Contents

Bluetooth (IEEE 802.15.1)

- Network topology
- FHSS operation
- Link delivery services
- System architecture & protocols
- Usage models

ZigBee (IEEE 802.15.4)

- Network topology
- Physical layer operation
- CSMA/CA operation

IEEE definition of WPAN

Wireless personal area networks (WPANs) are used to convey information over short distances among a private, intimate group of participant devices.

Unlike a wireless local area network (WLAN), a connection made through a WPAN involves little or no infrastructure or direct connectivity to the world outside the link. This allows small, power-efficient, inexpensive solutions to be implemented for a wide range of devices.

Bluetooth ≈ IEEE 802.15.1

A widely used WPAN technology is known as Bluetooth (version 1.2 or version 2.0)

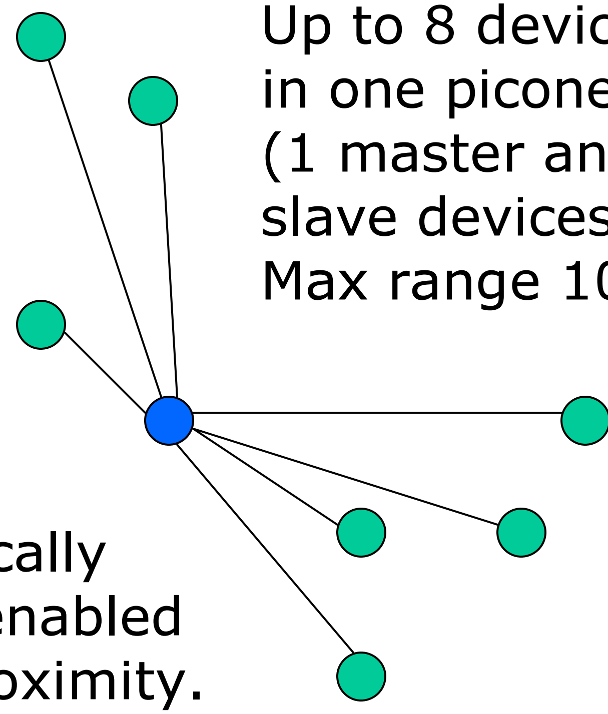
The IEEE 802.15.1 standard specifies the architecture and operation of Bluetooth devices, but only as far as physical layer and medium access control (MAC) layer operation is concerned (the core system architecture).

Higher protocol layers and applications defined in usage profiles are standardised by the Bluetooth SIG.

Piconets

Bluetooth enabled electronic devices connect and communicate wirelessly through short-range, ad hoc networks known as piconets.

Up to 8 devices in one piconet (1 master and 7 slave devices). Max range 10 m.



ad hoc => no base station

Piconets are established dynamically and automatically as Bluetooth enabled devices enter and leave radio proximity.

Piconet operation

The piconet master is a device in a piconet whose clock and device address are used to define the piconet physical channel characteristics. All other devices in the piconet are called piconet slaves.

At any given time, data can be transferred between the master and one slave. The master switches rapidly from slave to slave in a round-robin fashion.

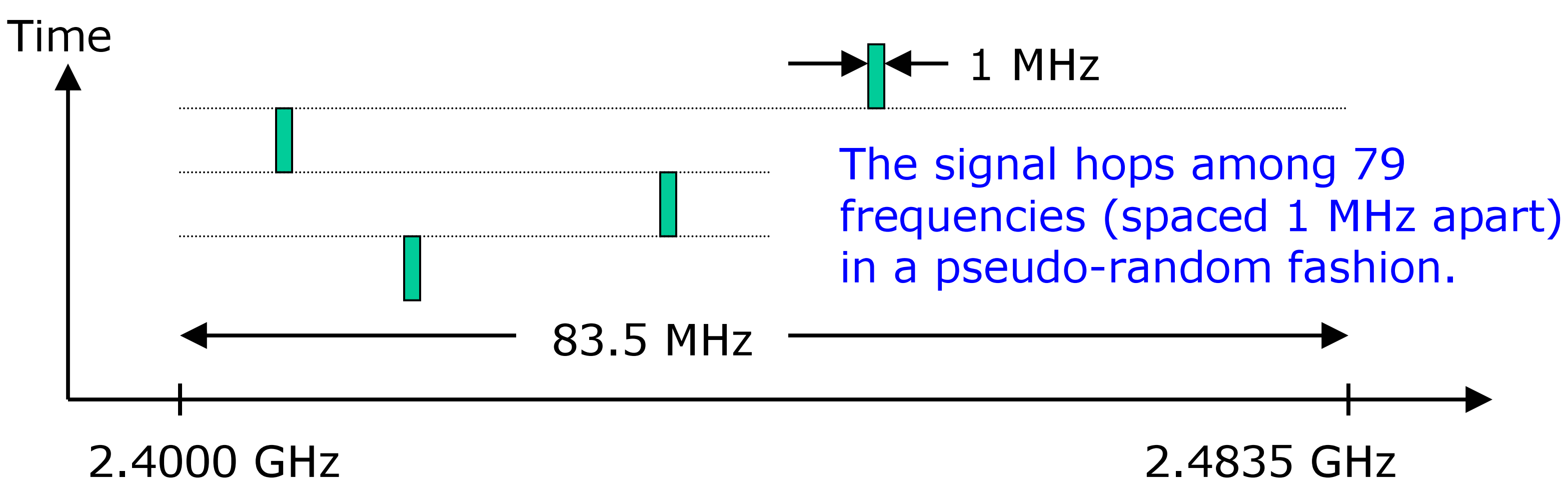
Any device may switch the master/slave role at any time.

Bluetooth radio and baseband parameters

Topology	Up to 7 simultaneous links
Modulation	Gaussian filtered FSK
RF bandwidth	220 kHz (-3 dB), 1 MHz (-20 dB)
RF band	2.4 GHz ISM frequency band
RF carriers	79 (23 as reduced option)
Carrier spacing	1 MHz
Access method	FHSS-TDD-TDMA
Freq. hop rate	1600 hops/s

