Short–Distance Low–Power Wireless Access System

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Abstract:
The short–distance low–power technologies for wireless access communications, including Bluetooth, Ultra–Wideband (UWB) and Wireless Fidelity (Wi–Fi), focus on the physical layer and Medium Access Control (MAC) layer. Bluetooth is a wireless protocol for exchanging data over short distances. It is an alternative to RS232 data cables. UWB is a radio technology that can be used at very low energy levels for short range. It provides flexible high–bandwidth wireless access. Wi–Fi enables the wireless connection of fast–access devices and mobile devices in Wireless Local Access Network (WLAN) and it is suitable for long distances. The standardizations of the above technologies have been developed and published soon after the emergence of these technologies. Among all the standards, Bluetooth and Wi–Fi are the most important ones.

In a short–distance low–power wireless access network, the communication range is less than 100 m and the transmitted power is between 1–100 mw. This kind of access network gives a solution for last–mile access and hot–spot communication coverage. Compared with the wired Local Area Network (LAN), it allows mobile users either access or quit from the network easily. It makes the terminal devices portable and exploration of wireless network resources easy. However, it has some disadvantages, such as low reliability, low data transmission rate and high power consumption. The data encryption and user security are also the problems need to be solved.

The short–distance low–power wireless access technologies, such as Bluetooth (IEEE 802.15), Ultra–Wideband (UWB)(IEEE 802.15.3a) and Wireless Fidelity (Wi–Fi) (IEEE 802.11), focus on the Physical Layer and Medium Access Control (MAC) Layer. Bluetooth is an alternative technology to RS232 data cables. UWB connects various electronic devices, providing flexibility and portability of wideband wireless access. Wi–Fi is a seamless extension to the short–distance wireless environment as an alternative to wired LAN.

1 Bluetooth

In 1994, Ericsson began to study low–power communication system to replace cable communication system mobile in short distance.. In 1998, Ericsson, Nokia, IBM, Toshiba and Intel organized the Bluetooth Special Interest Group (SIG). In 1999, the Bluetooth SIG released the first version of Bluetooth protocol. In 2000, 3COM, Agere, Microsoft and Motorola joined in the Bluetooth SIG. In 2002, the IEEE 802.15 group ratified the Bluetooth protocol as IEEE 802.15.1[1].

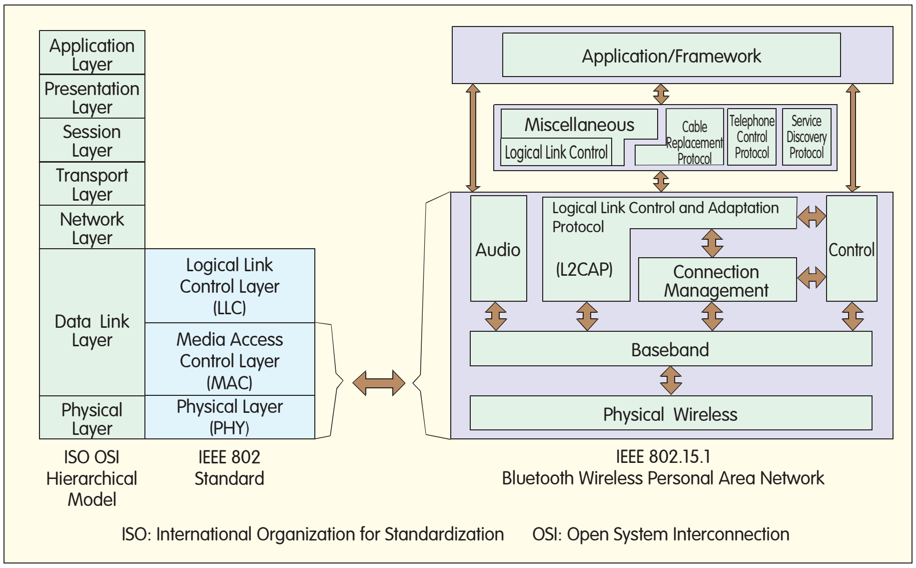
As a Wireless Personal Area Network (WPAN) access technology, Bluetooth is conceived as an alternative standard to short–distance, low–cost cable transmission. It is also used either as a bridge between other networks or a node in the Ad hoc network. An active Bluetooth device listens and responds to the callings of the master device. Once the master device knows the address of the user device, it starts to connect with the user device. The user device responds to the queries of the master device, establishes frequency–hopping sequence synchronization for authentication and communication. The devices which are not used for authentication or transmission are in the bandwidth and power–saving mode.

