded POTS system.

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Beside the use of electrical conductors the wireless technology has become a very important branch in telecommunications for transferring any kind of data over a short or long distance. The wireless technology has been the driving force for enabling new services such as satellite television, mobile telephones, personal digital assistants and wireless networking. For the home and business user, wireless has become popular due to ease of installation, and location freedom with the gaining popularity of laptops. The data exchange between computers demands for broadband and flexible computer network solutions such as in a local area network (LAN). Basically, a LAN covers a small geographic area, like a home, office, or group of buildings and provides access to a computer network at high data transfer rates. A Wireless Local-Area Network (WLAN) is a local-area network (LAN) without employing any kind of wires. WLAN solutions have been around for more than a decade, but these are just beginning to gain momentum because of falling costs and improved standards. In 1991, the IEEE 802.11 committee had started its activities to develop a standard for wireless LANs. By 1996, the technology became relatively mature, a variety of applications had been identified and addressed. The IEEE 802.11 standard supports various versions such as 802.11a and 802.11g offering 54 Mbit/s in the 5 GHz band and the 2.4 GHz, respectively.

Regardless of wireline or wireless communication solutions, on the physical layer there is a strong demand for wide band and high performance Analog-to-Digital (A/D)-data-converters being the link between the analog and digital world. Providing digitized data with sufficient quality allows for doing digital signal processing of the received data stream. The required performance of the A/D-converter is influenced by architectural considerations on system level in order to not compromise the maximum data-rate. That means, beside the right approach on system level, the architectural choice for the A/D-data-converter implementation is crucial for achieving the targeted performance and for keeping the overall costs low of the whole system implementation.

1.2 Organization of This Book

This book deals with oversampling converters processing baseband signals, i.e. signals with spectra centered around zero Hertz Direct Current (DC). The focus is on the design of delta-sigma modulators embedded in digital CMOS technologies for communication systems. The target applications will be Asymmetric Digital Subscriber Line (ADSL) as well as Wireless Local-Area Network (WLAN) covering bandwidths from 300 kHz up to 20 MHz. The resolution of the different converter solutions results in 10 bit to 14 bit. Chapter 1 gives a brief overview about the architecture of an ADSL and WLAN system.

Chapter 2 covers the basic aspects about analog-to-digital conversion as well as the main limitations on delta-sigma modulation techniques. The focus will be on embedded delta-sigma modulators discussing single-loop and cascaded-loop topologies as well as switched-capacitor and time-continuous implementations.

A design methodology is presented for continuous-time delta-sigma converters. An introduction on pulse-width modulation is given and the impact on clock-jitter will be shown. The further outline of this book is structured into three main parts.

Chapter 3 will present a delta-sigma converter designed for ADSL in 180 nm CMOS employing a dynamic biasing technique. Considerations are given on architectural-level as well as on circuit-design followed by measurement results. Considerations on the SNR are done by finding a careful balance of all relevant noise contributors. The power-optimization is addressed on circuit level by introducing a dynamic-biasing of all operational-amplifiers. An area- and power-efficient realization of a single-loop modulator consisting of a 2nd-order loopfilter and a 3 bit quantizer with an oversampling-ratio of 96 is presented. The delta-sigma modulator features an 85 dB dynamic-range (DR) over a 300 kHz signal bandwidth. The measured power consumption of the ADC core is 15 mW only from a mixed 1.8 V and 3.3 V supply. An innovative biasing circuitry is introduced for the switched-capacitor integrators. The FOM taking the dynamic-range as reference results in $1.8\,\frac{\text{pJ}}{\text{conv}}$.

A feed-forward delta-sigma converter is described in Chap. 4 presenting the architecture on system-level and showing solutions on circuit-level embedded in 130 nm digital CMOS. Attention is paid on system-level by going for a feedforward topology in order to improve the SNR by increasing the tolerable signal swing. Implementation issues are discussed for an operational-amplifier, an integrator, a quantizer and a reference buffer in open-loop configuration. A passive switched-capacitor adder is introduced to keep the power drain low. A 2nd-order modulator with high oversampling-ratio (OSR = 192) is presented employing a switched-capacitor loopfilter and a 3 bit quantizer. The delta-sigma modulator features a 14 bit and 13 bit dynamic-range over a 276 kHz and 1.1 MHz signal bandwidth, respectively. The measured power consumption of the ADC-core is 8 mW only. Including an on-chip reference buffer the total power consumption results in 15 mW from a single 1.5 V supply. The FOM of the ADC-core results in $0.7\,\frac{\text{pJ}}{\text{conv}}$.