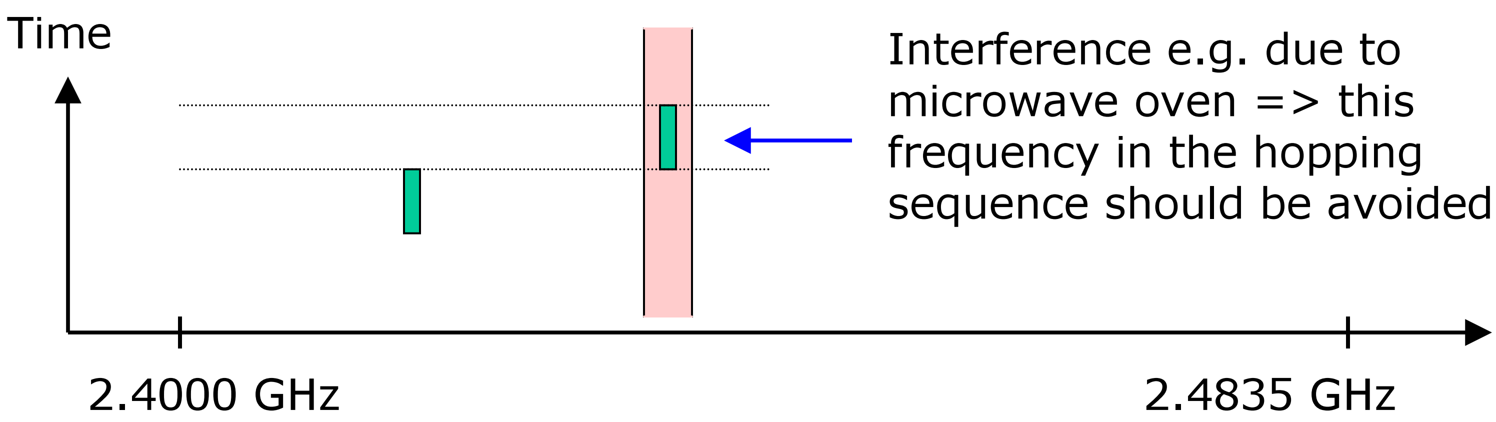
Frequency hopping spread spectrum (1)

Bluetooth technology operates in the 2.4 GHz ISM band, using a spread spectrum, frequency hopping, full-duplex signal at a nominal rate of 1600 hops/second.



Frequency hopping spread spectrum (2)

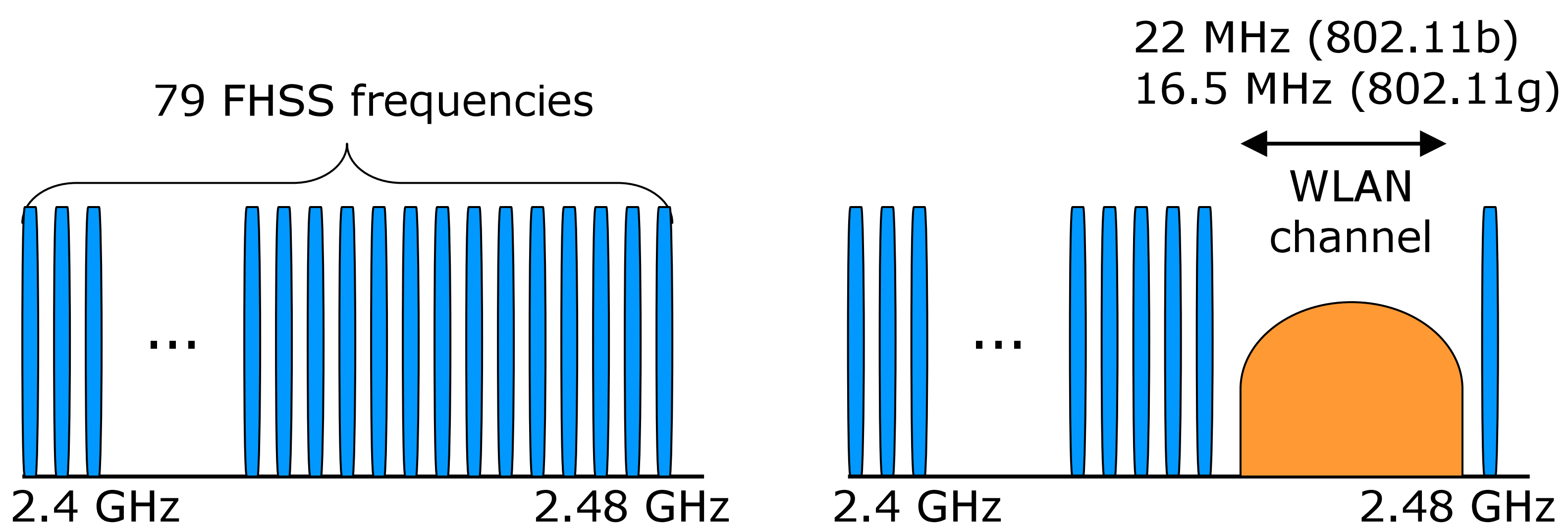
The adaptive frequency hopping (AFH) feature (from Bluetooth version 1.2 onward) is designed to reduce interference between wireless technologies sharing the 2.4 GHz spectrum.



Interference e.g. due to microwave oven => this frequency in the hopping sequence should be avoided.

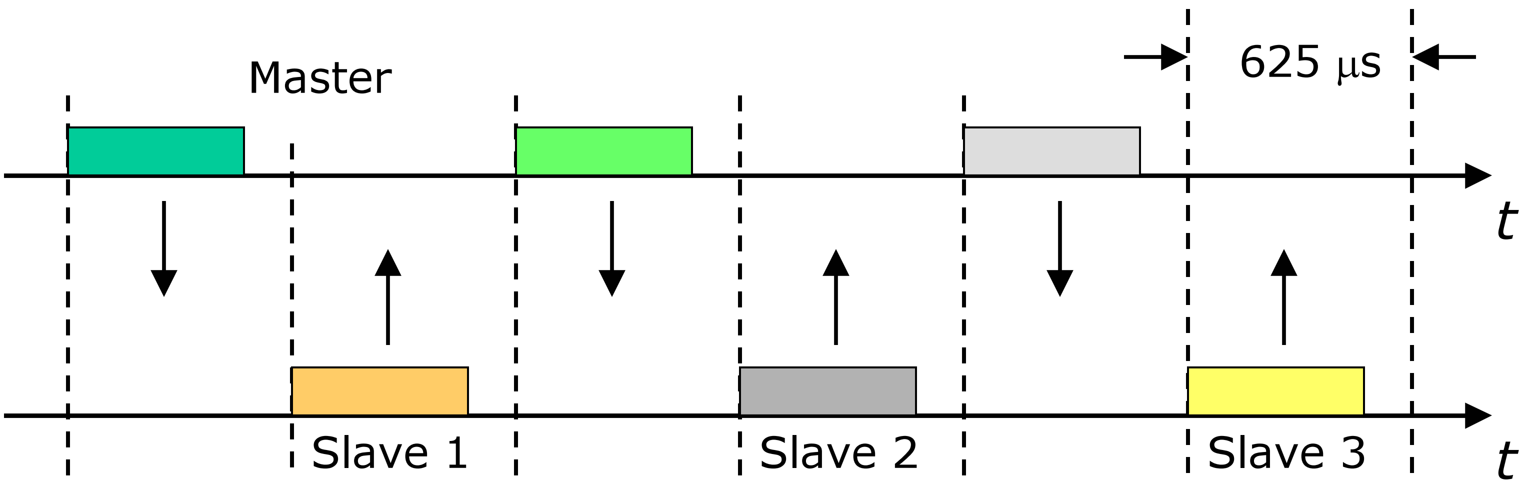
Frequency hopping spread spectrum (3)

