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Paving the Way for Gigabit Networking

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Abstract

Wired LANs soared to the gigabit level some years ago, and terabit networks are in place for wide area networking. However, in terms of data rate, wireless short-range networks tend to lag one generation behind wired LANs. The recent second generation of wireless short-range networks offers transmission rates of up to 54 Mb/s. The third wireless LAN generation is under development and will materialize in the IEEE 802.11n standard in about two years. IEEE 802.11n WLANs will offer a few hundred megabits per second, but the performance gap from wired networks remains. The recently started project Wireless Gigabit with Advanced Multimedia (WIGWAM) aims to close this gap with a heterogeneous 1 Gb/s fourth-generation system based on high-data-rate orthogonal OFDM transmission, MIMO, and efficient MAC protocol techniques.

Introduction

The historical trend of 802.11-type wireless short-range communication technology shows a fivefold increase in data rate for each generation based on 3–4-yr cycles [4]. This is driven by the fact that users want to access information or communicate wirelessly independent of time and location. On the other hand, this is facilitated by the success of personal mobile communications devices such as cellular telephones and wireless LAN (WLAN) cards. More important, user demands do increase. Nowadays users require the same service and quality from a wireless network as offered by wired networks. In this context example scenarios and applications over wireless links are email, Internet access, video distribution, consumer equipment interconnection, access to peripheral devices, and replacement of Ethernet network installations. However, popular second- (2G) and third-generation (3G) technologies are not able to cope with these requirements. Even wireless short-range communications networks tend to lag one generation behind their wired counterparts, limiting their use as a convenient replacement technology. Upcoming wireless short-range technologies like IEEE 802.11n do not completely close the gap. Therefore, the Wireless Gigabit with Advanced Multimedia (WIGWAM) project aims to develop a wireless short-range transmission technology to be on par with recent wired LANs. This wireless short-range communications system will offer adaptive data rates up to a maximum of 1 Gb/s using carrier frequencies in the 5, 17, 24, 38, and/or 60 GHz band. The extremely high data rates and carrier frequencies call for research and development efforts at the forefront of wireless technology.

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The ultimate goal of a 1 Gb/s wireless short-range system requires highly competent partners to develop the necessary components of the network interface. The WIGWAM project consortium has 10 principal partners, mainly from industry: Alcatel SEL AG, DaimlerChrysler AG, IHP GmbH, Infineon Technologies AG, MEDAV GmbH, Nokia GmbH, Philips GmbH, Siemens AG, Technische Universität Dresden (project coordinator), and Telefunken Racoms System GmbH & Co. KG. Additionally, 17 subcontractors from academia and research institutions are involved in the project. It started in March 2004 and runs for a period of three years. To stay at the cutting edge of wireless technology a tight schedule was chosen. The vital elements, parameters, and strategies of the high-speed wireless short-range communications system architecture were defined by the end of 2004, and first results demonstrating feasibility are expected this year. The WIGWAM project aims to present technically mature designs and even prototypical implementations in 2006–2007. The Federal Ministry of Education and Research (BMBF, Grant No. 01 BU 370) of Germany funds the project[1].

Other Wireless High Data Rate Activities

There is a common opinion throughout academia, industry, and business communities that the current wireless technology fulfills neither current nor future demands regarding data rate and service quality. Several activities around the globe are founded on this observation. The IEEE 802.11n standardization is a quite recent activity to define a wireless short-range network with mandatory data rates exceeding 100 Mb/s. The two main proposals for IEEE 802.11n [4, 6] optionally allow even higher data rates under certain conditions. The basis for data rate enhancement is orthogonal frequency-division multiplexing (OFDM) in conjunction with multiple-input multiple-output (MIMO) technology and improved coding. Additionally, in the context of IEEE 802.15.3, rate extension to 480 Mb/s using ultra wideband (UWB) technology and up to 2 Gb/s using millimeter waves are envisioned. However, IEEE 802.15.3 as well as MBOA is targeted for ultra-short-range communication. Obviously, it is not suitable as a universal replacement for LAN technologies. Due to the large bandwidth available in the 60 GHz band, quite a few companies have developed components in the millimeter wave area to achieve a data rate of 1 Gb/s (e.g., [2, 3]).

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WIGWAM Application Scenarios

The project has defined four practical scenarios that specify user and system requirements in different environments.

Home scenario: The home scenario covers typical characteristics of the mass market. The anticipated massive use of high bandwidth multimedia applications with high quality (HDTV, video streaming, and audio) will require data rates that well exceed 100 Mb/s for one user. For more users the bandwidth requirements can be even higher, legitimating the development of a wireless transmission system with a1 Gb/s data rate . Further key requirements in the home environment are self-configuration, zero maintenance, and low radio frequency (RF) transmission power to minimize electromagnetic radiation exposure.