In Chap. 5, a broadband delta-sigma A/D-converter is presented for a Wireless Local-Area Network (WLAN) application. The converter is implemented in a 65 nm CMOS technology. An area- and power-efficient realization of a single-loop delta-sigma modulator consisting of a 3rd-order continuous-time loopfilter and a time-encoding quantizer (TEQ) is discussed. The introduced TEQ will be implemented inside a delta-sigma modulator by replacing a multibit quantizer. An innovative TEQ is introduced to overcome design issues in a 1.0 V supply-voltage 65 nm digital CMOS technology. The TEQ allows an exchange of *amplitude-resolution* by *time-resolution*. The approach of time-resolution alleviates the scaling difficulties of mixed-signal circuits in nanometer technologies. This is accomplished by replacing a flash A/D-converter by a modulated oscillator producing a two-level signal. The TEQ comprises a self-oscillating pulse-width modulator (PWM) embodied as a passive circuit keeping the power-drain small. A clocked comparator is placed within the PWM, hence, the duty-cycle of the rectangular signal is discrete in time. The clocked PWM produces a binary rectangular signal with a period which is 8× longer than one clock-period. The duty-cycle is modulated by the output of the loopfilter and represents the information of a multibit signal. The binary

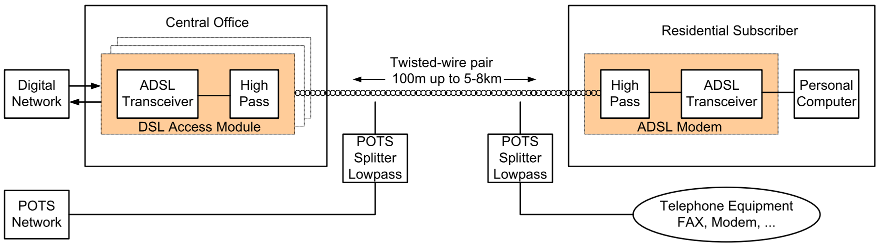


Fig. 1.1 Digital access through a POTS-splitter

signal is fed back through a single-bit D/A-converter to close the delta-sigma loop. The innovative step lies in the fact that a binary circuitry provides a performance of a multibit solution by employing resolution in time. The measured power consumption of the total ADC is 7 mW only thanks to the single-bit architecture of the TEQ and the D/A-converter. The delta-sigma modulator features a 63 dB dynamic-range over a 20 MHz signal bandwidth supporting the IEEE standard 802.11n (see Table 1.2). Employing the high-speed devices by choosing a clock-frequency of 2.5 GHz results in an attractively small chip-area of 0.079 mm^2 and in a FOM of 0.15 pJ/conversion-step as described in (2.7). Furthermore, a detailed concept study is presented for a TEQ showing architectural considerations as well as main issues on circuit implementation in a nanometer CMOS-technology (65 nm). Comprehensive measurement results will conclude chapter five.

The overall conclusions (Chap. 6) will summarize the issues on analog design in different CMOS technology nodes optimized for digital circuits and compare different solutions by calculating the achieved Figure Of Merit (FOM). The outlook on future activities will be discussed as well. At the end references are listed for all relevant publications in the field of this book.

1.3 Asymmetric Digital Subscriber Line

Basically, the Public Switched Telephone Network (PSTN) is dominated by digital technologies. High-speed digital transmission links between different telephone Central Office (CO) are capable of multiplexing and concentrating local data traffic according to the digital hierarchy. By bypassing the POTS interface at a local CO, a DSL system can utilize the full potential of a copper twisted-pair telephone subscriber loop to deliver a transmission throughput of up to a few Mbits per second depending on the length and the quality of the used line [73].

