Enabling Technologies for Pervasive Computing

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INTRODUCTION

Bluetooth (Bluetooth SIG, 2004) and ZigBee (ZigBee Alliance, 2004) are short-range radio technologies designed for wireless personal area networks (WPANs), where the devices must have low power consumption and require little infrastructure to operate, or none at all. These devices will enable many applications of mobile and pervasive computing. Bluetooth is the IEEE 802.15.1 (2002) standard and focuses on cable replacement for consumer devices and voice applications for medium data rate networks. ZigBee is the IEEE 802.15.4 (2003) standard for low data rate networks for sensors and control devices. The IEEE defines only the physical (PHY) and medium access control (MAC) layers of the standards (Baker, 2005). Both standards have alliances formed by different companies that develop the specifications for the other layers, such as network, link, security, and application. Although designed for different applications, there exists some overlap among these technologies, which are both competitive and complementary. This article makes a comparison of the two standards, addressing the differences, similarities, and coexistence issues. Some research challenges are described, such as quality of service, security, energy-saving methods and protocols for network formation, routing, and scheduling.

BLUETOOTH

Bluetooth originated in 1994 when Ericsson started to develop a technology for cable replacement between mobile phones and accessories. Some years later Ericsson and other companies joined together to form the Bluetooth Special Interest Group (SIG), and in 1998 the specification 1.0 was released. The IEEE published the 802.15.1 standard in 2002, adopting the lower layers of Bluetooth. The specification Bluetooth 2.0+EDR (Enhanced Data Rate) was released in 2004 (Bluetooth SIG, 2004).

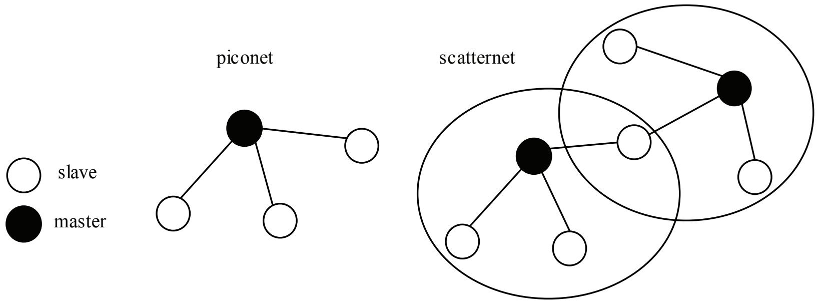
Bluetooth is a low-cost wireless radio technology designed to eliminate wires and cables between mobile and fixed devices over short distances, allowing the formation of ad hoc networks. The core protocols of Bluetooth are the radio, baseband, link manager protocol (LMP), logical link control and adaptation protocol (L2CAP), and service discovery protocol (SDP). The radio specifies details of the air interface, including frequency, modulation scheme, and transmit power. The baseband is responsible for connection establishment, addressing, packet format, timing, and power control. The LMP is used for link setup between devices and link management, while the L2CAP adapts upper-layer protocols to the baseband layer. The SDP is concerned with device information and services offered by Bluetooth devices.

Bluetooth operates on the 2.4 GHz ISM (Industrial, Scientific, and Medical) band employing a frequency-hopping spread spectrum (FHSS) technique. There are 79 hopping frequencies, each having a bandwidth of 1MHz. The transmission rate is up to 1 Mbps in version 1.2 (Bluetooth SIG, 2003) using GFSK (Gaussian frequency shift keying) modulation. In version 2.0+EDR new modes of 2 Mbps and 3 Mbps were introduced. These modes use GFSK modulation for the header and access code of the packets, but employ different modulation for data. The $\pi/4$ differential quadrature phase-shift keying (DQPSK) modulation and 8 differential phase-shift keying (DPSK) modulation are employed in 2 Mbps and 3 Mbps mode, respectively.

The communication channel can support both data (asynchronous) and voice (synchronous) communications. The synchronous voice channels are provided using circuit switching with a slot reservation at fixed intervals. The asynchronous data channels are provided using packet switching utilizing a polling access scheme. The channel is divided in time slots of 625 μs. A time-division duplex (TDD) scheme is used for full-duplex operation.