In addition to avoiding microwave oven interference, the adaptive frequency hopping (AFH) feature can also avoid interference from WLAN networks:



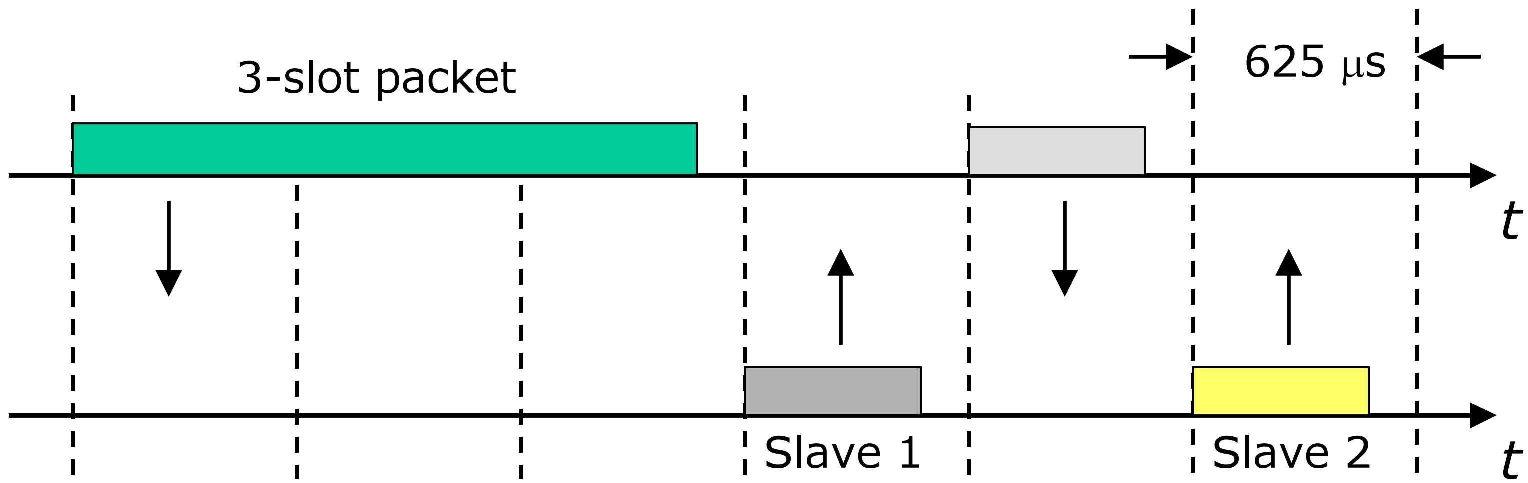
Frequency hopping in action (1)

The piconet master decides on the frequency hopping sequence. All slaves must syncronise to this sequence. Then transmission can take place on a TDD-TDMA basis.



Frequency hopping in action (2)

The packet length can be 1, 3 or 5 slots. Note that the following transmissions are synchronised to the hopping sequence (i.e., 0, 2 or 4 hop frequencies are skipped).



Power classes

Bluetooth products are available in one of three power classes:

Class	Power	Range	
Class 1	100 mW	~100 m	Industrial usage
Class 2	2.5 mW	~10 m	Mobile devices
Class 3	1 mW	~10 cm	

Data rates

Channel data rates:
Bluetooth version 1.2 offers a bit rate of 1 Mbit/s.
Bluetooth version 2.0 offers 3 Mbit/s.

Achievable user bit rates are much lower, (among others) due to the following reasons:

- overhead resulting from various protocol headers
- interference causes destroyed frequency bursts => information has to be retransmitted

Link delivery services

Two types of links can be established between the piconet master and one or more slaves:

Synchronous connection-oriented (SCO) link allocates a fixed bandwidth for a point-to-point connection involving the piconet master and a slave. Up to three simultaneous SCO links are supported in a piconet.

Asynchronous connectionless or connection-oriented (ACL) link is a point-to-multipoint link between the master and all the slaves in the piconet. Only a single ACL link can exist in the piconet.

SCO links

SCO links are used primarily for carrying real-time data (speech, audio) where large delays are not allowed (so that retransmission cannot be used) and occasional data loss is acceptable.

The guaranteed data rate is achieved through reservation of slots. The master maintains the SCO link by using reserved slots at regular intervals. The basic unit of reservation is two consecuive slots - one in each transmission direction. An ACL link must be established (for signalling) before an SCO link can be used.

ACL link

The ACL link offers packet-switched data transmission. No bandwidth reservation is possible and delivery may be guaranteed through error detection and retransmission.

A slave is permitted to send an ACL packet in a slave-to-master slot only if it has been adressed in the preceeding master-to-slave slot.