Figure 1.1 shows the possibility of providing digital transmission through the addition of POTS splitters. The shown configuration for ADSL employs a POTS splitter for separation of voice and data through highpass and lowpass filters to provide co-existing services.

The major network elements are the DSL access module in the CO and the ADSL modem at the residential subscriber. At both ends of the telephone twisted-pair,

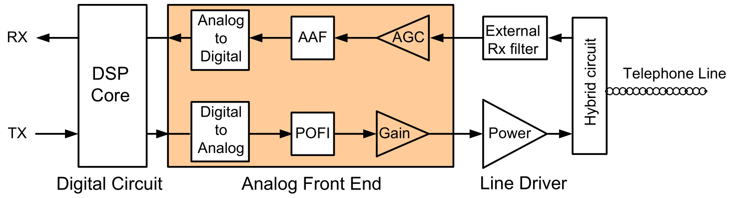


Fig. 1.2 A block diagram of an ADSL modem

a splitter-combiner filter multiplexes the POTS signals with the ADSL signals. This multiplexing can be accomplished by highpass- and lowpass-filtering since ADSL transmits in frequency overlay, that is, at frequencies above the existing telephony band as discussed in the next subsection. These filters also prevent mutual interference of both signals [73].

ADSL is currently a standard application in the field of wired communications. The data-rates for internet access at multiples of 1.5 Mbit/s up to 24 Mbit/s and a narrow upstream up to 3.5 Mbit/s (from the end user to the network) command channel could easily be adapted. The ADSL standard offers a flexible setting of data-rates and allocation of frequency bands. Rather than being limited to a fixed bit-rate, ADSL can be tuned dynamically to deliver any predefined rate, or even the maximum available bit-rate on the telephone line. With Asymmetric Digital Subscriber Line 2+ (ADSL2+), a new standard for increased data-rates and improved loop reach has become available. To remain competitive in this aggressive market segment, it is necessary to fulfill all the standard requirements and also optimize the performance of the whole product and its power consumption. Especially in the CO and Digital Loop Carrier (DLC) applications, the power consumption is a major issue. Such system solutions are based on high-density designs with typically 64 channels per linecard or even a higher number can be supported.

The Analog Front End (AFE) for an ADSL transceiver will be described briefly. The AFE serves as a four-wire system approach comprising a transmit-path and a receive-path. Figure 1.2 shows one single channel of a transceiver chip set comprising a line-driver, the AFE and a digital signal-processor. Furthermore, external components are used for building up a hybrid circuit as well as several filter stages and a transformer.

The hybrid circuit serves as four-wire to two-wire translator, since the telephone line supports two wires only. The transmit output of the AFE is connected to the line-driver which supplies the appropriate signal level to the line. The analog lowpass filter block in the transmit-path (POFI) serves as a smoothing filter after the Digital-to-Analog (D/A) conversion. The following gain stage drives the line-driver input impedance providing the required signal level to maintain the transmitted signal power on the line. The analog input signal to the AFE is received via the hybrid circuit, which is one of the main component influencing the overall system performance. The receive signal loss due to the hybrid has to be kept as small as possible. The automatic gain-control stage (AGC) amplifies the small receive signal accordingly and the anti-aliasing filter prevents any undesired folding of out of band

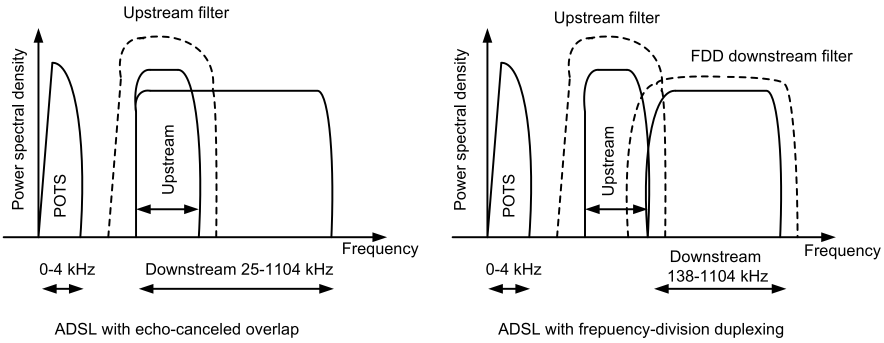


Fig. 1.3 Frequency band usage in ADSL, EC and FDM

disturbers into the band of interest before the signal enters the A/D-converter. An important transfer function is the so called *echo-path*. The echo-path describes the desired attenuation of the transmit signal leaking back through the hybrid circuit to the receive signal. Especially on long loops, the remaining echo is the dominating signal in the receive-path. The echo attenuation depends on the connected line and how well the hybrid circuit has been adapted to the attached line. This means, it is crucial to take the occurring echo into account in all system considerations.

