Radiocrafts
Embedded Wireless Solutions

AN014

ZigBee® simplified with RC2400-ZNM*

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***This application note is written for RC2400-ZNM, but all information is valid for all RC24xx products with ZNM, including high power versions.**

Introduction

ZigBee is a powerful and advanced technology, with almost unlimited possibilities. Hence it could also be a challenge to understand and to fully utilize the technology for newcomers to ZigBee. This application note aims to break down the barriers to ZigBee and make it more available.

This application note consists of two parts. The first part covers ZigBee basics and aim to give the reader an introduction to ZigBee and ZigBee terminology.

The second part goes into details on how the RC2400-ZNM module can easily be used to make the ZigBee network of your choice. Two complete examples are included to show how this can be done.

This application note is not intended to enable readers to implement ZigBee product for interoperability such as Smart Energy Profile compliant or Home Automation Profile compliant products. For such implementation see AN013 as a starting point.

References, Definitions and Abbreviations

[1]: RC24xx/RC24xxHP-ZNM User Manual
[2]: CC2530-ZNP Interface Specification

ZigBee Basics

ZigBee is a standard for low power wireless communication built on the IEEE 802.15.4 standard. Compared to standards as WiFi and Bluetooth, the ZigBee standard is characterized with:
- Longer range
- Multihop
- Lower power consumption
- Lower data rate

The reference protocol stack for ZigBee is shown in Figure 1

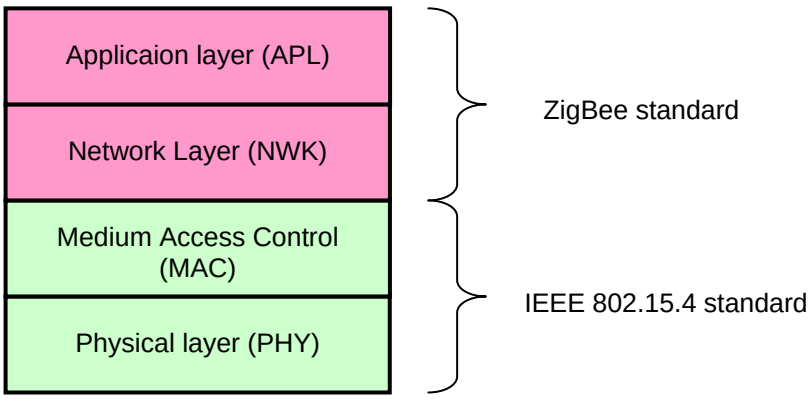


Figure 1 802.15.4 and ZigBee stack

ZigBee history

ZigBee is an evolving standard. The first variant was release as *ZigBee 2003* and later became *ZigBee 2006*. The current version is *ZigBee 2007*, which include both *standard feature set* and *PRO feature set*. The PRO feature set is normally the preferred solution and also the default for RC2400-ZNM.

Physical Radio

IEEE 802.15.4 defines 3 different radio frequency bands, 868 MHz (1 channel), 915 MHz (10 channels) and 2450 MHz (16 channels). The 2450 MHz band covering 2405-2480 MHz are by far the most widespread and it's the only band covered by RC2400 and this application note. The 2450 MHz band supports a data rate of 250 kbps and has 16 separate channels.

A ZigBee network

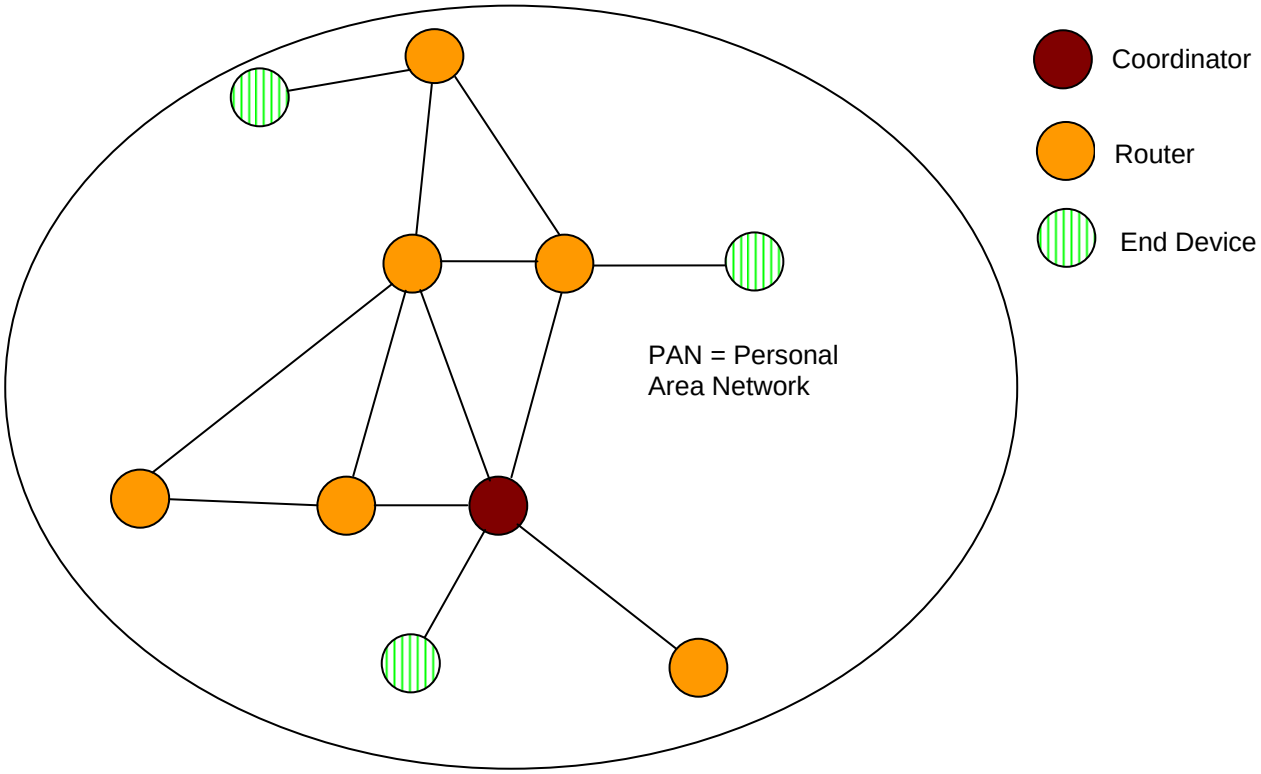


Figure 2 A ZigBee network

Figure 2 illustrate a ZigBee network. The ZigBee network is identified with a PAN ID and extended PAN ID. The PAN ID is 2 bytes and selected by the coordinator at start-up. The extended PAN ID is an 8 byte number introduced in ZigBee 2007 to resolve PAN ID conflicts.