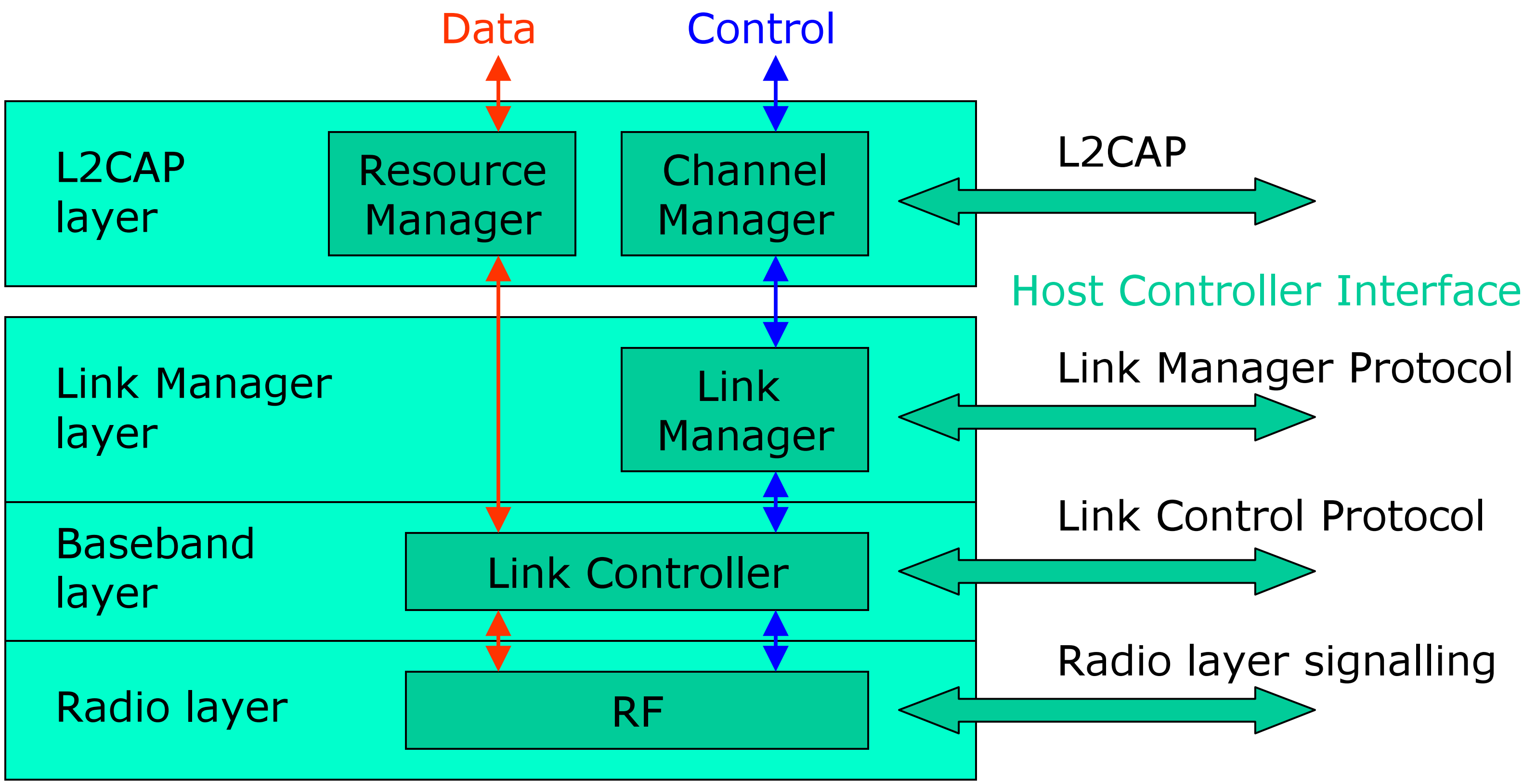
For ACL links, 1-, 3-, and 5-slot packets have been defined. Data can be sent either unprotected (although ARQ can be used at a higher layer) or protected with a 2/3 rate forward error correction (FEC) code.

Achievable user data rates (ACL)

Type	*Symmetric (kbit/s)*	*Asymmetric (kbit/s)*	
DM1	108.8	108.8	108.8
DH1	172.8	172.8	172.8
DM3	256.0	384.0	54.4
DH3	384.0	576.0	86.4
DM5	286.7	477.8	36.3
DH5	432.6	721.0	57.6

DMx = x-slot FEC-encoded
DHx = x-slot unprotected

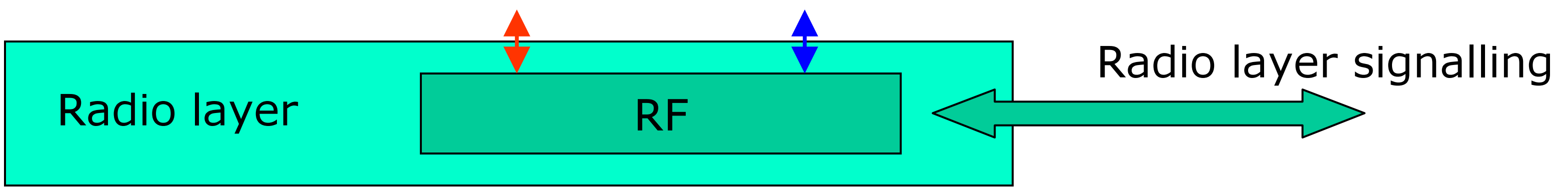
Bluetooth core system architecture



Radio layer (physical layer)

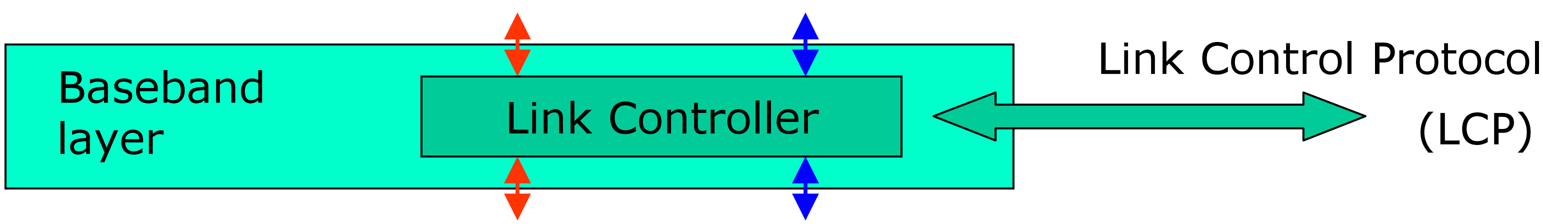
The radio layer specifies details of the air interface, including the usage of the frequency hopping sequence, modulation scheme, and transmit power.

The radio layer FHSS operation and radio parameters have been presented on previous slides.



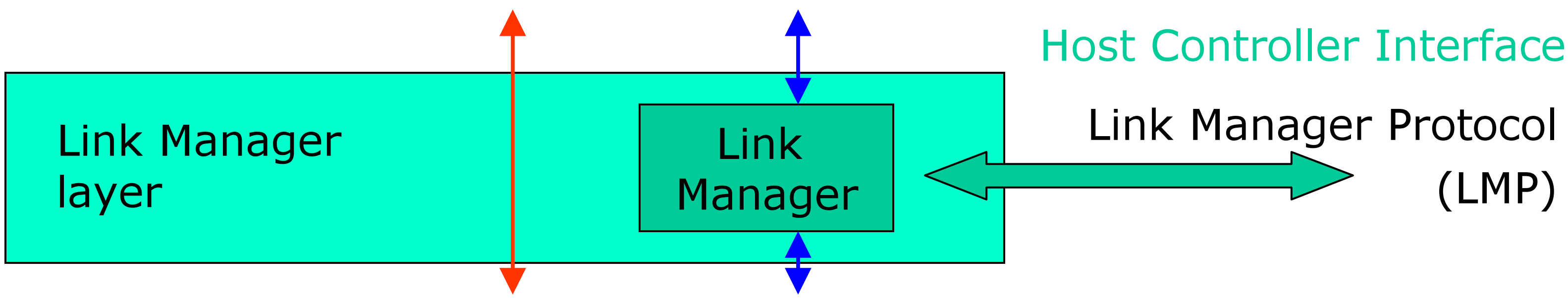
Baseband layer

The baseband layer specifies the lower level operations at the bit and packet levels, e.g., forward error correction (FEC) operations, encryption, cyclic redundancy check (CRC) calculations, and handling of retransmissions using the Automatic Repeat Request (ARQ) Protocol.