1.3.1 ADSL System Configuration

In order to provide a data exchange in both directions at the same time, two duplexing variants have been standardized. The first one, depicted in Fig. 1.3 (shown left), has a downstream signal overlapping the upstream and requires echo canceling to separate both signals. The second one uses frequency-division duplexing (FDD) with separate bands for the up- and down-stream, as shown right in Fig. 1.3. Obviously, the echo-cancellation implementation is much more difficult, since the frequency-division duplexing can be made with filters and requires a much smaller dynamic-range of the analog components. This fact influences strongly the robustness and gave an early preference for the second variant.

The upstream band is used for communication from the Customer Premises Equipment (CPE) to the telephone central-office. The downstream band is used for data transmission from the central-office to the end user. Each of these bands is further divided into smaller frequency channels of 4.3125 kHz. During initial training, the ADSL modem tests which of the available channels have an acceptable signal-to-noise ratio. The distance from the CO, noise on the twisted-pair, or interference from any radio stations may introduce errors on some frequencies. By keeping the channels small, an error on one frequency thus need not render the line unusable. The channel will not be used, merely resulting in reduced throughput on an otherwise functional ADSL connection. The discrete-multi-tones

Table 1.1 Overview of ADSL standards

Standard name	Common name	Downstream rate	Upstream rate
ANSI T1.413-1998	ADSL	8 Mbit/s	1.0 Mbit/s
ITU G.992.1	ADSL (G.DMT)	8 Mbit/s	1.0 Mbit/s
ITU G.992.1 Annex-A	ADSL over POTS	8 Mbit/s	1.0 Mbit/s
ITU G.992.1 Annex-B	ADSL over ISDN	8 Mbit/s	1.0 Mbit/s
ITU G.992.2	ADSL-Lite (G.Lite)	1.5 Mbit/s	0.5 Mbit/s
ITU G.992.3/4	ADSL2	12 Mbit/s	1.0 Mbit/s
ITU G.992.3/4 Annex-J	ADSL2	12 Mbit/s	3.5 Mbit/s
ITU G.992.3/4 Annex-L	RE-ADSL2	5 Mbit/s	0.8 Mbit/s
ITU G.992.5	ADSL2+	24 Mbit/s	1.0 Mbit/s
ITU G.992.5 Annex-L	RE-ADSL2+	24 Mbit/s	1.0 Mbit/s
ITU G.992.5 Annex-M	ADSL2+M	24 Mbit/s	3.5 Mbit/s

(DMT) modulation technique was chosen for the first International Telecommunications Union-Standardization Sector (ITU-T) ADSL standard. Table 1.1 depicts an overview about the different ADSL standards. Note that the displayed data-rates are theoretical maximums. The commonly deployed annex-A splits both frequency bands at 138 kHz. Whereas annexes-J and -M shift the upstream and downstream frequency-split up to 276 kHz in order to boost upstream rates. Additionally, the "all-digital-loop" variants of ADSL2 and ADSL2+ (annexes-I and -J) support an extra 256 kbit/s of upstream if the bandwidth normally used for POTS voice calls is allocated for ADSL usage. While the ADSL access utilizes the 1.1 MHz band, ADSL2+ utilizes the 2.2 MHz band.