A ZigBee network consists of 3 device types

Coordinator

The Coordinator forms the network and allows other devices to join/associate
There is only one Coordinator per network.

Router
A Router is normally “on” at all time and mains power operated. It has the ability to receive a packet and forward it in the network (= Routing). A Router can also store a packet to an associated End Device while the End Device is sleeping.

End Device
End devices are ideal for battery operated equipment as they can sleep most of the time and only wake up seldom to transmit data or poll for incoming messages. End devices do not have routing capability.

Addressing
There are two types of addresses used in ZigBee

- Short address/network address 2 bytes
- MAC address/IEEE address 8 bytes

The MAC address is an 8 bytes HW related address. It is locked to a given device and the address ranges are governed by IEEE.

The Short address is a 2 byte address only valid within a PAN. The short address for a new device is given by the parent at the time of joining the network. To reduce overhead the short address is the most used address type in a ZigBee network.

The short address is dynamic. A device that store its network related data in non-volatile memory can rejoin a network and keep its short address, but if the device has forgotten its previous short address it will be given a new address when joining.

End point
ZigBee also includes sub addressing within the same physical Radio device. This is referred to end point (as in USB). For example a switch with two buttons but one radio. There are hence two buttons that can be pressed and we want to identify from which button a "toggle" command is sent. This can be done by allocating different end points to the two buttons.

End point addresses can be selected from 1 to 240.

Binding
Binding is the capability of a logically connection to an application. This allows for two devices to connect to some sort of press-button-installation.

Security and encryption
ZigBee includes a 128 bits AES encryption on the network layer. The network key can either be preinstalled in all devices or distributed unsecured to new devices joining the network.
More advanced security options are also available, but out of scope for this application note.

Profiles, interoperability and Cluster ID
All description above defines how two ZigBee devices can send messages between each other. However for interoperability between devices the application messages must also be standardized. This is done in ZigBee through Cluster library and Profiles.

This is out of scope for this application note. See application note 013 as an example for profile interoperability.

ZigBee simplified with RC2400-ZNM

The concept of the RC2400-ZNM module is that the application is implemented in one MCU/processor and the ZigBee Network part in the other. In RC2400-ZNM is preloaded with a ZigBee PRO compliant stack and offers an easy to use API via UART or SPI to an external processor. The external application processor can be of any type or brand, and the development can be done with the tool and platform most convenient to the developer.

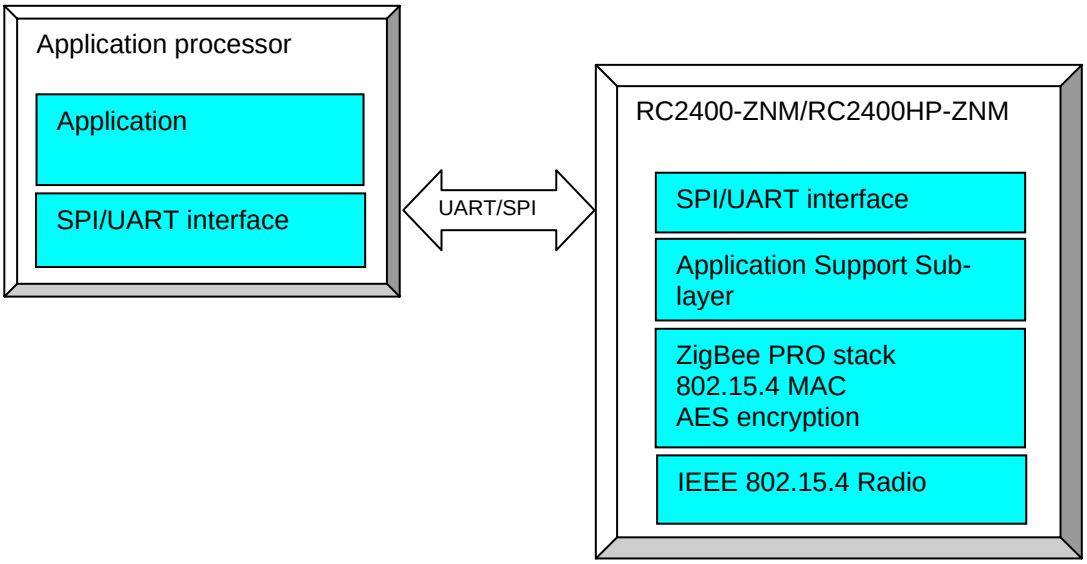


Figure 3 ZigBee Network Module concept

For more detail on the interface between RC2400-ZNM and the host application processor see [1] and [2]. The RC24xx-ZNM User Manual [1] should be read before reading the next part of the application note.

Building and decoding the UART transport Frame Format

The frame format for UART transmission between the application processor and the RC2400-ZNM are given in Figure 4.

