ZigBee Technical Datasheet

Roke Manor Research
A Siemens Company

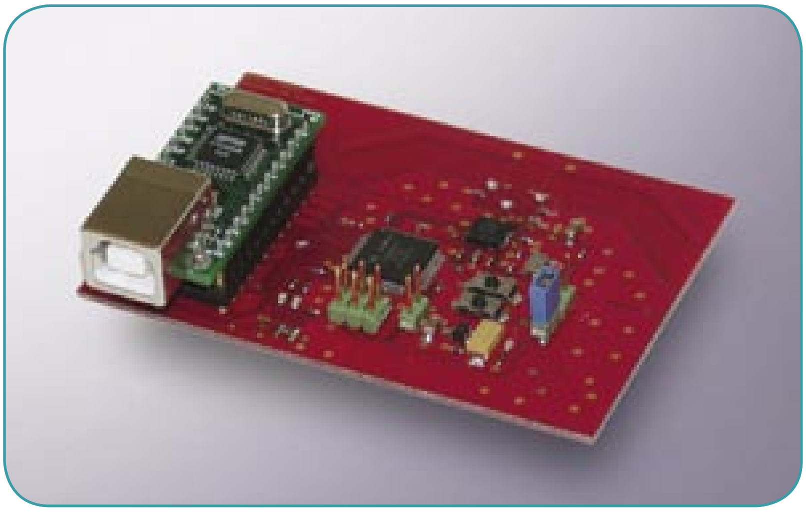
ZigBee is set to drastically expand the low data rate wireless market by providing a standardised air interface and low cost products. To help you understand how you can benefit from revolution this data sheet provides a description of the ZigBee standard, and the expertise of Roke Manor Research that can help get your products to market quicker.

Our Expertise in Zigbee Radio Systems

Roke Manor Research has developed extensive expertise in the ZigBee air interface specification, and in developments using the products from the leading semiconductor and software stack vendors. We have experience in using the Ember and Freescale ASICs and software, and also the Figure 8 Wireless stack.

Through development partnerships we have access to advanced information and ASIC samples, enabling us to accelerate your product developments. High product investment has produced two-chip solutions consisting of an RF ASIC along with a standard microcontroller to implement the software stack. Continuing development will see the product size falling with single-chip solutions.

ZigBee allows complex networks to be developed, and supports many options for optimising the air interface for each application. Therefore careful system design is required. To support this, along with a detailed knowledge of the air interface, we have developed simulation tools to predict system performance, in particular mesh networks.



ZigBee Core Markets

Industrial and Commercial

- Monitors
- Movement sensors
- Automation
- Control links

Personal Healthcare

- Patient monitors
- Ultrasonic wands
- Data loggers
- Remote diagnosis
- Wireless autopilot control
- National Marine Electronics Association standard data over ZigBee

Building Automation

- Security
- Heating, ventilation and air conditioning (HVAC)
- Lighting
- Fire and safety systems

Data Storage Tags

- Automotive service records
- Inventory control/tracking
- Maintenance logging

The Standards

The ZigBee standard has been developed to address the market for low data rate (250kbps) short- range communications in the 1 to 75 metres range. It uses the ISM bands at 868MHz (Europe), 915MHz (USA) and 2.4GHz (International).

It has been developed with the emphasis on low-cost, battery powered applications such as consumer electronics, home and building automation, industrial controls, PC peripherals, medical sensor applications, toys and games.

The IEEE approved draft 18 of the 802.15.4 standard issued on 12th May 2003 specifies the PHYsical and Medium Access Control (MAC) layers.

The ZigBee standard is published by the ZigBee Alliance, an industry group of over 50 companies. It defines the network, security and application layers of the system.