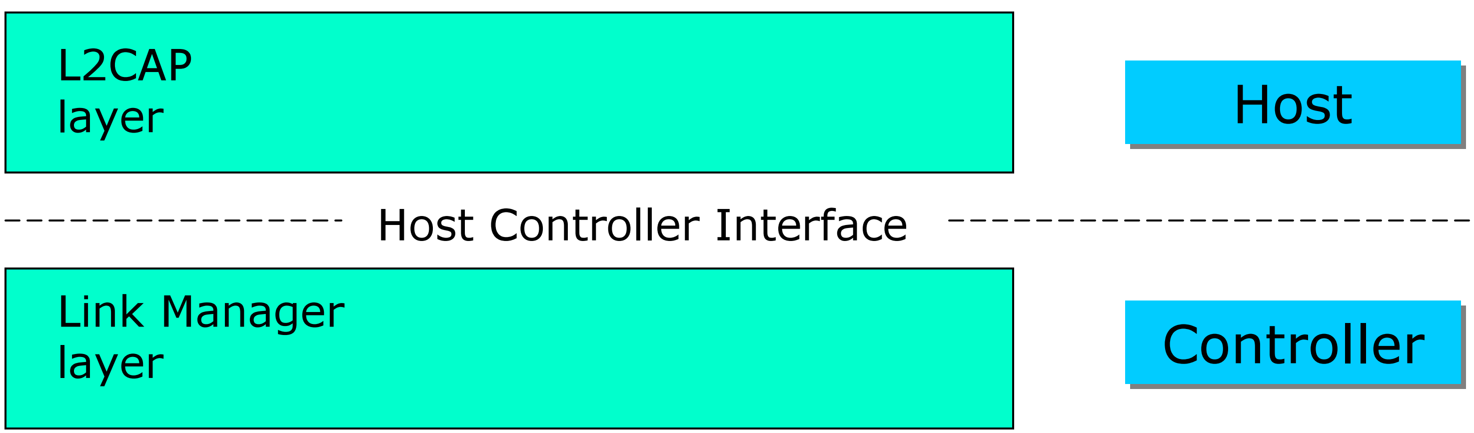
Link Manager layer

The link manager layer specifies the establishment and release of SCO and ACL links, authentication, traffic scheduling, link supervision, and power management tasks. These are "control plane" tasks. This layer is not involved in "user plane" tasks (i.e., handling of the user data).



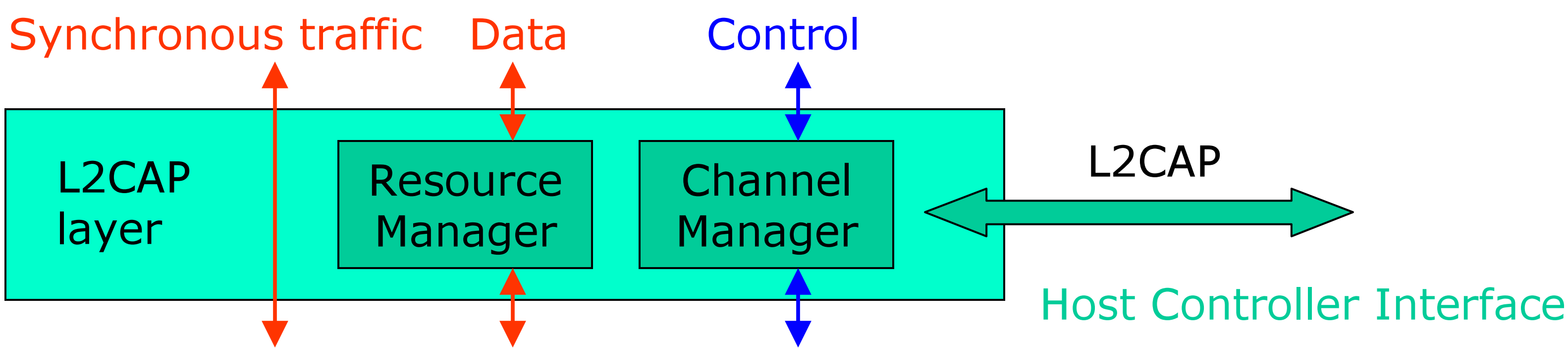
Host controller interface

The open host controller interface resides between the Bluetooth controller (e.g. PC card) and Bluetooth host (e.g. PC). In integrated devices such as Bluetooth-capable mobile devices this interface has little or no significance.



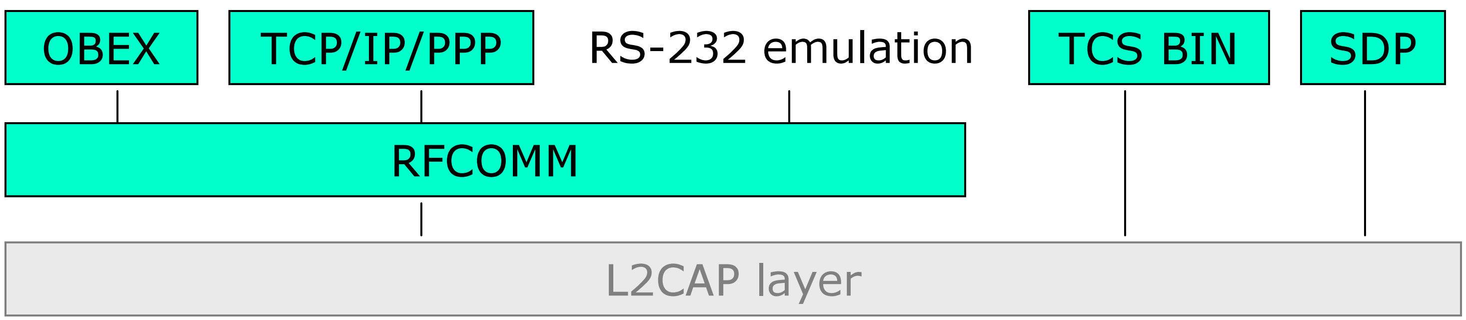
L2CAP layer

The Logical Link Control and Adaptation Protocol (L2CAP) layer handles the multiplexing of higher layer protocols and the segmentation and reassembly (SAR) of large packets. The L2CAP layer provides both connectionless and connection-oriented services.