Each Bluetooth data packet has three fields: the access code (72 bits), header (54 bits), and payload. The access code is used for synchronization and the header has information such as packet type, flow control, and acknowledgement. Three error correction schemes are defined for Bluetooth. A 1/3 rate FEC (forward error correction) is used for packet header; for data, 2/3 rate FEC and ARQ (automatic retransmission request). The ARQ scheme asks for a retransmission

Figure 1. Piconet and scatternet



of the packet any time the CRC (cyclic redundancy check) code detects errors. The 2/3 rate FEC is a (15,10) Hamming code used in some packets. The ARQ scheme is not used for synchronous packets such as voice.

The devices can communicate with each other forming a network, called piconet, with up to eight nodes. Within a piconet, one device is assigned as a master node and the others act as slave nodes. In the case of multiple slaves, the channel (and bandwidth) is shared among all the devices in the piconet. Devices in different piconets can communicate using a structure called scatternet, as shown in Figure 1. A slave in one piconet can participate in another piconet as either a master or slave. In a scatternet, two or more piconets are not synchronized in either time or frequency. Each of the them operates in its own frequency-hopping channel while the bridge nodes in multiple piconets participate at the appropriate time via TDD. The range of Bluetooth devices depends on the class power, ranging from 10 to 100 meters.

ZIGBEE

ZigBee has its origins in 1998, when Motorola started to develop a wireless technology for low-power mesh networking (Baker, 2005). The IEEE 802.15.4 standard was ratified in May 2003 based on Motorola's proposal. Other companies joined together and formed the ZigBee Alliance in 2002. The ZigBee specification was ratified in December 2004, covering the network, security, and application layers (Baker, 2005).

ZigBee has been designed for low power consumption, low cost, and low data rates for monitoring, control, and sensor applications (Akyildiz, Su, Sankarasubramaniam, & Cayirci, 2002). The lifetime of the networks are expected to be of many months to years with non-rechargeable batteries. The devices operate in unlicensed bands: 2.4 GHz (global), 902-928 MHz (Americas), and 868 MHz (Europe). At 2.4 GHz (16 channels), the raw data rates can achieve up to 250 Kbps, with offset-quadrature phase-shift keying (OQPSK) modulation and direct sequence spread spectrum (DSSS). The 868 MHz (1 channel) and 915 MHz (10 channels) bands also use DSSS, but with binary-phase-shift keying (BPSK) modulation, achieving data rates up to 20 Kbps and 40 Kbps, respectively. The expected range is from 10-100m, depending on environment characteristics.

Each packet, called PHY protocol data unit (PPDU), contains a preamble sequence, a start of frame delimiter, the frame length, and a payload field, the PHY service data unit (PSDU). The 32-bit preamble is designed for acquisition of symbol and chip timing. The payload length can vary from 2 to 127 bytes. A frame check sequence improves the reliability of a packet in difficult conditions. There are four basic frame types: data, acknowledgement (ACK), MAC command, and beacon. The ACK frame confirms to the transmitter that the packet was received without error. The MAC command frame can be used for remote control and nodes configuration.

In 802.15.4 two channel-access mechanisms are implemented, for non-beacon and beacon network. A non-beacon network uses carrier-sense medium access with collision avoidance (CSMA-CA) with positive acknowledgements for successfully received packets. For a beacon-enabled network, a structure called superframe controls the channel access to guarantee dedicated bandwidth and low latency. The network coordinator is responsible for set up of the superframe to transmit beacons at predetermined intervals and to provide 16 equal-width time slots between beacons for contention-free channel access in each time slot (IEEE Std. 802.15.4, 2003; Gutierrez, Callaway, & Barret, 2003).

A ZigBee network can support up to 65.535 nodes, which can be a network coordinator, a full function device (FFD), or a reduced function device (RFD). The network coordinator has general network information and requires the most memory and computing capabilities of the three types. An FFD supports all 802.15.4 functions, and an RFD has limited functionalities to reduce cost and complexity. Two topologies are supported by the standard: star and peer-to-peer, as shown in Figure 2. In the star topology, the communication is performed between network devices and a single central controller, called the PAN coordinator, responsible

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