Bluetooth replaces short cables and transmits an Equivalent Isotropic Radiation Power (EIRP) of 30–100 mV or 15–20 dBm. Bluetooth operates in the license–free band at 2.4–2.4835 GHz. To avoid interfering with other protocols that use the same bandwidth, such as IEEE 802.11g, Bluetooth protocol divides the band into 79 channels (each 1 MHz wide) and changes channels up to 1,600 times per second by Gaussian Frequency Shift Keying (GFSK) modulation and Frequency–Hopping Spread Spectrum (FHSS) features. The Automatic Repeat Request (ARQ) error correction mechanism is used on the MAC layer to protect against strong narrow–band interference. The earlier version Bluetooth protocols support 1 Mbit/s data rate, however, the data rate are adaptable to change according to different wireless application environments.

In terms of service quality, the connectionless–oriented Asynchronous Connectionless Link (ACL) of Bluetooth uses complex channel admission control and planning policy to ensure Quality of Service (QoS). Asynchronous service QoS parameters include long–period data rate, peak data rate, latency and jitter. Bluetooth also provides synchronous services at a constant bit rate on Synchronous Connection–Oriented (SCO) links. The definition of Bluetooth space capacity is the ratio of the total data transmission rate over the covered area. Generally, Bluetooth covers 20 picocells with a diameter of 10 m. The maximum data transmission rate of a picocell is 400 kbit/s. The Bluetooth space capacity is 25 kbit/s per square meter. The traffic in all the picocells is controlled by the Bluetooth host point. The picocell host controls the subordinate access channels. The LAN access protocol is used to connect external networks.

All the Bluetooth scatternets are kind of Ad hoc networks with different types of topologies. The scatternet has a picocell sub-architecture, in which a global connection function is operated between mobile stations by the IP layer using a global addressing and routing mechanism.

Bluetooth initializes the communication link between devices by a query process. The host starts the query program periodically to discover the MAC address list of the devices in the covered area. The master device queries through paging using the MAC addresses and clocks of the user devices. Bluetooth defines the wireless interface and the communication stack for allowing mutual device authentication and service provisioning. Figure 1 shows a Bluetooth communication stack.



▲Figure 1. Bluetooth communication stack.

The link management layer in Figure 1 is responsible to the type of link structure, authentication, encryption, QoS, power consumption and transmission format. The control layer provides a command interface for the link management layer and baseband, and provides relevant interfaces to hardware devices. The Logical Link Control and Adapatation Protocol (L2CAP) provides connection-oriented and connectionless data services to the upper layers (for example, the segmentation and reassembly from the upper-layer protocol data unit, and the support for QoS). The RFCOMM Point-to-Point Protocol (PPP) can be used directly on L2CAP.

Bluetooth devices work in the master and slave mode[2]. In the basic Bluetooth network, one master device and seven slave devices form a picocell There would be up to 255 slave mobile stations in the waiting mode, when mobile stations do not exchange data. Picocells are able to be connected to make up a scatternet. A scatternet is a multi-hop wireless network in terms of topology, in which there are no direct path between two nodes, so they must be relayed through other nodes. In addition, two picocells can communicate through their common node, which would be the master node or a slave node .

Bluetooth supports three types of encryptions: No encryption (Type 1), encryption at the service layer after a channel is established (Type 2) and the encryption at the link layer before a channel is established (Type 3). There are two levels of encryptions: Trusted and untrusted. There are three levels of encrypted services: Open service, authenticated service and authenticated and authorized service. The authentication and encryption at the link layer depend on four basic parameters: Bluetooth-corresponding 48-bit address identifier, special authentication key, special encryption key and 128-bit random frequency variable.

2 UWB

Different from the conventional continuous wave radio technology, UWB encodes mass information on the short-pulse sequence and allows the transmission on UWB spectrum with the extension of very low power spectrum. The UWB technology can be used for the wireless Ad hoc network, Free Space Optical (FSO), ZigBee, Radio Frequency Identification (RFID), Radio over Fiber (RoF), Bluetooth and Home Radio Frequency (HomeRF) systems. The short-distance low-power wireless access system using UWB has the following advantages:

(1) High capacity

Signaling energy spreads on the UWB spectrum with white noise, which increases channel capacity.