1.3.2 A/D-Converter Requirements for ADSL

It has been a common practice to combine the current and upcoming expected capabilities of Very Large-Scale Integrated Circuits (VLSI) with the desired performance of a DSL system under development. This combination has resulted in both a challenge and rewarding experience for DSL concept engineers. For example, high resolution, low sampling-rate and low resolution, high sampling-rate A/D-converters have been developed for voice and video applications, respectively. The development of ADSL technology resulted in a market need of high resolution and high sampling-rate, 13 bits and more than 1 MHz. Due to the asymmetrical nature of ADSL, that means different bandwidth for upstream and downstream, the band of interest for the A/D-converter depends on which side of the twisted-pair the converter will be placed. In other words, the band of interest results at the central-office's side and at the subscriber's side in 276 kHz and 1.1 MHz (2.2 MHz), respectively. The dynamic range depends on the chosen system architecture such as the hybrid and comes to the range of 13 bits to 14 bits. In order to not compromise the maximum data-rate the harmonic distortion must not exceed 80 dBc for a single tone. Finally, the intermodulation products of the applied discrete multi-tones count for the linearity and will be expressed in Missing-Tone Power Ratio (MTPR). An area- and power-efficient realization of a converter is mandatory to remain competitive in the market. This point will be one of the major challenges in the design procedure beside keeping the required performance. The right choice for the converter topology and architecture will be the success factor for the product and needs to be done very carefully.

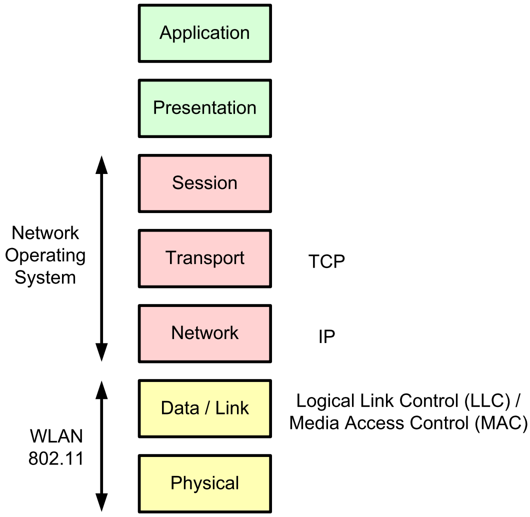
1.4 Wireless Local-Area Network

Wireless Local-Area Network (WLAN) solutions transfer data through the air using radio frequencies instead of cables providing location independent network-access between computing devices. In the corporate enterprise, WLAN solutions are typically used as the final link between the existing wired network and a group of client computers, giving these users wireless access to the full resources and services of the corporate network across a building. The major benefit and motivation from WLAN is increased mobility. In contrast to conventional wired network connections, users can move about almost without restriction and access Local-Area Network (LAN) systems from nearly anywhere. Furthermore, a WLAN approach offers cost-effective network setup for locations which are hard to wire such as older buildings and solid-wall structures. Costs per device and user can be reduced in case of frequent modifications in dynamic environments for the wiring and installation [49].

The 802.11 specification as a standard for WLAN solutions was ratified by the Institute of Electrical and Electronics Engineers (IEEE) in the year 1997. This version of 802.11 provides for 1 Mbps and 2 Mbps data-rates and a set of fundamental signaling methods and other services. Like all IEEE-802 standards, the 802.11 standards focus on the bottom two levels of the Open System Interconnection (OSI) model, the physical layer and link layer (see Fig. 1.4).

Any LAN application, network operating-system, protocol, including Transmission Control Protocol/Internet Protocol (TCP/IP), will run on a an 802.11-compliant WLAN solution as easily as they run over some Ethernet application. The WLAN architecture is configurable in a quite flexible manner. Each computer, mobile, portable or fixed, is referred to as a station in WLAN. The difference between a portable and mobile station is that a portable station moves from point to point but is only used as a fixed point. Mobile stations can even access the LAN during movement. When two or more stations come together to communicate with each other, they form a Basic Service Set (BSS). The minimum BSS consists of two stations. 802.11 LANs use the BSS as the standard building block. A BSS that stands alone and is not connected to a base is referred to as an ad-hoc network or a so called Independent-BSS. That means, all stations communicate only peer to peer without any base and no one gives permission to talk. Such a network can be set up rapidly. When BSS's are interconnected the network becomes one with infrastructure comprising two or more BSS's interconnected to a so called distribution system (DS).