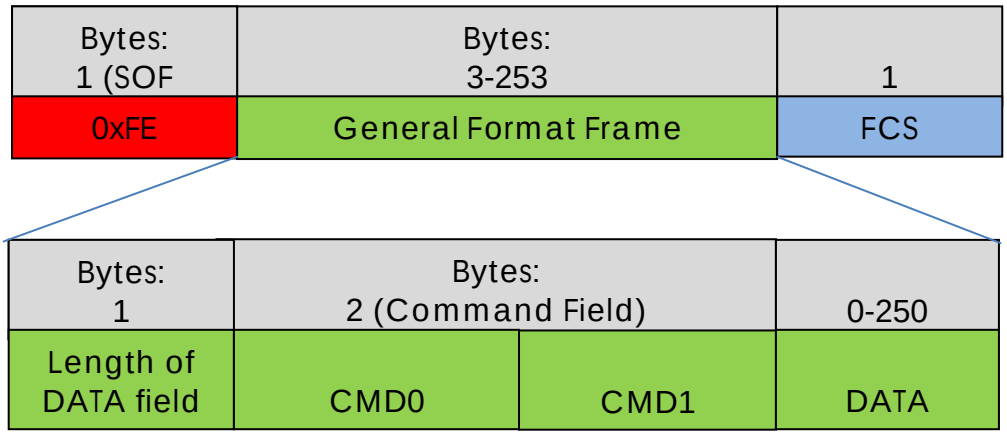


Figure 4 UART frame format

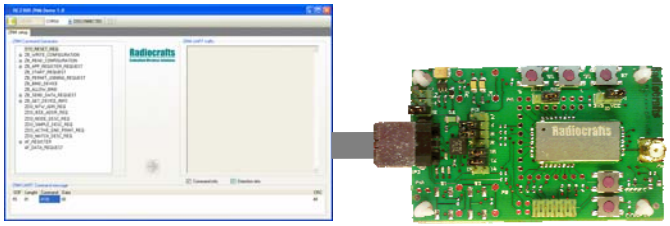
The command field indicate the type of frame being transmitted. It can be a data frame, an acknowledge frame or some sort of configuration frame. For complete overview of all available commands see [2].

FCS: Frame-Check Sequence (Last byte of UART frame): XOR of all bytes in the General Format Frame field

The data field can consist of several fields depending on the command. If one field consist of more than 1 byte, the Least Significant Byte is transmitted first within the field. It is recommended to keep the DATA length less than 128 bytes.

How to understand the examples

The examples are implemented with the PC tool ZNM-CCT. The ZNM-CCT requires access to the modules UART via an available COM-port. Typically UART-access is obtained via an UART-to-RS232 or UART-to-USB converter. The Demo Boards (DB) from Radiocrafts contains an on-board level shifter for direct plug-in to a PC and further access to the related COM-port. A dedicated command-text file for the examples in this application note is available.



The yellow boxes are transcript from the ZNM-CCT tool

```
PC-->ZNM:(The black text is information on direction of communication +
description of command sent)
GREEN IS HEX CODE SENT TO MODUEL FE 01 41 00 00 40
ZNM-->PC:
BLUE IS HEX CODE RECEIVED FROM MODULE FE 01 41 80 02 C6
```

Table 1 Explanation of transcript boxes

General setup - with or without storage of history

First thing is to consider if device need a total memory erase as many network and configuration parameters could be stored from previous use. During development this is often the case.