The following alliance members are amongst those offering solutions for the ZigBee system

- Ember
- Freescale
- Chipcon
- Invensys
- Mitsubishi
- CompXs
- AMI Semiconductors
- Figure 8 Wireless
- ENQ Semiconductor

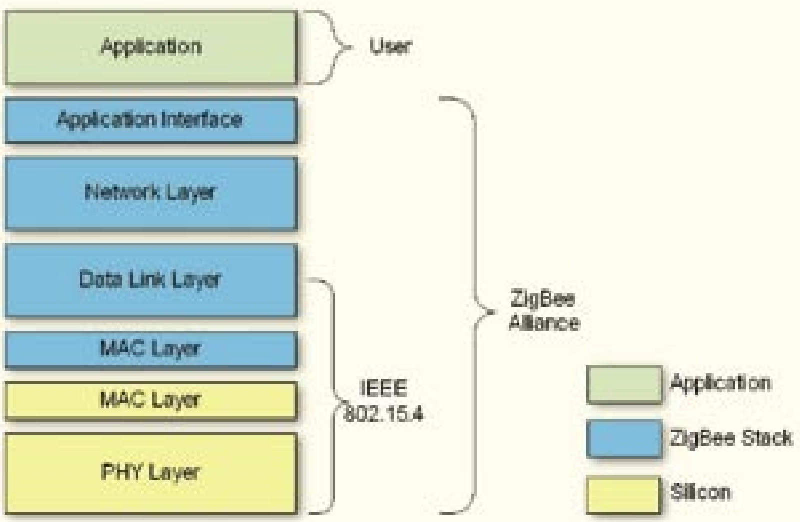


Figure 1 ZigBee Protocol Stack

Network Topology

The specifications permit three different network topologies to be implemented depending on the application. These are: Star, Cluster Tree and Mesh.

Star Topology

In the star configuration, one device acts as the Personal Area Network (PAN) coordinator through which all communications on a given radio channel takes place. The PAN coordinator must be capable of communicating with any other device on the network. This functionality is described as a full-function device and is implemented using a software stack of about 30 Kbytes.

A PAN coordinator must be in receiving mode when not transmitting. The unit is likely to consume too much current to allow battery operation and would probably be mains powered.

A reduced-function device can be implemented using a low-cost, small-memory micro controller. The reduced function device cannot particiapte in any routing activity and can only communicate with a full function device. The reduced function device cannot be a PAN coordinator itself. As it only has to receive and transmit for short periods of time it is suitable for battery operation.

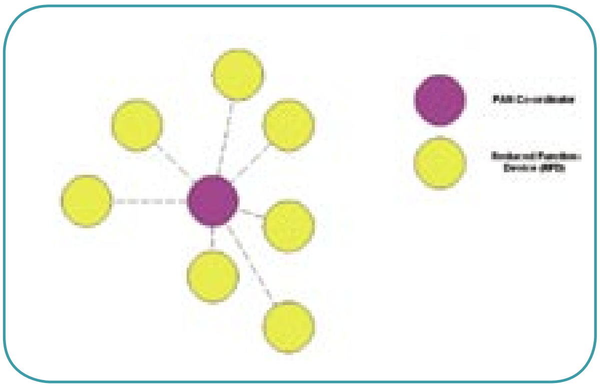


Figure 2 ZigBee Star Topology

Cluster Tree Topology

The cluster tree topology is formed by modifying the star topology. One or more of the RFD's connected to the PAN co-ordinator is replaced with a FFD and from these FFD's more RFD/FFDs may be attached. One advantage of the cluster tree is that it may be used to extend the geographical spread of the network.

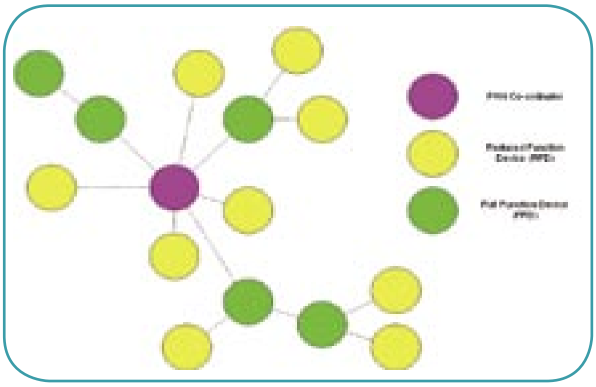


Figure 3 ZigBee Cluster Tree Topology

Mesh Topology

The third topology supported by ZigBee is Mesh. In the Mesh configuration there is full connectivity between all FFDs participating in the network with one of the FFDs acting as the PAN co-ordinator. RFDs may also participate in the network but these are only connected to their parent FFD and do not participate in routing. The key advantages of mesh topology are reliability and network throughput provided via the multiple paths.