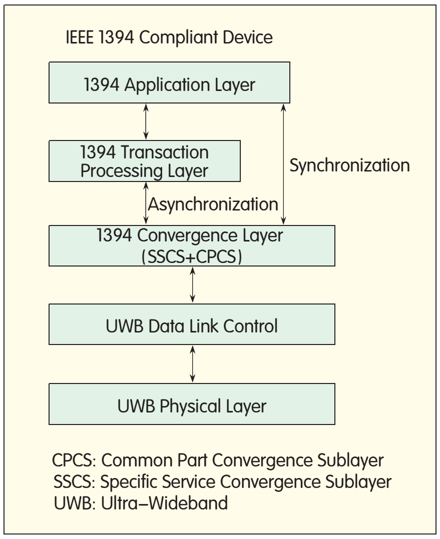
(2) Low possibility of multipath fading and high interference immunity

The resolution of short-pulse signals in multipath channels is higher than 1 ns, which can greatly reduce the effect of multipath fading. The interference immunity is proportional to the signal bandwidth. The greater the signal bandwidth is, the higher the interference immunity is.

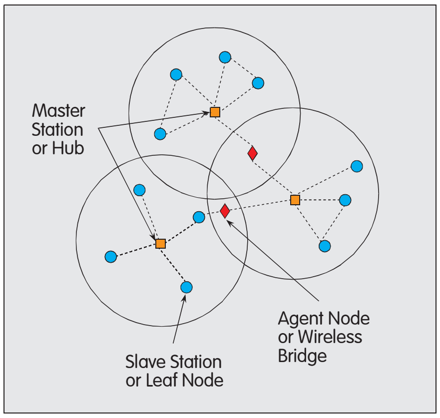
(3) Time diversity and frequency diversity

UWB pulses last a very short time, leaving blank spaces between the previous and current pulses. It is easy for the rake receiver to combine UWB pulse signals from different paths to increase the density of detected signals. As the preferred technology for the Personal Area Network (PAN), the IEEE 802.15.3a UWB has many advantages, including high data rate from 100 Mbit/s to 1 Gbit/s, low power consumption and low cost. However, it uses a very high bandwidth, which may cause interference and compatibility problems when it shares a channel with other communication systems[3].

Figure 2 illustrates the protocol architecture of a UWB system. The IEEE 1394 convergence layer is similar to the IEEE 1394 link layer. It is responsible for the mapping between the transaction



▲Figure 2. Protocol stack architecture.



▲Figure 3. UWB centralized control network topology.

layer and the UWB lower layers. The convergence layer contains an IEEE 1394 Specific Service Convergence Sublayer (SSCS) and a Common Part Convergence Sublayer (CPCS).

In the Physical Layer and Data Link Layer of the UWB system, the phases of the short pulse sequence are modulated by information symbols. UWB pulses can be modulated using biphasic Gaussian pulses or pulse amplitude, or modulated strictly using pulse intervals according to the position of the very–narrow Gaussian pulses. The typical pulse bandwidth is 0.2–2.0 ns, and the pulse interval is between 10–100 ns. Pulse positions can be changed, at random or pseudo–random intervals.

Figure 3 illustrates a UWB centralized control network topology. This architecture adopts P2P communication and Ad hoc centralized control in the Ad hoc network. It consists of several picocells. Each picocell selects a master station and controls other slave stations automatically. If UWB is used for the network topology in a distributed control mode, it is difficult to control the output power and interference of each node.