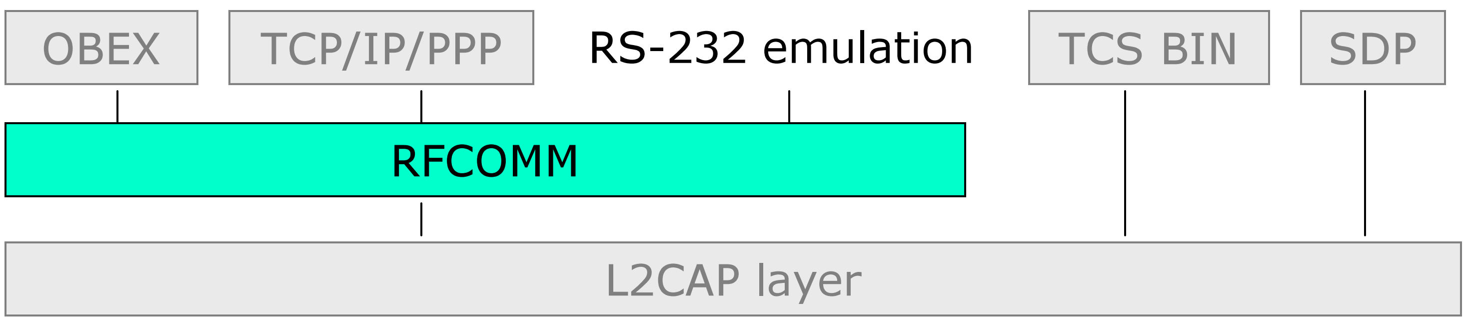
Higher protocol layers (1)

The operation of higher protocol layers is outside the scope of the IEEE 802.15.1 standard (but included in the Bluetooth SIG standards). The usage of these protocols depends on the specific Bluetooth profile in question. A large number of Bluetooth profiles have been defined.



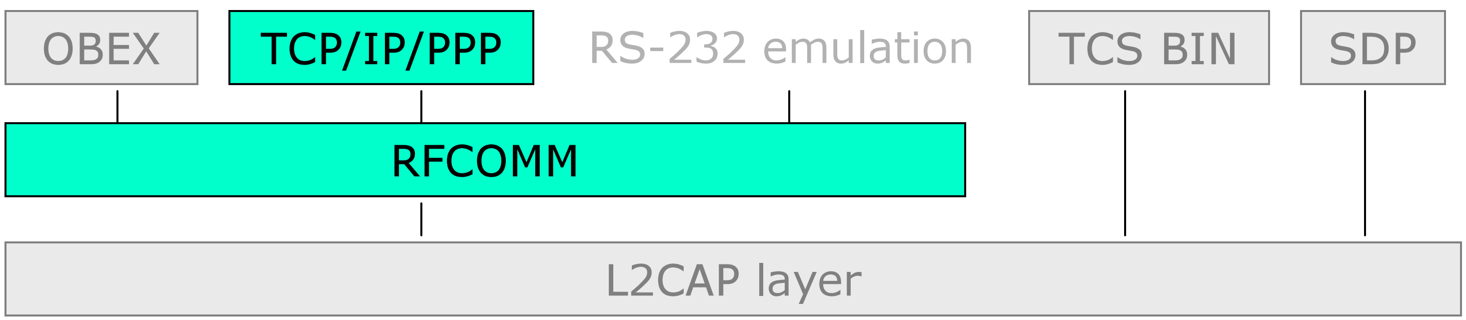
Higher protocol layers (2)

The radio frequency communication protocol RFCOMM enables the replacement of serial port cables (carrying RS-232 control signals such as TxD, RxD, CTS, RTS, etc.) with wireless connections. Several tens of serial ports can be multiplexed into one Bluetooth device.



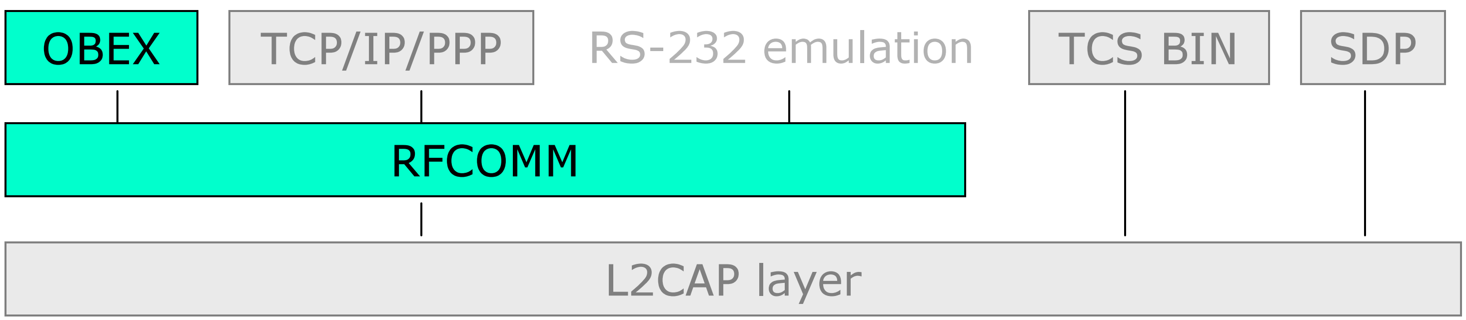
Higher protocol layers (3)

TCP/IP based applications, for instance information transfer using the Wireless Application Protocol (WAP), can be extended to Bluetooth devices by using the Point-to-Point Protocol (PPP) on top of RFCOMM.



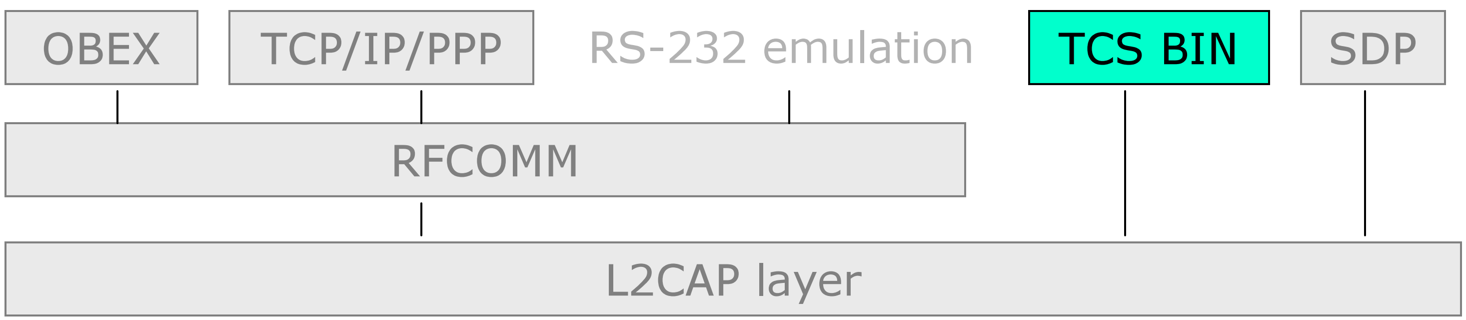
Higher protocol layers (4)

The Object Exchange Protocol (OBEX) is a session-level protocol for the exchange of objects. This protocol can be used for example for phonebook, calendar or messaging synchronisation, or for file transfer between connected devices.