Fig. 1.4 OSI model for WLAN



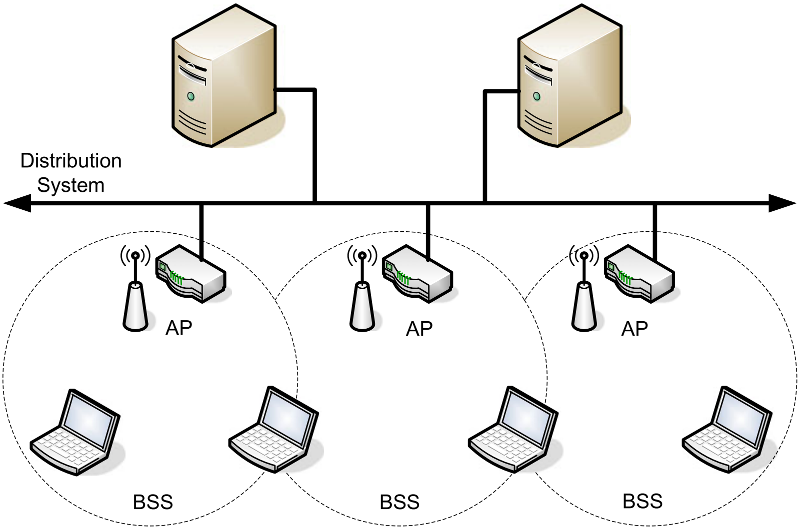


Fig. 1.5 WLAN infrastructure mode

The implementation of the DS is not specified by IEEE-802 standards. Therefore, a distribution system may be created from existing or new network technologies. Entry to the distribution system is accomplished with the use of access points (AP), which are addressable and offer distribution system services along with bridging functionality.

Data moves between the BSS and the distribution system with the help of these access points (AP), as depicted in Fig. 1.5 [49].

Table 1.2 Overview of 802.11 PHY-layer

Standard	Data rate per stream	Transfer method	Frequency band
IEEE 802.11	1 and 2 Mbit/s	optical	infrared
IEEE 802.11	1 and 2 Mbit/s	FHSS	2.4 GHz
IEEE 802.11	1 and 2 Mbit/s	DSSS	2.4 GHz
IEEE 802.11a	6, 9, 12, 18, 24, 36 and 54 Mbit/s	OFDM	5 GHz
IEEE 802.11b	5.5 and 11 Mbit/s	DSSS	2.4 GHz
IEEE 802.11g	6, 9, 12, 18, 24, 36, 48 and 54 Mbit/s	OFDM	2.4 GHz
IEEE 802.11n	7.2 up to 150 Mbit/s	OFDM	2.4 GHz/5 GHz
IEEE 802.11ac (draft)	433 up to 867 Mbit/s	OFDM	5 GHz

The physical layer is the bottom layer of the OSI model (see Fig. 1.4). The three different physical layers originally defined in 802.11 included two spread-spectrum radio techniques and a diffuse infrared specification. The spread-spectrum technique spreads the narrow baseband signal over a wide frequency band in order to improve the immunity against any discrete disturbers. The originally radio-based standards operate within the 2.4 GHz band. This band is called Industrial-Scientific-Medical (ISM) band which does not require any licensing. Spread-spectrum techniques increase reliability, boost throughput and allow many unrelated products to share the spectrum without explicit cooperation and with minimal interference. The original 802.11 wireless standard defines data-rates of 1 Mbps and 2 Mbps via radio waves using frequency hopping spread spectrum (FHSS) or direct sequence spread spectrum (DSSS). It is important to note that both techniques are fundamentally different signaling mechanisms and will not interoperate with each other. Using the frequency hopping technique, the 2.4 GHz band is divided into 75 adjacent 1 MHz subchannels. The sender and the receiver agree on a hopping pattern and data is sent over a sequence of the subchannels. Each conversation within the network occurs over a different pattern to avoid using the same subchannel by two senders simultaneously. In contrast, the direct sequence spread spectrum technique divides the 2.4 GHz band into 14 adjacent 22 MHz subchannels. Data is sent across one of these 22 MHz subchannels without hopping to other channels [49].