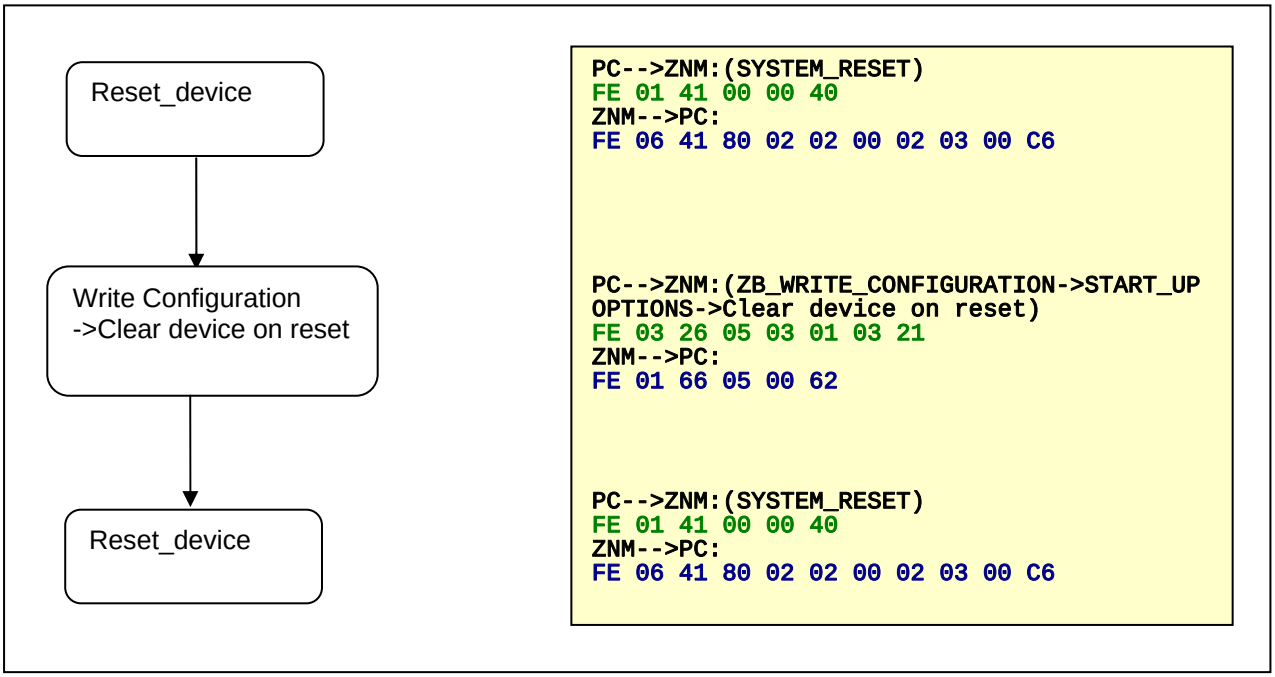


Figure 5 Clearing a device of history

Example 1- Building automation/climate control system

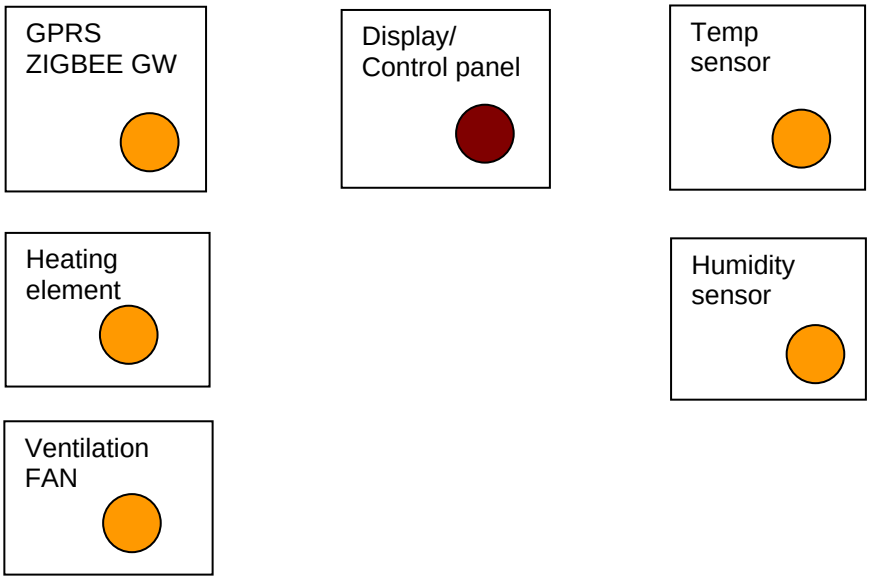


Figure 6 A logical ZigBee network

Function/command	From	To	Command ID	Data/attributes
Temperature reading	Temp sensor	Display	0x0001	1 Byte
Temperature reading	Temp sensor	GW	0x0001	1 Byte
Humidity reading	Humidity sensor	Display	0x0002	1 Byte
Humidity reading	Humidity sensor	GW	0x0002	1 Byte
Set Heat level	Display	Heating element	0x0003	1 Byte
Set Ventilation	Display	Ventilation fan	0x0004	1 Byte
Set temp set point	Gateway	Display	0x0005	1 Byte
Set hum. set point	Gateway	Display	0x0006	1 Byte

Table 2 Commands and command ID

Devices	Device ID	Device version	End point in example	Input commands	Output commands
Display	0x0001	0x01	0x01	0x0001 0x0002 0x0005 0x0006	0x0003 0x0004
GW	0x0002	0x01	0x01	0x0001 0x0002	0x0005 0x0006
Temp sensor	0x0003	0x01	0x01		0x0001
Humidity sensor	0x0004	0x01	0x01		0x0002
Heating element	0x0005	0x01	0x01	0x0003	
Ventilation fan	0x0006	0x01	0x01	0x0004	

Table 3 Device types in the ZigBee network

The example consists of an environment control system. The central control element is the Display /Control Panel. It is always present and required and hence is chosen as coordinator in the system. Then there are two sensors, one for temperature and one for humidity. As actuators we have similar function, one for heating and one for ventilation.

The basic function in this example network is as follows:

The sensor report to the Display/Control Panel every 5 minute, and every 1 hour to the GPRS gateway. The Control panel have a built in set point and based on the sensor data it sends new settings to the heating and ventilation system. The gateway sends data to a server for logging. In addition the operator can set new temperature and humidity set points. The intelligence for reducing temperature at night can be implemented in Display/control panel or in central server.

The setup for all device include

- Device type (Coordinator, Router, End Device)
- Encryption key usage
- Application information

(PAN ID and channel are other parameters that could be set up, but in this example we use default)

Setting up the Coordinator

The coordinator creates the ZigBee network and hence must be started first.

The application information is registered inside the RC2400 with the *ZB_APP_REGISTER* command and is mandatory. It enables automatic service discovery (not covered in this application note).

After setup the ZigBee radio is started with a *ZB_START_REQUEST* command. The radio then starts and the coordinator create a network.

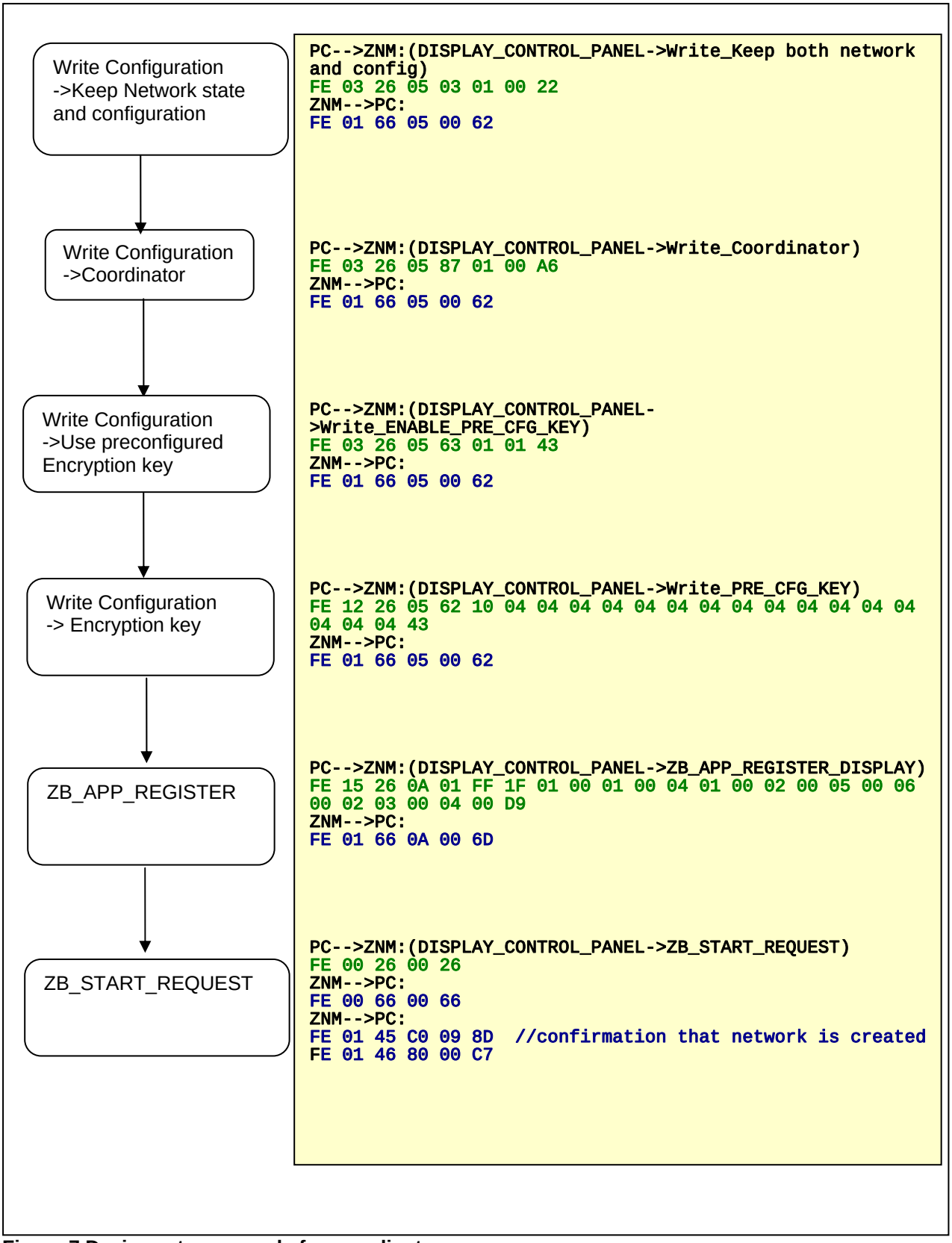


Figure 7 Device setup example for coordinator

Setting up the Routers

There are several ways to ensure correct joining of the other devices in a network
(Correct means no unwanted devices joins and the wanted devices chooses the correct network)