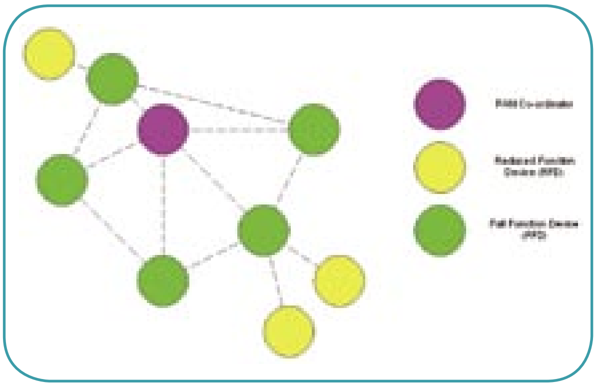


Figure 4 ZigBee Mesh Topology

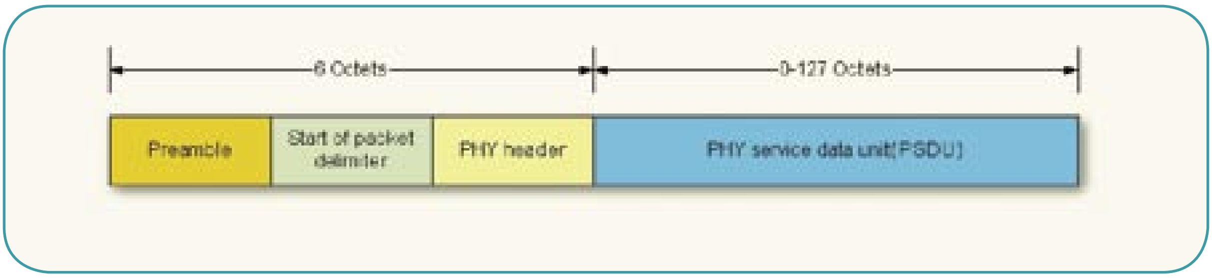


Figure 5 802.15.4 PHY Packet Structure

Packet Structure

The 802.15.4 PHY packet can vary between 48 and 1064 bits. The packet structure is shown above.

The 32 bit preamble allows the receiver to synchronise to the incoming packet. The 8 bit long PHY header indicates the length of the PSDU. The PSDU structure varies depending on which of four frame types are being transmitted.

- A beacon frame is used by a coordinator to transmit beacons.
- A data frame is used for all transfers of data.
- An acknowledgment frame is used for confirming successful frame reception.
- A MAC command frame is used for handling all MAC peer entity control transfers.

Chanel Access

Non Beacon Mode

The standard allows two types of channel access mechanism, depending on the network configuration. Non beacon-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 back off, it shall transmit its data. If the channel is found to be busy, following the random back off, 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.

The ZigBee standard allows a relative velocity of 5m/s between units.

Beacon Mode

The standard allows the optional use of a superframe structure. The PAN coordinator defines the format of the superframe. The superframe, bounded by network beacons, is sent by the coordinator and is divided into 16 equally sized slots. The beacon frame is transmitted in the first slot of each superframe.

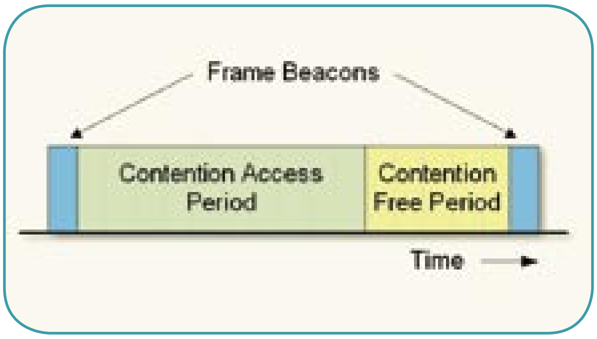


Figure 6 Superframe Structure with Guaranteed Time Slots

For low latency applications or applications requiring specific data bandwidth, the PAN coordinator may dedicate portions of the active superframe to that application. These portions are called guaranteed time slots (GTSs). The guaranteed time slots comprise the contention free period (CFP), which always appears at the end of the active superframe starting at a slot boundary immediately following the contention access period. The PAN coordinator may allocate up to seven of these GTSs and a GTS may occupy more than one slot period.