To further expand the coverage of the UWB system, data flow control and network layer management connect the UWB wireless bus and the IEEE 1394 backbone network through two types of bridges, as shown in Figure 4.The IEEE 1394 bridge works as an interface to the wired and wireless buses. It provides the following functions for the data flow between the IEEE 1394 backbone network and the UWB wireless bus:

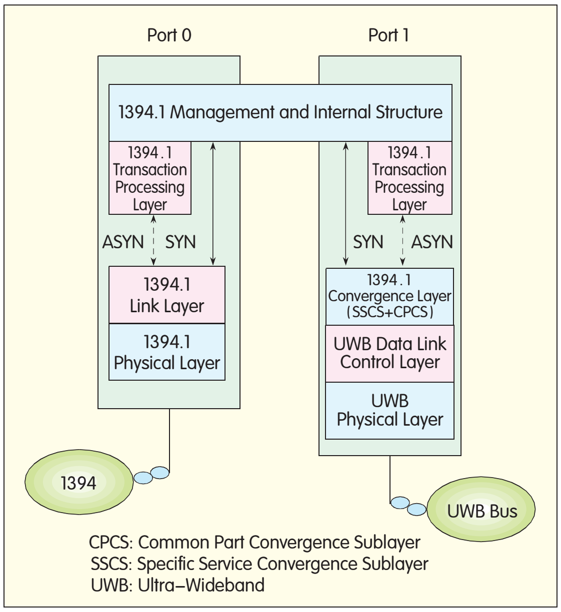
- Establishing synchronous channels;
- Logical mapping between channels and UWB data link channels;
- Asynchronous packets and control data flow routing between the wired and wireless;
- Clock synchronization between IEEE 1394 and UWB;
- Synchronization between frames and groups;
- Adding or removing IEEE 1394 nodes and UWB mobile terminals;
- Configuring relevant frequency resources.

3 Wi–Fi

In 1997, IEEE published IEEE 802.11 standards, which is the basis of Wi–Fi. Wi–Fi operates at 2.4 GHz (2.4–2.4835 GHz in North America, 2.471–2.497 GHz in Japan), and supports 1 Mbit/s or 2 Mbit/s data rate. Wi–Fi provides wireless connections for fast access devices and mobile devices within WLAN. The Wi–Fi standard specifies the MAC programs accessing the physical media, MAC layer processing portability and the cross–cell hand–over between adjacent cells. In 1997, IEEE released IEEE 802.11a[4] that uses the rates of 6, 9, 12, 24, 36, 48 and 54 Mbit/s, with the bandwidth of 5 GHz. It cannot use the IEEE 802.11h dynamic frequency selection and auto–sensing power control technologies. After the verifications of Lucent and Harris, IEEE approved IEEE 802.11b[5] that uses the rate of 5.5 or 11 Mbit/s. In 2003, IEEE released IEEE 802.11g[6], which has similar performance to IEEE 802.11a, and is compatible with IEEE 802.11b.

Besides using the 5 GHz frequency–bands, Wi–Fi uses the Direct Sequence Spread Spectrum (DSSS) with a bandwidth of 16 MHz, Complementary Code Keying (CCK) and Orthogonal Frequency–Division Multiplexing (OFDM) technologies. DSSS can reduce broadband noise. Wi–Fi sends and receives signals at the same frequency. The gain for retransmitting packets comes from time diversity. Wi–Fi adapts to the rate at the Physical Layer and is transparent to the higher layers. It uses different modulation depending on different rates. Wi–Fi supports the rates between 1–54 Mbit/s. Wi–Fi uses ARQ error correction, coding and multiplex technologies at the MAC layer to protect against the effect of noise. IEEE 802.11a and the cordless phone share the 5 GHz frequency band. Wi–Fi resists interference by using a transmission power control technology.

Once a Wi–Fi mobile station is powered on, it scans all the wireless channels and searches for the primary



▲Figure 4. A bridge connecting a UWB wireless bus and an IEEE 1394 backbone network.

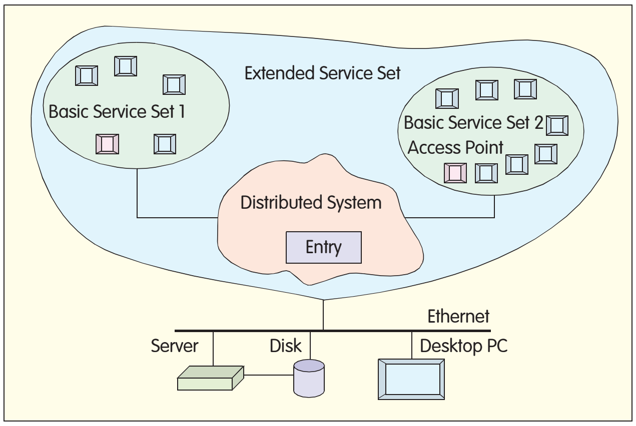


Figure 5.
Wi-Fi network components.