For this example we have chosen 2 features.
- Secure joining with preconfigured network key
- Limited time window to allow joining

The coordinator was set up with a default encryption key and all joining devices must include the same. In addition the coordinator can allow join for *x* seconds. This function can be connected to a installation button at the Display/Control panel. During this time all devices with correct network key can join.

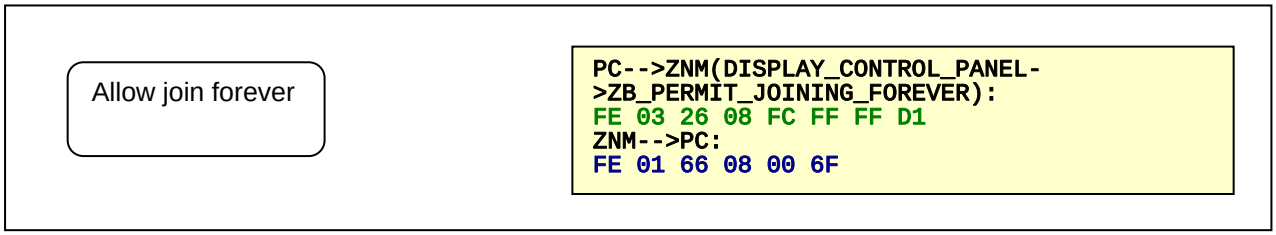


Figure 8 Permit joining at Coordinator

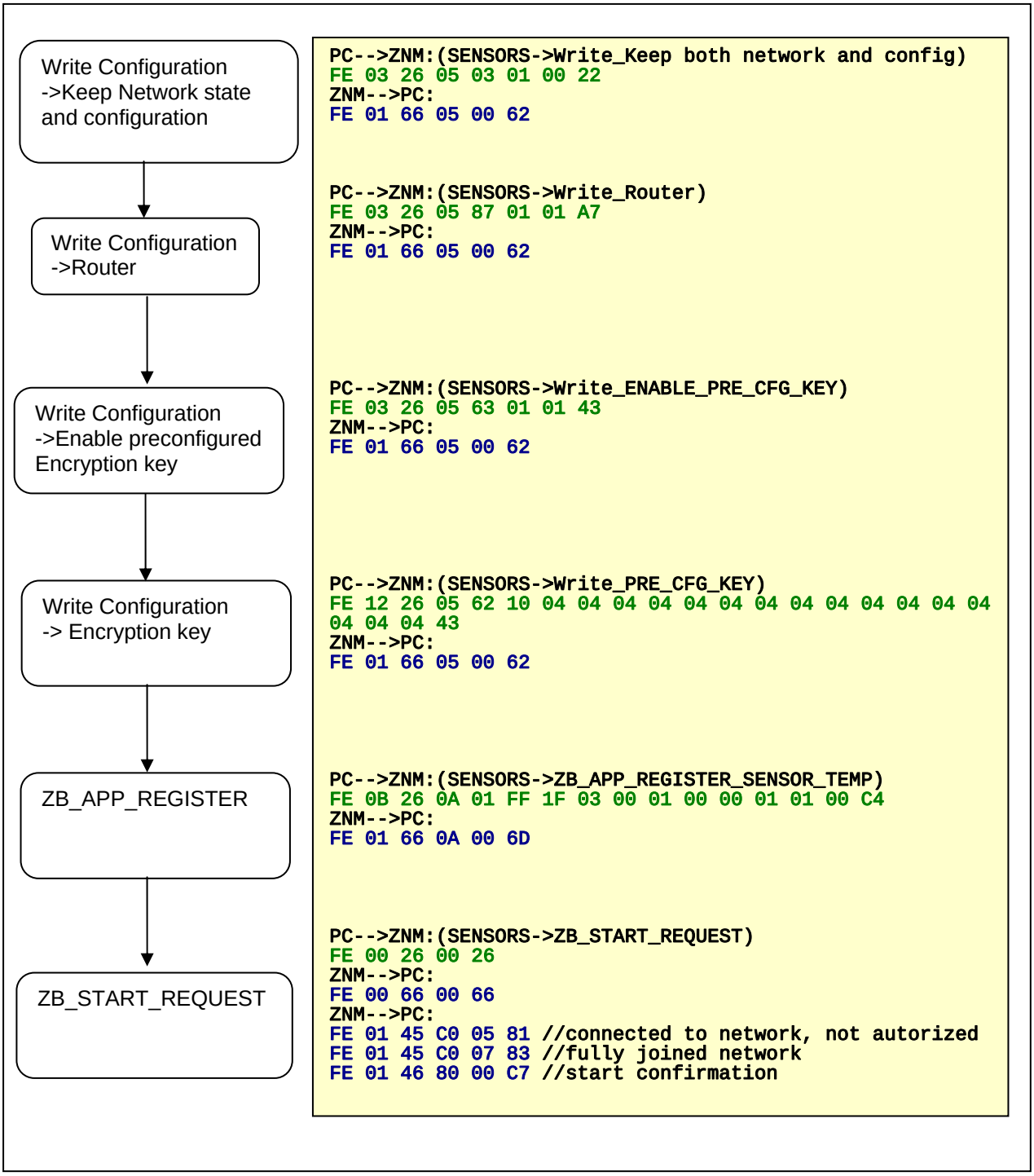


Figure 9 Device setup example at Router (temp sensor)

Other routes follow exact same procedure, but with different *ZB_APP_REGISTER* message

- Humidity sen. `FE 0B 26 0A 01 FF 1F 04 00 01 00 00 01 02 00 C0`
- Heating elem. `FE 0B 26 0A 01 FF 1F 05 00 01 00 01 03 00 00 C0`
- Vent. fan `FE 0B 26 0A 01 FF 1F 06 00 01 00 01 04 00 00 C4`
- Gateway `FE 11 26 0A 01 FF 1F 02 00 01 00 02 01 00 02 00 02 05 00 06 00 DF`

Service discovery/network discovery

After all devices have joined the network the devices must identify the other devices. The control panel must identify the actuators, what type they are and what address they have. To identify means to find their short address used for addressing data messages. The application processor must store and hold the short address of the devices it shall send data packets to.