The most critical issue affecting WLAN demand has been limited throughput. Recognizing the critical need to support higher data-rates, new standards were ratified as shown in Table 1.2. The transfer method employs three different principles of modulation schemes, Frequency-Hopping Spread-Spectrum (FHSS) or Direct-Sequence Spread-Spectrum (DSSS) or Orthogonal Frequency-Division Multiplexing (OFDM). Basic information about these methods can be found in [49].

In Table 1.2 an overview about the different WLAN standards is shown. The different standards are listed with the achievable data-rates and the used transfer methods along with used frequency bands. The first generation of IEEE 802.11 was released in 1997 followed by the second generation 802.11b two years later. The main use case was the internet and the exchange of e-mails. The third generation 802.11g was driven by the demand for enabling the rich-data internet experience such as sharing pictures and low-resolution video streaming. In 2007, the increasing demand for higher data-rates consequently asked for the fourth generation WLAN 802.11n. IEEE 802.11n is an amendment which improves upon the previous 802.11 standards by adding multiple-input multiple-output antennas (MIMO). The most common data-rate is 150 Mbit/s and by employing 4 streams in parallel 600 Mbit/s are achievable. 802.11n operates on both the 2.4 GHz and the less frequently used 5 GHz bands. The standard for the fifth generation has not yet being released fully. The IEEE 802.11ac standard is still under development which will provide high throughput in the 5 GHz band. This specification will enable multi-station WLAN throughput of 1000 Mbit/s and a maximum single link data-rate of at least 433 Mbit/s, which is at least three times faster than that of most commonly used wireless standard 802.11n. The increased speed can be accomplished by using wider RF bandwidth (80–160 MHz) and up to 8 streams. The fifth generation will bring fast, high quality video streaming and fast data syncing and backing up of data storage to notebooks, tablets and mobile phones.

The data-link layer is the second layer of the OSI model (see Fig. 1.4). The data-link layer within 802.11 consists of two sublayers: Logical Link Control (LLC) and Media Access Control (MAC). The MAC is designed to support multiple users on a shared medium by having the sender sensing the medium before accessing it. In an 802.11 WLAN, collision detection is not possible as for conventional Ethernet which is known as the “near/far” problem: to detect a collision, a station must be able to transmit and listen at the same time, but in radio systems the transmission drowns out the ability of the station to “hear” a collision. To overcome this issue, 802.11 uses a protocol known as Carrier-Sense Multiple-Access with Collision-Avoidance (CSMA/CA). CSMA/CA attempts to avoid collisions by using explicit packet acknowledgment, which means an acknowledgment packet is sent by the receiving station to confirm that the data packet arrived intact. In other words, this approach provides a way of sharing access over the air. Finally, the MAC-layer provides robustness features such as the checksum for cyclic redundancy check and packet fragmentation and reassembling of received packets. Time-bounded data such as voice and video is supported in the MAC specification through the point coordination function where a single access-point controls access to the media and the access time is spliced to guarantee an acceptable latency. It is worth mentioning that beside WLAN further wireless solutions have been standardized such as Hiper-LAN, Home-RF, Bluetooth Zig-Bee and WiMax [49].

1.4.1 WLAN 802.11n System Configuration

The 4th generation of WiFi networking standards IEEE 802.11n was released in 2009. This release is an amendment which improves upon the previous 802.11 standards by adding multiple-input multiple-output antennas (MIMO). Up to a number of 4 MIMO streams are supported in parallel. The IEEE has approved the amendment and it was published in October 2009. This extension defines a new physical layer supporting data-rates up to 150 Mbit/s and optionally up to 600 Mbit/s