Office scenario: State-of-the-art technology for office networking is 100 Gb/s Ethernet, summing up to an overall capacity of several hundred megabits per second for a well partitioned Ethernet network. The high network capacity requirement in this scenario is a result of the bandwidth needs of high-quality videoconference, streaming media, telephony, remote desktop, and database access as well as server-based computer network setups (e.g., Network File System). Although current WLANs enable office staff to work detached from their desktop to a certain degree, they do not meet the service quality and bandwidth requirements to replace a wired network technology. Several key challenges besides data rate extension and quality of service provision have yet to be tackled (e.g., powerful and fast encryption to enable security).

Public access scenario: The foreseen future of wireless public access, already partly reality, is the coexistence of large-coverage systems with low and medium data rates — Global System for Mobile Communications (GSM,) General Packet Radio Service (GPRS), and Universal Mobile Telecommunications System (UMTS) — and short-range systems with high data rates in urban or hot spot scenarios. Fkurthermore, multihop communication might be applied to enable high-data-rate coverage extension. The continuously changing number of users, user mobility, different quality of service requirements, and data rates require a highly flexible and efficient medium access control (MAC) protocol. Seamless horizontal and vertical handover must be supported, allowing the system to be an integral high-data-rate part of future mobile communications systems.

High velocity scenario: Classical examples for this scenario are trains or cars on highways. Wireless access to a backbone network is provided by line-of-sight connections between vehicles and access points. The access points are naturally positioned along roadsides or rails. The high vehicle velocity calls for fast and soft handover techniques, and methods to counteract the large Doppler spreads and shifts. The MAC protocol must be able to efficiently handle very diverse service demands arising from Internet, multimedia, and real-time traffic (vehicle control and active safety assistance).

Each application scenario is backed by one or more industry member of the WIGWAM project, reflecting the diversity of company backgrounds. However, the WIGWAM project is devoted to covering these scenarios with a single 1 Gb/s system, although the diverse scenarios could demand tailored solutions for specific system components. Notwithstanding these ambitions, the implementation requirements of the WIGWAM system should be based on a cost-efficient technology that can be anticipated for the year 2007, when the projects terminates.

Technical Challenges

The WIGWAM project covers research and development activities from the physical (PHY) layer up to the networking level. The focus is from implementation aspects to the PHY and MAC layers up to mobility issues. We discuss some of the challenges in wireless high-speed networking in the following.

Reliable information on the channel characteristics for the different application scenarios is a necessity for an efficient system concept. The 3GPP single-carrier modulation (SCM) and IEEE 802.11n channel models are good references, but they do not cover all situations (change of parameters, bandwidth, etc.). Therefore, measurements are conducted at 5 GHz and 60 GHz. Even challenging environments like railway stations are being measured currently.

Analog-to-digital conversion (ADC) is probably one of the most crucial issues for a 1 Gb/s wireless short-range system. The necessary increased resolution and sampling rate result in higher power consumption contradicting the goal of an energy-efficient communication system. Advances in ADC technology are necessary to cope with a target spectral efficiency of 10 b/s/Hz at the WIGWAM working assumption of 100 MHz bandwidth.

The use of MIMO technology is another prerequisite to achieve the aforementioned spectral efficiency. The main challenges in this field are a precise channel estimation and baseband signal processing complexity.

MAC protocols of current WLANs cannot cope with the high data rate targeted here. In effect, they utilize only a fraction of the available bandwidth due to the atomic data-acknowledgment exchange, frequently used interframe spaces, and many control frame exchanges. It is evident that a 1 Gb/s-capable MAC protocol needs several boosting methods like block transmissions, block acknowledgments, or a central scheduler for channel access arbitration. Additionally, the anticipated small cell sizes require MAC features for fast network setup and mobility handling.

To increase flexibility and robustness of the PHY, as many operations as possible will be executed in the digital domain. The remaining RF domain requires leading-edge performance in the presence of a very noisy environment, the consideration of challenging power constraints and influencing statistical process parameter deviations. Close cooperation with sister projects (DETAILS, LEMOS) within the BMBF innovation alliance Mobile Internet have been established in order to consider the newest low-power RF design concepts and high-level RF/digital compatible modeling techniques for partitioning of the PHY architecture. These actions allow reliable and cost-efficiant multiband RF front-end solutions to be deployed [7]. A similar challenging aim is pursued in the selection of process technology. From the cost point of view, the preferred choice is complementary metal oxide semiconductor (CMOS) for digital circuitry and high-performance RF-CMOS for the analog front-end. However, for the 60 GHz analog front-end, we are designing circuits for a high-performance SiGe BiCMOS technology, avoiding the use of even more expensive III-V semiconductor technologies like GaAs or InP.

An architecture suitable for a baseband implementation is developed. It is planned to develop a parallel digital baseband processor including a tool chain and a reference silicon design.

Realizing a 1 Gb/s system causes yet some other difficulties to be considered in WIGWAM. Handling system complexity, low power dissipation, and crosstalk minimization are some of the challenges in this area.

Project Structure

The WIGWAM project is focused on the three lower layers of the open systems interconnection (OSI) reference model, including handover techniques. Because of the complexity arising from this wide spectrum of tasks, the project is subdivided into five work packages. Each work package comprises members with specialized know-how to address dedicated research topics.