network that transmits beacons. It selects the Ad hoc network that contains the Wi-Fi mobile station, and authorizes, authenticates and connects the Wi-Fi mobile station through the Access Point (AP), and provides QoS from best-effort to priority assurance. When Wi-Fi mobile stations become components of the Ad hoc network, they have the capability to discover a new network or disconnect from the old network and form a new network. Wi-Fi mobile stations can roam among communication networks, share public distribution system resources and allow seamless mobile transmission. When Wi-Fi mobile stations become the infrastructure of the fixed communication, the access point will release authentication and convergence and enter a sleep status.

Wi-Fi has defined two types of access: Distributed Coordination Function (DCF) and Point Coordination Function (PCF).The simplest network architecture is an Independent Basic Service Set (IBSS). It contains the Ad hoc topology of at least two base stations. A Basic Service Set (BSS) is the expanded network of an Extended Service Set (ESS). In the fixed communication infrastructure, an extended service set is a set of BSSes connected through a distribution system. Figure 5 illustrates the typical components of a Wi-Fi network. Services provided by base stations include base-station service and distribution system service. Distribution system services allow data to be transmitted between the base stations in different BSSes.

To ensure reliable access, Wi-Fi authenticates user devices at the link layer. User devices are authenticated in two ways. One is Open System Authentication (OSA) and the other is Shared Key Authentication (SKA). Communication devices in an IEEE 802.1X/EAP framework can provide algorithm options at different security levels.

The Wi-Fi WLAN architecture is based on the BSS. A BSS is a set of mobile or fixed Wi-Fi mobile stations, which access network transmission media with certain a control mode. Wi-Fi allows four interference-free BSSes. The BSS data transmission rate in a coverage with a diameter of 100 m is 900 kbit/s, or 31.4 Mbit/s in a coverage with a diameter of 10 m. IEEE 802.11g supports a space capacity of 0.1 kbit/s per square meter at the lowest rate, and 400 kbit/s per square meter at the highest rate.

The multiplexing technologies that Wi-Fi uses include DSSS and OFDM. DSSS uses the 11-bit Barker series. The 11-chip sequence modulates one information bit. 1Mbit/s and 2 Mbit/s modulations use Binary Phase Shift Keying (BPSK) and Orthogonal Phase Shift Keying (QPSK), respectively. CCK is the 16-bit sequence number 4 or 8 information bits.

In the fixed network and the Ad hoc network, Wi-Fi mobile stations run the MAC protocol using DCF, and use Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) as the channel access technology. There are many types of basic DCF access. Mobile stations can optimize and select the Request To Send/Clear To Send (RTS/CTS) mechanism to reduce the collision caused by hidden terminals. Network Allocation Vector (NAV) calculates the termination time of the data transmission as a mobile station counter. IEEE 802.11e defines the Enhanced Distribution Channel Access (EDCA) and Hybrid Coordination Function Controlled Channel Access (HCCA) as the new coordination modes to provide the Hybrid Coordination Function (HCF) function. EDCA provides 8 data priority levels. Each mobile station assigns a different Inter-Frame Space (IFS) value to the channels at different priority levels. A queue with a higher level uses a shorter IFS to get a higher priority of channel access and a higher priority of back-off time. In HCCA, a mobile station is responsible for providing the HCF function with centralized control. HCCA ensures the QoS of service rate, time delay and jitter.

Wireless packets are often lost in the short-distance low-power wireless access system, so it is very difficult to maintain the synchronization between encryption and decryption at any time interval. The Wi-Fi security framework uses the Wireless Equivalent Protocol (WEP) that utilizes the RC4 stream cipher. In 2002, it defined the Wireless Protection Access (WPA) as an improvement of WEP, and is used by IEEE 802.11i. WPA uses 802.1 X/EAP as the framework, uses the Temporary Key Integrity Protocol (TKIP) for cipher encryption and the Extensible Authentication Protocol (EAP) for authentication. In 2004, the IEEE 802.11i Task Group announced WPA2 as an integrated authentication framework based on IEEE 802.1X and EAP. Different authentication and keys for different application environments generate different EAP. Two cipher suites are defined, i.e., the upgrade software TKIP for the existing devices and Advanced Encryption Standard (AES)-based Counter Mode with Cipher Block Chaining Message Authentication Code Protocol (CCMP).