Beacon operation allows device power consumption to be reduced by requiring that receivers are only active whilst a beacon is being transmitted. The beacon message contains an address field that can be used to alert a device to an impending message from the controller.

The time interval between frame beacons may be between 15.36ms and 251.66s depending on the latency and power requirements of the network. In addition the PAN coordinator may switch off its receiver for up to 251.64s.

The superframe may have an active and an inactive portion. During the inactive portion the coordinator shall not interact with its PAN and may enter a low power mode.

Beacon mode is not supported in mesh configuration.

PHY Layer

Three ISM bands have been specified for 802.15.4 operation. The 868MHz band is available in Europe, 915MHz in the USA and 2.4GHz is available world wide. Figure 7 describes the allocations.

The 802.15.4 specification uses direct sequence spread spectrum coding and either BPSK or O-QPSK modulation depending on the operating band. The data rates and chip rates are shown below.

868/915 MHz Band Modulation

The transmitter must be capable of transmitting at least –3dBm although this should be reduced when possible to reduce interference to other users. The maximum allowable power will depend on local regulatory bodies. The receiver must achieve a packet error rate of <1% for input signals at the antenna connector of >-92dBm.

2450 MHz Band Modulation

The transmitter must be capable of transmitting at least –3dBm although this should be reduced when possible to reduce interference to other users. The maximum allowable power will depend on local regulations.

In the European Union the maximum transmitter power allowed is 10mW / MHz ERP for a direct sequence spread spectrum signal.

The receiver must achieve a packet error rate of <1% for input signals at the antenna connector of >-85dBm.

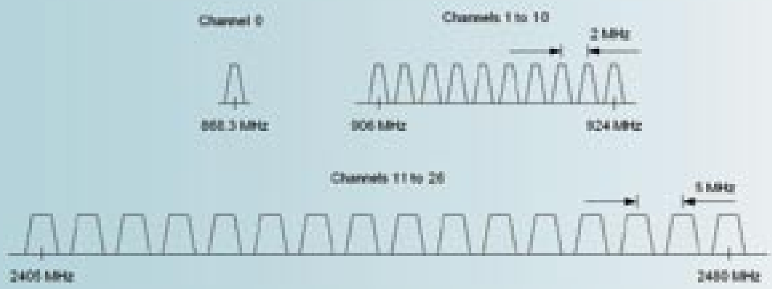


Figure 7 PHY Band Allocations

Frequency (MHz)	Spreading parameters		Data parameters		
	Chip rate (kchips/s)	Modulation	Bit rate (kbits/sec)	Symbol rate (ksymbols/sec)	Symbols
868-868.6	300	BPSK	20	20	Binary
902-928	600	BPSK	40	40	Binary
2400-2483.5	200	O-QPSK	250	62.5	16-ary Orthogonal

Table 1: Frequency bands and data rates

Coexistance with other systems

2.4 GHz Band

The 2.4GHz ISM band is shared with a variety of other systems. The issue of co-existence with these systems should be addressed. The most likely to be encountered is 802.11b (Wireless LAN, direct sequence spread spectrum).

Clear channel assessment – 802.15.4 receivers have the capability to measure the power on the received channel and perform automatic transmission backoff if it is in use.

Modulation – The use of a quasi-orthogonal modulation scheme is power-efficient and a low cost detector is expected to meet the 1% PER requirements at 5-6 dB SNR. Wideband interference from an 802.11b transmitter would appear like white noise to the 802.15.4 receiver. The SIR performance will be 9-10dB better than an 802.11b receiver as only a fraction of the 802.11b 22MHz wide signal power will fall in the receiver bandwidth of the 802.15.4 device. The impact of narrowband interferers will be reduced due to the DSSS processing gain.

Low Duty Cycle – It is anticipated that the 802.15.4 system will operate at low duty cycles (<1%) which will make it less likely to cause interference with other systems.

Low Transmit Power – The maximum transmitter power in Europe is 10 mW / MHz ERP for a direct sequence spread spectrum system. Being 1MHz wide the maximum ZigBee signal will be 10mW ERP. This will limit the interference with other systems.

Channel Alignment – There are four 802.15.4 channels that lie in the guard bands between the 802.llb channels. Whilst these will contain some energy its level will be lower than within the 802.11b channels and may be selected for use in high 802.11b activity areas.