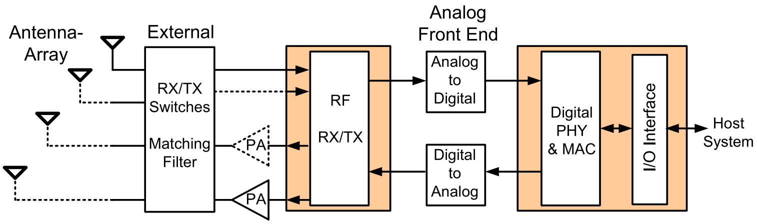


Fig. 1.6 WLAN block diagram

by exploiting 4 MIMO streams. Furthermore, the MAC-layer is extended to ensure high efficiency at high data-rates along with an improved offering for feasibility. The core of the physical layer is an intelligent antenna system—the so called smart-antenna approach. The smart antennas comprise several identical antennas with a distance of $\frac{\lambda}{2}$ whereas the antennas are driven by an intelligent algorithm for signal-processing. This intelligent controlling improves the quality of receiving and transmitting data. This solution can achieve higher data-rates. Applying the smart-antenna approach on both sides, receiver and transmitter, results in the so called Multiple-Input, Multiple-Output (MIMO) system. The basic idea of MIMO is the fact that several antennas can receive more signals and can transmit more signals than a single antenna, whereby the data-rate can be improved. The use of several antennas on both sides is an already well known approach in wireless systems [49].

A basic block diagram for a WLAN solution is depicted in Fig. 1.6. The data are received and transmitted through an array of antennas. The number of antennas is configurable due to the supported standard of 802.11. The employment of semi-duplex transmission mode is one important feature of WLAN. That means, the whole system is either in receive mode or in transmit mode. Data transmission in both directions at the same instant is not possible. This fact allows an easier circuit implementation around the antenna. Time multiplexing between receive and transmit direction is employed by means of a switch in front of the antenna.

The antenna receives a signal which goes through a matched filter and is further switched to an additional lowpass filter stage. Moreover, the signal enters the RX-path of the RF-transceiver for down-conversion into the baseband. Several techniques are well known such as heterodyne- or homodyne-receivers [5]. After removing any occurring dc-offset, the RF-signal is directly down-converted by means of a mixer and an appropriate local oscillator frequency. The demodulated signal is applied to a programmable gain amplifier and followed by the required anti-aliasing filter. The baseband signal needs to be digitized by means of an A/D-converter to provide digitized receiver signal to be processed in a digital signal processing unit. The D/A-converter provides an analog signal defined in the digital signal processing unit for the transmit-path. After passing through the smoothing filter stage a low-noise-amplifier (LNA) drives the amplified signal into the mixer to up-convert the transmit signal into the desired frequency band. The baseband signal is modulated and up-converted by the TX-path of the RF-transceiver. Any occurring offset voltage is suppressed in the channel, the RF signal is amplified accordingly and switched to the antenna. The power amplifier (PA) provides sufficient power to the antenna. The multiplexing switch connects the power amplifier to the antenna array. A common RF-transceiver consists of several data channels whereas one data channel comprises both I/Q sub-channels featuring quadrature modulation [5].

1.4.2 A/D-Converter Requirements for WLAN 802.11n

The A/D-converter connects the RF-transceiver to the digital signal-processor as illustrated in Fig. 1.6. Commonly, different technology nodes are used for the RF-transceiver and the digital part to optimize the overall production costs. The choice for A/D-converter placement either onto the RF-die or on the baseband-die needs to be done carefully. One major impact is the required type of interface. A converter on the RF-die implies an high-speed digital interface to reduce the number of package pins. High switching activities may cause severe crosstalk on the RF-die. This fact favors the converter placement onto the digital chip to allow an analog interface avoiding steep transitions. This latter approach constrains the technology node for the converter. In our days, cost-effective implementations go for nanometer technologies in case of digitally dominated integrated-circuits (IC). In other words, the A/D-converter for WLAN needs to be designed in a nanometer technology. The development of WLAN standards has resulted in a need of moderate resolution but high-speed A/D-converters, that means 10 bits and up to 20 MHz. The total data-rate will be deteriorated by any occurring mismatch between both I/Q-channels, since quadrature-modulation is employed. To overcome that issue, the tolerable I/Q-mismatch needs to be specified in terms of I/Q-gain-error and I/Q-phase-error. Proper system simulations revealed a specification of 0.5 dB and 5°, respectively. The group delay variation must not exceed 10 ns. The transition-time between sleep- and active-mode needs to be faster than 1 µs to allow power saving during multiplexing in time domain of transmit- and receive-path. An area- and power-efficient converter realization is mandatory to remain competitive in the market. This point will be one of the major challenges in the design procedure beside keeping the required performance in a challenging nanometer technology.

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