4 Power Consumption Control

The short-distance low-power wireless access system is mainly used for the communication access of pocket-size terminals which are mobile in a short distance and have a limited power supply. Bluetooth and UWB require very

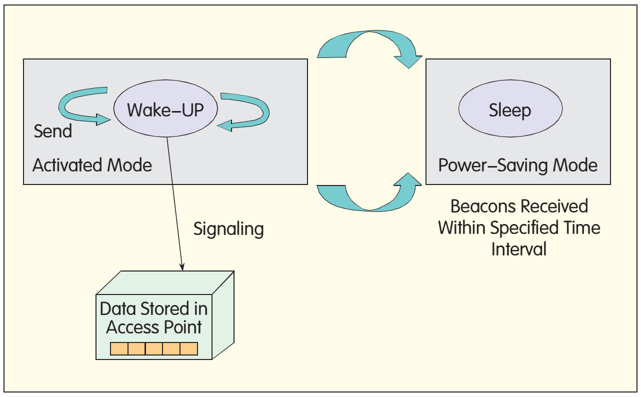


Figure 6. Wi-Fi power management statuses in a fixed-architecture network.

low power consumption. Wi-Fi is used for long-distance connections and supports the access of mobile terminals with a certain power.

4.1 Bluetooth Power Management

Bluetooth power can be managed using the following methods: Backup mode without data switching but clock running only; and data switching mode in which terminal devices are connected to the picocell host. There are 4 modes of connections: Activated mode, in which devices in the picocell are in active status; listening mode, devices are in listening status with low power consumption; hold mode, in which the device ACL traffic is blocked in a period of time; waiting mode, in which devices are no long members of the picocell but are still synchronous with the picocell host, with the lowest power consumption.

Cambridge Silicon Radio (CSR) has developed a Complementary Metal-Oxide Semiconductor (CMOS) single-chip Bluetooth device. Single-chip Bluetooth includes baseband BlueCore and wireless BlueCore. Baseband BlueCore contains the firmware that provides link controller, link management and host controller interface layer functions. Wireless BlueCore provides flash storage and power-saving functions. BlueCore supports two modes of low power consumption: Doze mode, which lowers the processor clock rate; and deep sleep mode, in which most of circuits are in closed status.

4.2 Wi-Fi Power Management in Fixed Infrastructure Network

Wi-Fi devices have two statuses: Wake-up and sleepy status in which devices neither transmit nor receive signals. The devices have two power management modes: Activated mode and power-saving mode. Figure 6 illustrates the Wi-Fi power management statuses in a fixed-architecture network. To enter power-saving mode from activated mode, mobile stations must send the power management bits in the packet header to the access point. The access point stores the traffic of all the mobile stations that are in power-saving mode. With certain algorithm, the mobile stations in power-saving mode are switched over to the activated mode to receive beacons. The mobile stations without access traffic returns back to power-saving mode.

4.3 Wi-Fi Power Management in Ad Hoc Network

There is no access point in the Ad hoc network, so the mobile stations in power-saving mode transmit Ad hoc Traffic Indication Message (ATIM) frames to switch over to the wake-up status during the ATIM window period. The activated stations store the traffic of all the mobile stations in power-saving mode. Mobile stations receiving the ATIM frames keep in the wake-up status to receive message traffic until the next ATIM window, and then go back to power-saving mode.

Compared with the power management in the fixed infrastructure network, because no access point can be used as a reference station, the wake-up or sleepy status of mobile stations is evaluated by other mobile stations in the Ad hoc network. During the ATIM window period, the transmission and reception of ATIM frames obey the DCF and Carrier Sense Multiple Access/Collision Avoidance (CSMA/CA) access algorithms.

5 Latest Development of Short-Distance Low-Power WACS System

The short-distance low-power wireless access system is standardized at a fast speed. There are many standards, but Bluetooth and Wi-Fi are the most useful ones.

So far there have been five core versions of technologies since Bluetooth was published. In 2007, the Bluetooth Special Interest Group released the latest version of Bluetooth technology, 2.1+ Enhanced Data Rate (EDR). The transmission rate of Bluetooth has improved greatly since then. With new EDR function, Bluetooth can support a rate up to 2 or 3 Mbit/s, while previous Bluetooth generally provides a rate of 1 Mbit/s. In 2009, the Bluetooth Special Interest Group[7] launched one high rate solution and one low power-consumption solution.