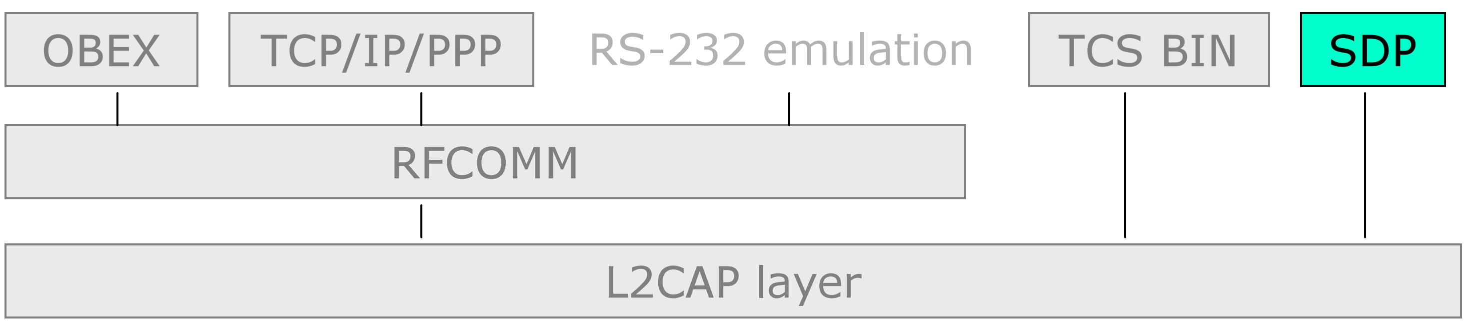
Higher protocol layers (5)

The telephony control specification - binary (TCS BIN) protocol defines the call-control signalling for the establishment of speech and data calls between Bluetooth devices. In addition, it defines mobility management procedures for handling groups of Bluetooth devices.



Higher protocol layers (6)

The Service Discovery Protocol (SDP) can be used to access a specific device (such as a digital camera) and retrieve its capabilities, or to access a specific application (such as a print job) and find devices that support this application.



Usage models

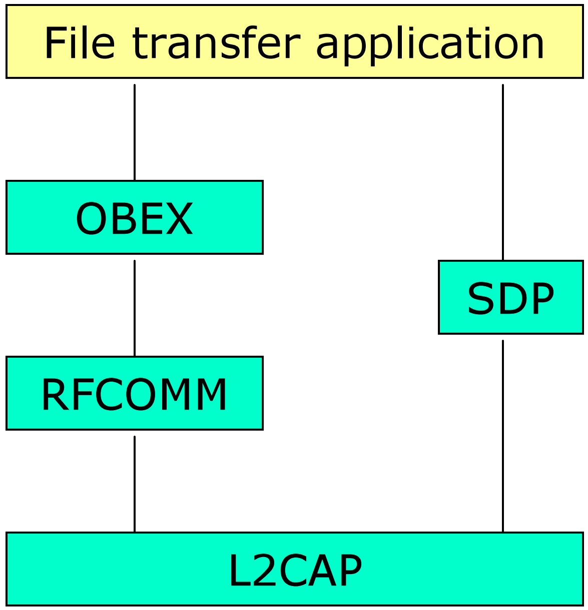
A number of usage models are defined in Bluetooth profile documents. A usage model is described by a set of protocols that implement a particular Bluetooth-based application. Some examples are shown on the following slides:

- File transfer
- LAN access
- Wireless headset
- Cordless (three-in-one) phone.

File transfer application

Using the file transfer profile:

A Bluetooth device can browse the file system of another Bluetooth device, can manipulate objects (e.g. delete objects) on another Bluetooth device, or - as the name implies - files can be transferred between Bluetooth devices.

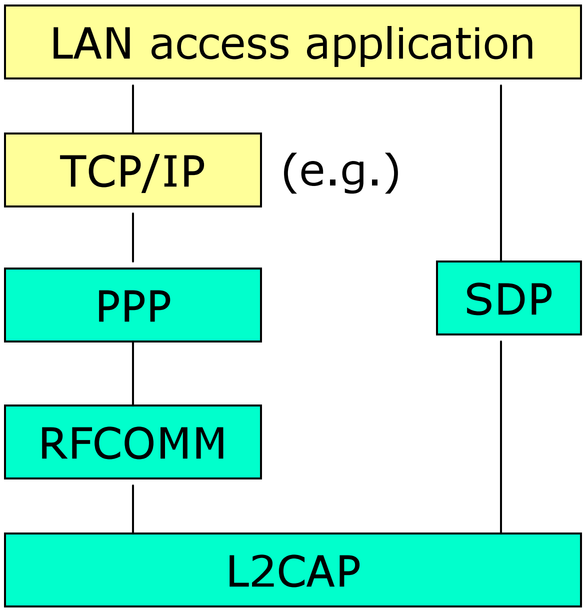


LAN access application

Using the LAN profile:

A Bluetooth device can access LAN services using (for instance) the TCP/IP protocol stack over Point-to-Point Protocol (PPP).

Once connected, the device functions as if it were directly connected (wired) to the LAN.

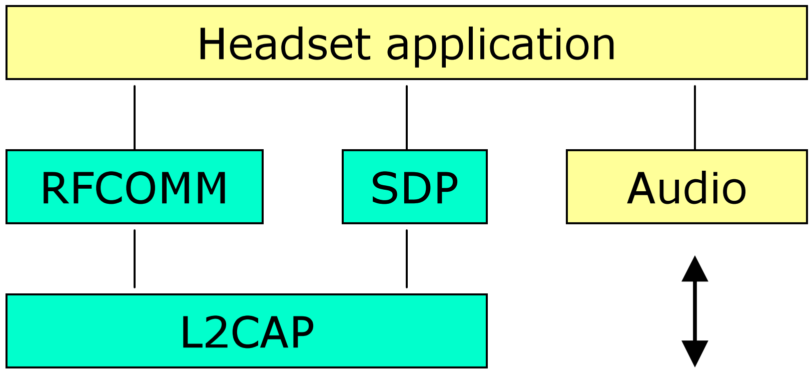


Wireless headset application

Using the headset profile:

According to this usage model, the Bluetooth-capable headset can be connected wirelessly to a PC or mobile phone, offering a full-duplex audio input and output mechanism.

This usage model is known as the *ultimate headset*.