For the sensor it's easy to identify the Display/control unit as it is always the coordinator and have short address 0x0000. But they also have to identify the GPRS gateway for sending hourly sensor data.

The easiest way to do this is to identify devices by using devices with a known IEEE address. The IEEE address is physically locked to the device and the IEEE address of a device can be known to the application processors of the other devices. E.g. the IEEE addresses of the Ventilation fan can be pre-programmed in the Display/Control panel application processor.

For this example it is assumed that the IEEE address for the different devices are know.

When doing the example you might want to learn the IEEE addresses of the different devices and to do that over UART use the *ZB_GET_DEVICE_INFO* command.

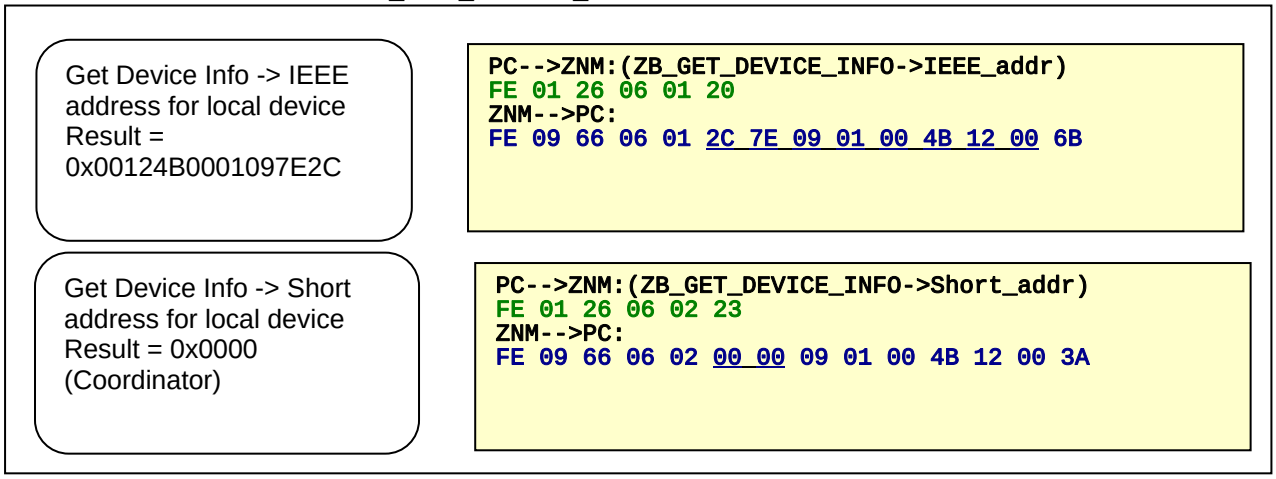


Figure 10 Reading out local information with ZB_GET_DEVICE_INFO

Based on the IEEE address the *ZB_FIND_DEVICE* function can be used to identify the short addresses needed for communication.

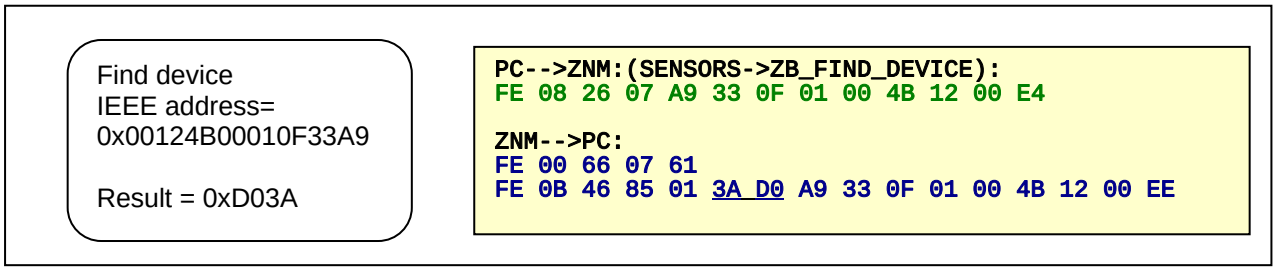


Figure 11 Identifying nodes in a network

Sending and receiving data

When all nodes know the short address of the devices they shall communicate with, the network is completely set up and data can be sent and received with the *ZB_SEND_DATA_REQUEST* and the *ZB_RECEIVE_DATA_INDICATION*.

ZB_SEND_DATA_REQUEST

1	1	1	2	2	1	1	1	1	0-84
Len(1)	CMD0	CMD1	Dest..	Com.ID	Handle	Ack	Radius	Len(2)	Data
0x09	0x26	0x03	0xNNNN	0xCCCC	0xHH	0x01	0x04	1	0xDD

Len(1) - Length of packet from *Dest*. including *Data*.

Dest. - 0xNNNN = Short address of receiver. 0xFFFF is address for broadcast.
Com.ID - 0xCCCC Command ID, (see Table 2)

Handle - 0xHH is an identifier of the sent message, so when sending more the one message the host can identify which messages an acknowledge is received for.
Ack - 0x01 indicate that the host requests a application acknowledgement that the packet is received by receiving application
Radius - Max number of hops for a message. 0x04 should be OK for this application.
Len(2) Length of Data field = 0x01 in all our cases.
Data - See Table 2

ZB_SEND_DATA_CONFIRM

1	1	1	1	1
Len(1)	CMD0	CMD1	Handle	Status
0x02	0x46	0x83	0xHH	0x01

Len(1) - Length of packet from *Handle*

Handle. - 0xHH is an identifier of the sent message, so when sending more the one message the host can identify which messages a acknowledge is received for.
Status - 0x00 = OK, Packet was received.