In 2006, the Bluetooth Special Interest Group announced to use the WiMedia Alliance's UWB technology as the high-speed solution for Bluetooth. The Bluetooth Special Interest Group also utilizes Wi-Fi by adding 802.11a, b and g into the Bluetooth 802.11 AMP specification to realize device interoperation and high-speed data transmission. In 2008, the Bluetooth Special Interest Group announced a high-speed development policy formally. It developed a new wireless Radio Frequency (RF) solution as a replacement, which supports the temporary use of the backup wireless connection preset in the consumer Bluetooth devices to realize a higher transmission rate besides the previous support for the Bluetooth protocol, functions, security and pairing.

The Bluetooth low-power consumption specification will meet the consumer electronic product industry's requirement for the interactive remote control in communications. The low power consumption technology is designed for the long life of the Bluetooth devices.

To use the UWB technology, it is

necessary to solve the problem of coexistence with other wireless systems. For the coexistence of UWB and 4G, Detection And Avoidance (DAA) has been paid great attention as an anti-interference technology for UWB in Japan and Europe. Current researches include the MB-OFDM-UWB solution integrating OFDM, spread spectrum and interleave and frequency hopping mechanisms; the MIMO-OFDM-UWB assumption that uses the Multi-Input Multi-Output (MIMO) technology in the UWB system; applications integrating UWB and Mesh, and the convergence of UWB and smart antennas.

The Wi-Fi Alliance launched the Wi-Fi Protected Setup (WPS) technology[8] in the later 2006. This technology integrates the safest encryption WPA/WAP2. Furthermore, the simple configuration makes it easier for the WLAN products to be accepted by ordinary customers Wi-Fi is planning to use the MIMO technology in the next standard version. Airgo has developed the MIMO chip at a data rate of 108 Mbit/s, which is compatible with the existing Wi-Fi. The IEEE 802.11n Task Group has defined the MIMO physical layer specifications.

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Biographies

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Tan Zhenhui is a professor and PhD advisor of Beijing Jiaotong University. He is also a member of the personal communication speciality expert group of the first, second and third China “863” Communication Subject. His research interests include wireless ATM, spread spectrum communications and personal communications. He has published more than 60 research papers.

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Roundup

ZTE Showcases LTE Product Line in Germany

On November 26, 2009, ZTE Corporation (ZTE), a leading global provider of telecommunications equipment and network solutions, was showcasing its Long Term Evolution (LTE) products and solutions to network operator Vodafone, demonstrating its leading position in the field of end-to-end mobile broadband technologies. With its Software Defined Radio (SDR) solution, ZTE enables operators to cost-effectively host multiple networks on the same base station, enabling them to easily upgrade to an LTE commercial network.

LTE will offer mobile phone users more bandwidth, faster data transmission and high-speed access to mobile Internet applications, and is expected to be introduced in Germany in stages from 2010 onwards. This will be partly done using frequencies made available by the digitization of radio broadcasting (the "digital dividend").

"With our LTE mobile telephony solutions, we can respond in a flexible way to all requirements of network operators in terms of connectivity and performance optimization," explains Dr. Zhigang Zhang, vice president of ZTE Europe and North America. "In our SDR base station, all mobile phone standards can operate in parallel, which significantly reduces operator costs and at the same time is very environment-friendly and saves space. For the‘digital dividend’ frequency range, ZTE has developed its own LTE DD solution based on the SDR platform," adds Dr. Zhang.

As a pioneer in the field of HSPA+/LTE, ZTE has long been involved in the development of LTE technology and supports network operators in their efforts to drive the commercialization of this next generation technology. Over 2,000 engineers are devoted to developing LTE in R&D centers in Xian, China. Moreover, ZTE recently opened a new LTE research and development centre in Richardson, Texas.

In the last two years ZTE has successfully built a series of LTE test networks all over the world, including a commercial trial with Telefónicas, and it has tendered for all major LTE projects in Germany. To demonstrate the applications of LTE technology to an international public, ZTE will construct a special LTE network for the China pavilion at Expo 2010 in Shanghai.

(ZTE Corporation)