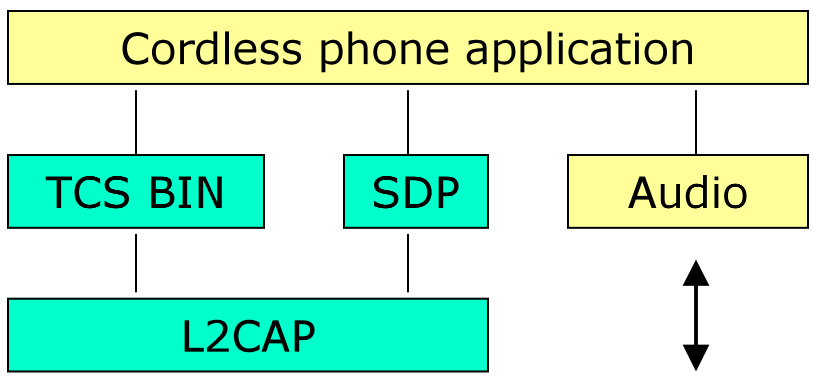


Cordless (three-in-one) phone application

Using the cordless telephone profile:

A Bluetooth device using this profile can set up phone calls to users in the PSTN (e.g. behind a PC acting as voice base station) or receive calls from the PSTN.

Bluetooth devices implementing this profile can also communicate directly with each other.



IEEE 802.15.4 LR-WPAN (ZigBee)

ZigBee technology is simpler (and less expensive) than Bluetooth.

The main objectives of an LR-WPAN like ZigBee are ease of installation, reliable data transfer, short-range operation, extremely low cost, and a reasonable battery life, while maintaining a simple and flexible protocol.

The raw data rate will be high enough (maximum of 250 kbit/s) to satisfy a set of simple needs such as interactive toys, but is also scalable down to the needs of sensor and automation needs (20 kbit/s or below) using wireless communications.

LR-WPAN device types

Two different device types can participate in an LR-WPAN network:

- Full-function devices (FFD) can operate in three modes serving as a personal area network (PAN) coordinator, a coordinator, or a device.
- Reduced-function devices (RFD) are intended for applications that are extremely simple.

An FFD can talk to RFDs or other FFDs, while an RFD can talk only to an FFD.

Network topologies (1)

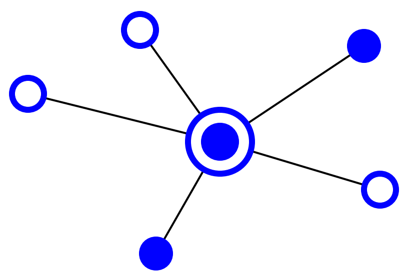
Two or more devices communicating on the same physical channel constitute a WPAN. The WPAN network must include at least one FFD that operates as the PAN coordinator.

The PAN coordinator initiates, terminates, or routes communication around the network. The PAN coordinator is the primary controller of the PAN.

The WPAN may operate in either of two topologies: the star topology or the peer-to-peer topology.

Network topologies (2)

Star topology



In a star network, after an FFD is activated for the first time, it may establish its own network and become the PAN coordinator.

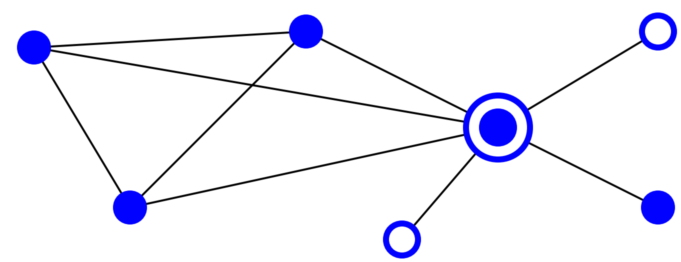
The PAN coordinator can allow other devices to join its network.

◉ PAN coordinator (always FFD) ● FFD ○ RFD

Network topologies (3)

In a peer-to-peer network, each FFD is capable of communicating with any other FFD within its radio sphere of influence. One FFD will be nominated as the PAN coordinator.

Peer-to-peer topology



A peer-to-peer network can be ad hoc, self-organizing and self-healing, and can combine devices using a mesh networking topology.

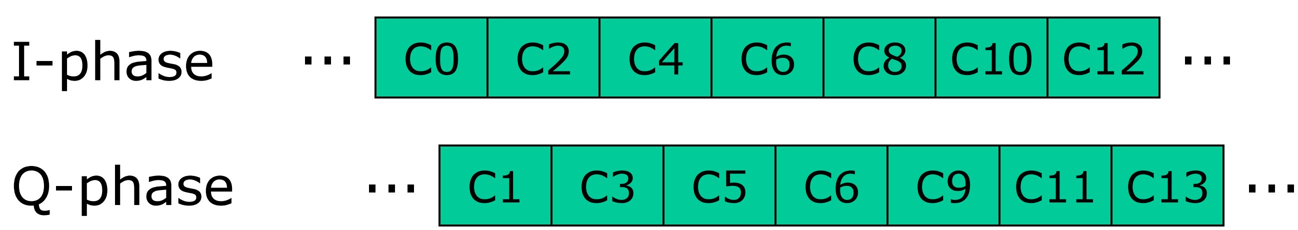
ZigBee PHY and MAC parameters

Topology	Ad hoc (central PAN coordinator)
RF band	2.4 GHz ISM frequency band
RF channels	16 channels with 5 MHz spacing
Spreading	DSSS (32 chips / 4 bits)
Chip rate	2 Mchip/s
Modulation	Offset QPSK

Access method	CSMA/CA (or slotted CSMA/CA)

Spreading and modulation

Four consecutive bits are mapped into a data symbol. Each symbol is mapped into a 32-chip pseudorandom sequence. The even-indexed and odd-indexed chips of the chip sequence representing each data symbol are modulated onto the carrier using Offset-QPSK in the following way:



Beacon frames

The LR-WPAN standard allows the optional use of a superframe structure. The format of the superframe is defined by the coordinator. The superframe is bounded by network beacons, sent by the coordinator, and is divided into 16 equally sized slots. The beacon frame is transmitted in the first slot of each superframe. If a coordinator does not wish to use a superframe structure, it may turn off the beacon transmissions. The beacons are used to synchronize the attached devices, to identify the PAN, and to describe the superframe structure.

CSMA/CA operation (1)

Nonbeacon-enabled networks use an unslotted CSMA-CA channel access mechanism. Each time a device wishes to transmit data frames or MAC commands, it shall wait for a random period. If the channel is found to be idle, following the random backoff, the device shall transmit its data. If the channel is found to be busy, following the random backoff, the device shall wait for another random period before trying to access the channel again.

Acknowledgment frames shall be sent without using a CSMA-CA mechanism.

CSMA/CA operation (2)

Beacon-enabled networks use a slotted CSMA-CA channel access mechanism, where the backoff slots are aligned with the start of the beacon transmission.

Each time a device wishes to transmit data frames, it shall wait for a random number of backoff slots. If the channel is busy, following this random backoff, the device shall wait for another random number of backoff slots before trying to access the channel again. If the channel is idle, the device can begin transmitting on the next available backoff slot boundary.