868 MHz Band

Operation in the 868MHz unlicensed band is covered by ERC Recommendation 70-03. It is split up into different bands for a mixture of non-specific and alarm applications. The band is only available in Europe.

System Implementation

This section gives estimates of the parameters that are likely to be achievable with a real system in a telemetry application.

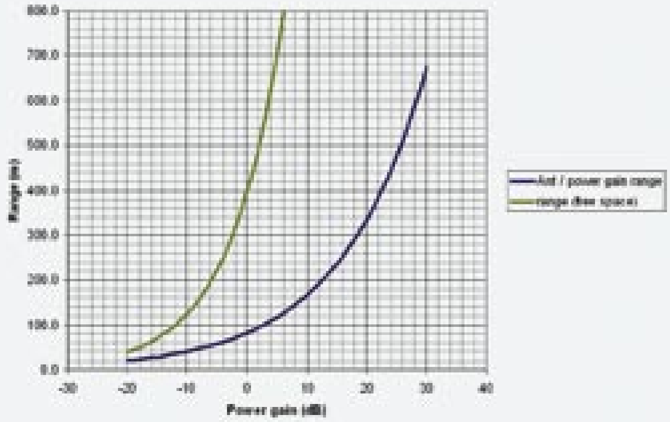
Expected Range

The 802.15.4 specification gives two equations for the channel loss between receiver and transmitter one for distances greater than 8 metres and one for less. The former has been used to estimate the expected range of a system.

The following graph shows the range that is to be expected using an 802.15.4 transmitter with an output power of 0dBm and 0dBi antennae on the transmitter and the receiver. Typical sensitivity is –92dBm and this has been used for the calculation. Figure 8 shows how the range will vary as the transmit power or antennae gain is varied. For example, increasing the transmit antenna gain to 10dB (the maximum ERP allowed in Europe is 10dBm) and the receiver gain to 15dB will give a range of 500 metres.

The ERP of a system operating in the USA may be higher. Using a 28dBm transmitter with 12 dBi antennae for transmit and receive could extend the operating range to about 3Km.

Figure 8 802.15.4 Estimated Range v Antenna / Transmit Power Gain



Antennae

The wavelength in free space for a 2.4GHz signal is 125mm. A dipole (gain = 3 dBi) for the signal will be approximately 53mm long and may be implemented using pcb tracks or free-standing wires. If gain is needed from the antenna then a 250mm long disc Yagi will give a gain of 10dBi, a boom length of 875mm will give a gain of 15dBi.

For size constrained applications, a large range of pcb mounted chip antennae are available. The smallest have a gain of approximately 0dBi and typically measure 7.2 x 5.3 x 1.3 mm.

When the antenna is likely to be shielded by casing, an external antenna can be used. These are typically 10cm long.

Power Consumption

ZigBee provides an number of operating modes to minimise current consumption. The table below shows typical figures from one of the leading chip sets.

Using the total current consumption figures it is possible to estimate the power supply requirements for several different scenarios:

	Reduced Function Device (RFD)			Full Function Device (FFD)			PAN Coordinator		
	Micro	RFIC	Total	Micro	RFIC	Total	Micro	RFIC	Total
Idle	STOP2 =0.5µA	Hibernate =3µA	=3µA	STOP2 =0.5µA	Hibernate =3µA	3.5µA	STOP2 =0.5µA	Hibernate =3µA	3.5µA
Receive	Run (4MHz) =4mA	Receive =35mA	39mA	Run (8MHz) =6.5mA	Receive =35mA	41.5mA	Run (16MHz) =13mA	Receive =35mA	48mA
Transmit	Run (4MHz) =4mA	Transmit =30mA	34mA	Run (8MHz) =6.5mA	Transmit =30mA	36.5mA	Run (4MHz) =13mA	Transmit =30mA	43mA

Example Applications

The following table shows three example applications with possible battery lifetime estimates. The lifetimes may be increased by using larger batteries.

Application	Transmission rate	Battery	Lifetime
Light Switch	6 ops / day	3V LiMn coin cell	10 years
Water level sensor	1 op / hour	3V LiMn coin cell	1-2 years
Patient heart monitor	1 op / 5ms	3V LiMn coin cell	1 day

For further information about ZigBee and how Roke Manor Research can help you, please contact us.

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