ZB_RECEIVE_DATA_INDICATION

1	1	1	2	2	1	1	0-84
Len(1)	CMD0	CMD1	Source	Com.ID	Len(2)	unused	Data
0x06	0x46	0x87	0xNNNN	0xCCCC	1	0x00	0xDD

Len(1) - Length of packet from *Source*. including *Data*.

Dest. - 0xNNNN = Short address of receiver. 0xFFFF is address for broadcast.
Com.ID - 0xCCCC Command ID, (see Table 2)

Handle - 0xHH is an identifier of the sent message, so when sending more the one message the host can identify which messages a acknowledge is received for.
Ack - 0x01 indicate that the host requests a application acknowledgement that the packet is received by receiving application
Radius - Max number of hops for a message. 0x04 should be OK for this application.
Len(2) Length of Data field = 0x01 in all our cases.
Data - See Table 2

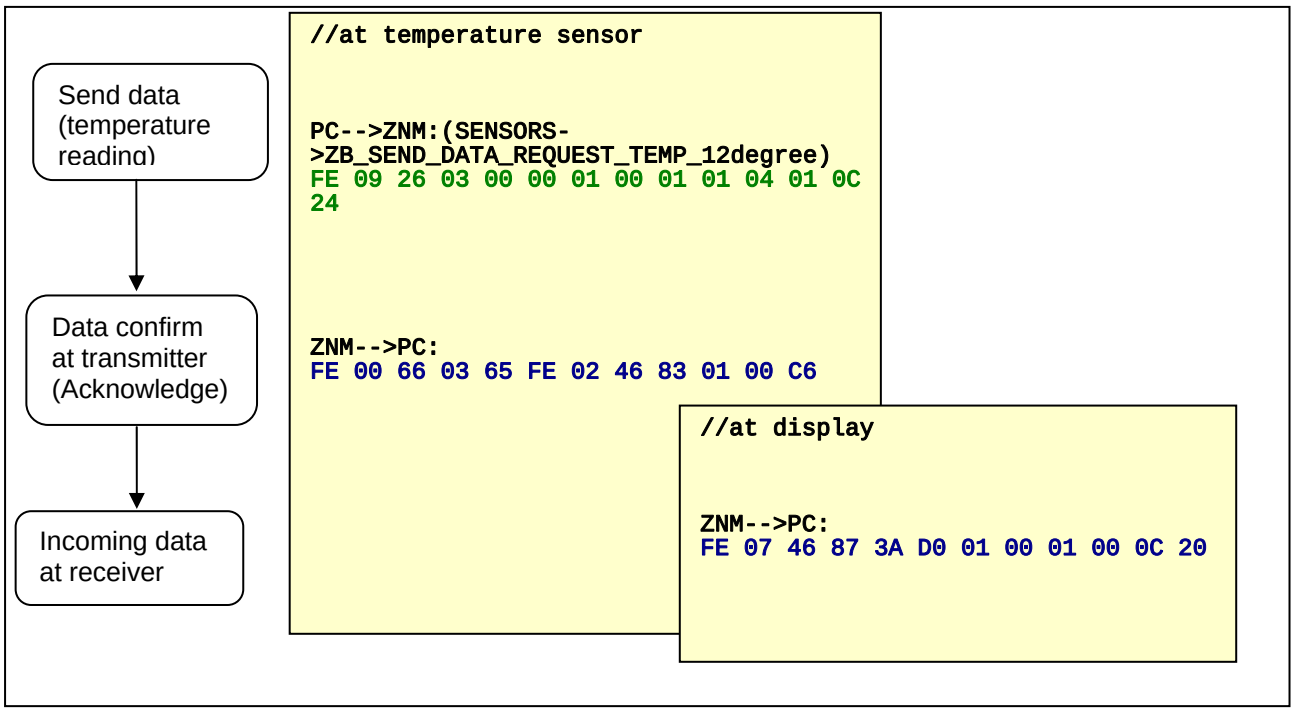


Figure 12 Sending a temperature reading from sensor to display

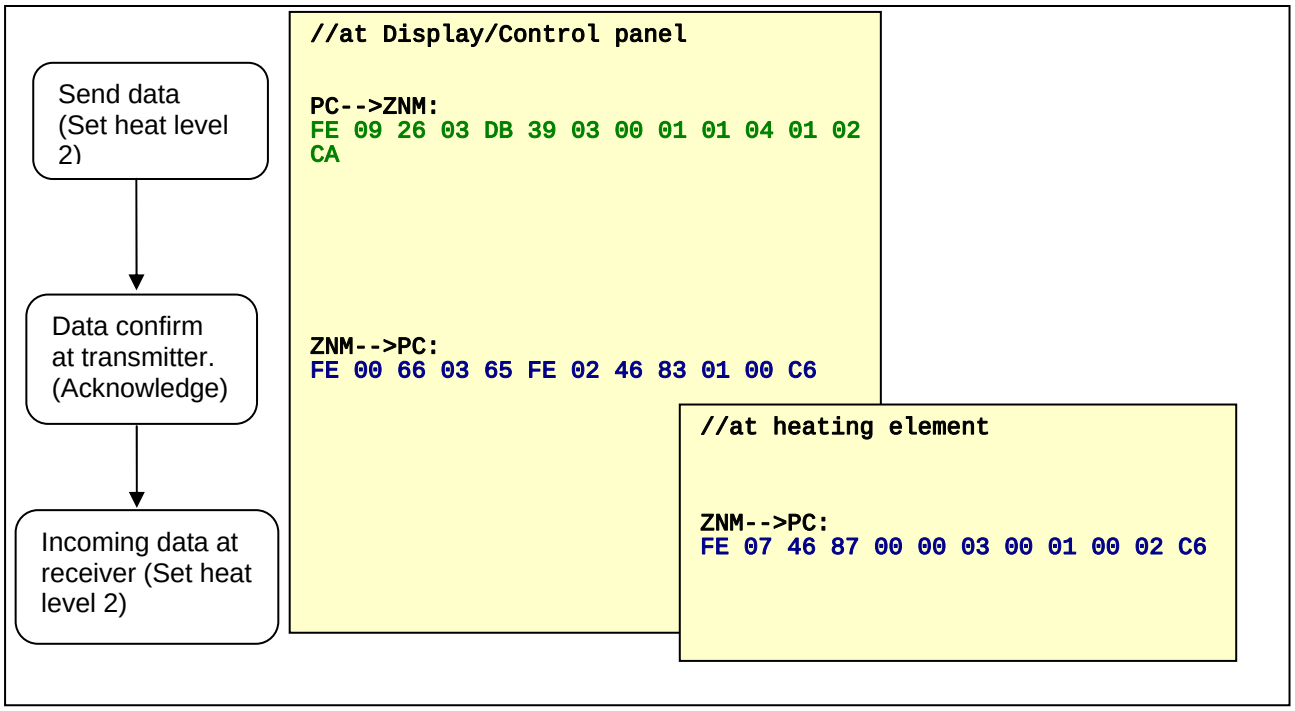


Figure 13 Sending heat level from display to heating element

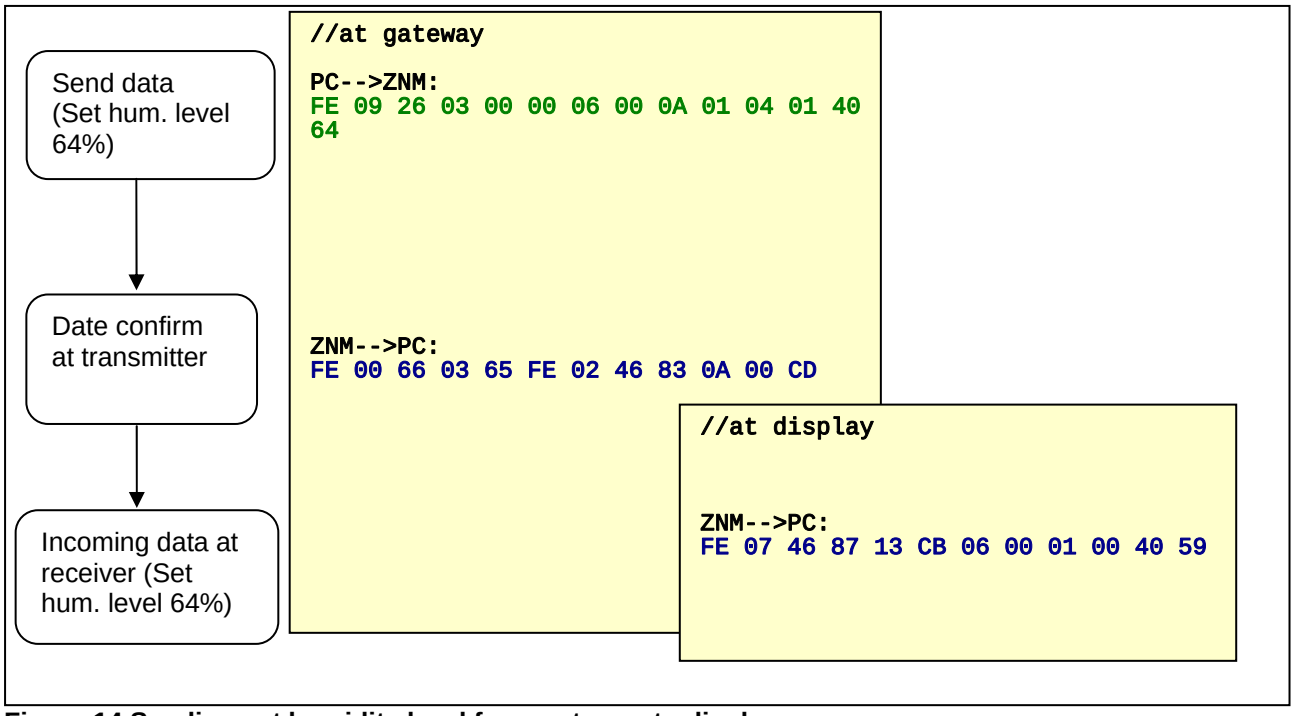


Figure 14 Sending set humidity level from gateway to display

Example 2- Transparent data