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System concept: The task of this working group is to coordinate research efforts, and define requirements and parameter sets based on application scenarios, standard bodies, and other sources as guidelines for the other work packages. The results obtained in all work packages will be published and brought to the respective standardization bodies.

Hardware platform: This group defines and develops the hardware technology and platform necessary to support transmission, reception, and processing of data rates at 1 Gb/s. Also included are antenna design activities and ADC development, with emphasis on cost and power efficiency.

Physical layer: The key focus of this group is the development of adaptive and robust modulation and coding schemes according to predefined channel models reflecting the characteristics of different scenarios. MIMO techniques promising to improve spectral efficiency are investigated.

Link layer: There are very specific conditions like small cell sizes and very high transmission speeds that require the development of a new MAC protocol. The MAC protocol development concentrates on high utilization of available bandwidth, but also considers self-configuration, handover, multihop, multicell, interoperability, and quality of service (QoS) aspects.

Network layer: The supply of a steady wireless connection in short-range radio cells at 1 Gb/s is a challenging task, particularly under the constraint of mobility. The problem can only be handled with cross-layer optimization and radio resource management. Additionally, handover scenarios to different wireless standards are considered to ensure service continuity.

The (intermediate) results of the respective research efforts in every work package are used as feedback for the system concept. The system concept, maintained by the system concept group, is the basis for ongoing research and will be refined or even completely changed periodically to reflect changing requirements and intermediate findings. Each work package and partner reports on advances and results at an annual status seminar.

Work Progress

During the first phase of the project until March 2004, all project members worked together to identify requirements and parameters that allowed the four main application scenarios to be specified. To keep the design space open, the parameters are solely based on environment condition and user/application requirements, not on specific implementation and technology aspects. Two sets of parameters were identified: system and implementation parameters. System parameters are subdivided into user parameters (aggregate data rate, range, mobility, required services, number of users, mobility), resource parameters (bandwidth, carrier frequency, adjacent channel suppression), network parameters (addressing capabilities, multihop support, coexistence and interoperability, type of channel access), and channel parameters (delay, delay spread, Doppler shift, Doppler spread, path loss, line of sight/non-line of sight). The implementation parameters are further subdivided into terminal parameters (size, weight, shape, and cost constraints, transmit power, operation time, localization support, number of antennas, number of supported users) and MAC parameters (supported service, latency/delay, jitter, synchronous asynchronous operation, multihop capabilities).

Subsequently, the work packages discussed and agreed on parameters for the different scenarios. The analysis of commonalities between the scenario definitions resulted in the main features of the envisioned system. For instance, the RF output power should not exceed 100 mW for terminals and 1000 mW for base stations. Similarly, the bill-of-material (BOM) should not exceed U.S.$10/100 for terminals/base stations to ensure market success. Regarding size/shape, the chipset, antenna, and peripheral elements have to fit in a PCMCIA, a MiniPCI, or an even smaller Compact Flash II card format. MIMO is an option to ensure spectral efficiency and will require at least two antennas per device. IP packet, streaming media, and voice over IP are services that must be supported in all scenarios.

At present, proposals for PHY and MAC parameters are generated by the work packages that meet the identified parameters and requirements. The scenarios mainly vary by the channel models used and fallback modes. Obviously, data rates and offered services have to be traded for range, number of users, and mobility patterns. As far as the physical layer is concerned, carrier frequencies in the 5, 38, and 60 GHz bands are under investigation. OFDM and single-carrier modulation as well as LDPC or turbo coding schemes are considered for the baseband. A good basis for the MAC protocol is given by the proposals of the IEEE 802.11n task group; however, various measures are being discussed to improve the efficiency further, particularly when considering simultaneous communication of many terminals.

Demonstration of Results

Provision of technological concepts and solutions that facilitate the development of a 1 Gb/s short-range system is the envisioned result of the WIGWAM project. A necessary outcome of the project is the proof of concept. The task of demonstrating a full-featured 1 Gb/s wireless short-range system is stretching the given budget of this project. However, key components will be realized in different demonstrators, including the following:

Vertical demonstrator: The integration of millimeter wave analog front-end, digital baseband, and MAC processing will show the feasibility of a 1 Gb/s short-range system. However, only a subset of parameters (range), mechanisms, and algorithms will be used. Another goal is to realize some of the components as integrated circuits (ICs) for a system on chip (SoC) solution.

Multiband pilot demonstrator: The goal here is to demonstrated reconfigurability, adaptivity, and flexibility of multiband RF platforms.

Easy and secure network self-configuration demonstrator: Simplicity of installation and maintenance as well as secure communication are two key issues for home and office networking, which will be shown by this demonstrator.

Components: The implementation and presentation of functionality of core components will be demonstrated separately. Such components include MIMO processing units and beamformers.

Summary

WIGWAM is an activity that defines and develops core components and solutions for a fourth-generation wireless short-range system. This system yields a data rate of 1 Gb/s. In contrast to WLANs of the second and third generations, the latter is under development and standardization; right now, the WIGWAM system works in heterogeneous environments and delivers QoS for a variety of applications. This is achieved by its wide adaptation and tuning range. For more information on WIGWAM see [1, 5].

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