If you do not have the need to specify different devices and just want to send transparent data between nodes in a network, this example shows how to make such a network. The functionality of this network is very basic. Transparent data should be sent from one device to one or more receivers. All application oriented information and use of the data is handled by host microcontroller.

A setup procedure include:

- Device type (Coordinator, Router, End Device)
- Encryption key usage
- Application information

(PAN ID and channel are other parameters that could be set up, but in this example we use default)

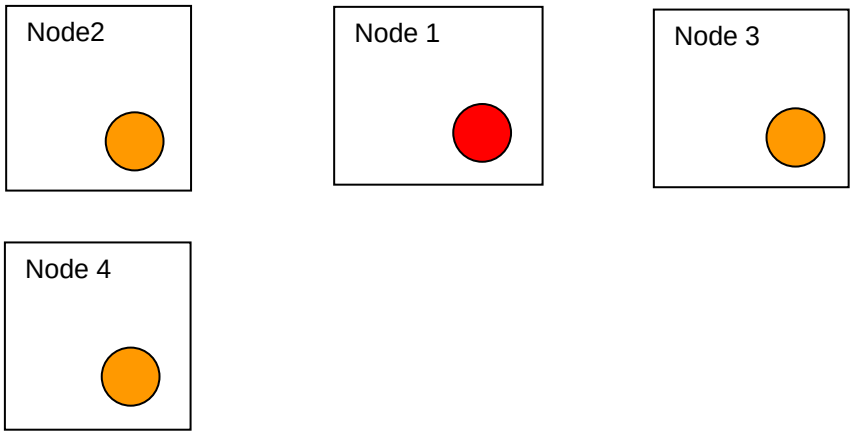


Figure 15 A logical ZigBee network

Function/command	From	To	Command ID	Data/attributes
Send data	all devices	all devices	0x0001	N Bytes

Table 4 Commands and command ID

Devices	Device ID	Device version	End point in example	Input commands	Output commands
Transparent data device	0x0001	0x01	0x01	0x0001	0x0001

Table 5 Device types in the ZigBee network

Setting up the Coordinator

The Coordinator starts the ZigBee network and hence must the RC2400-ZNM Coordinator be set up first

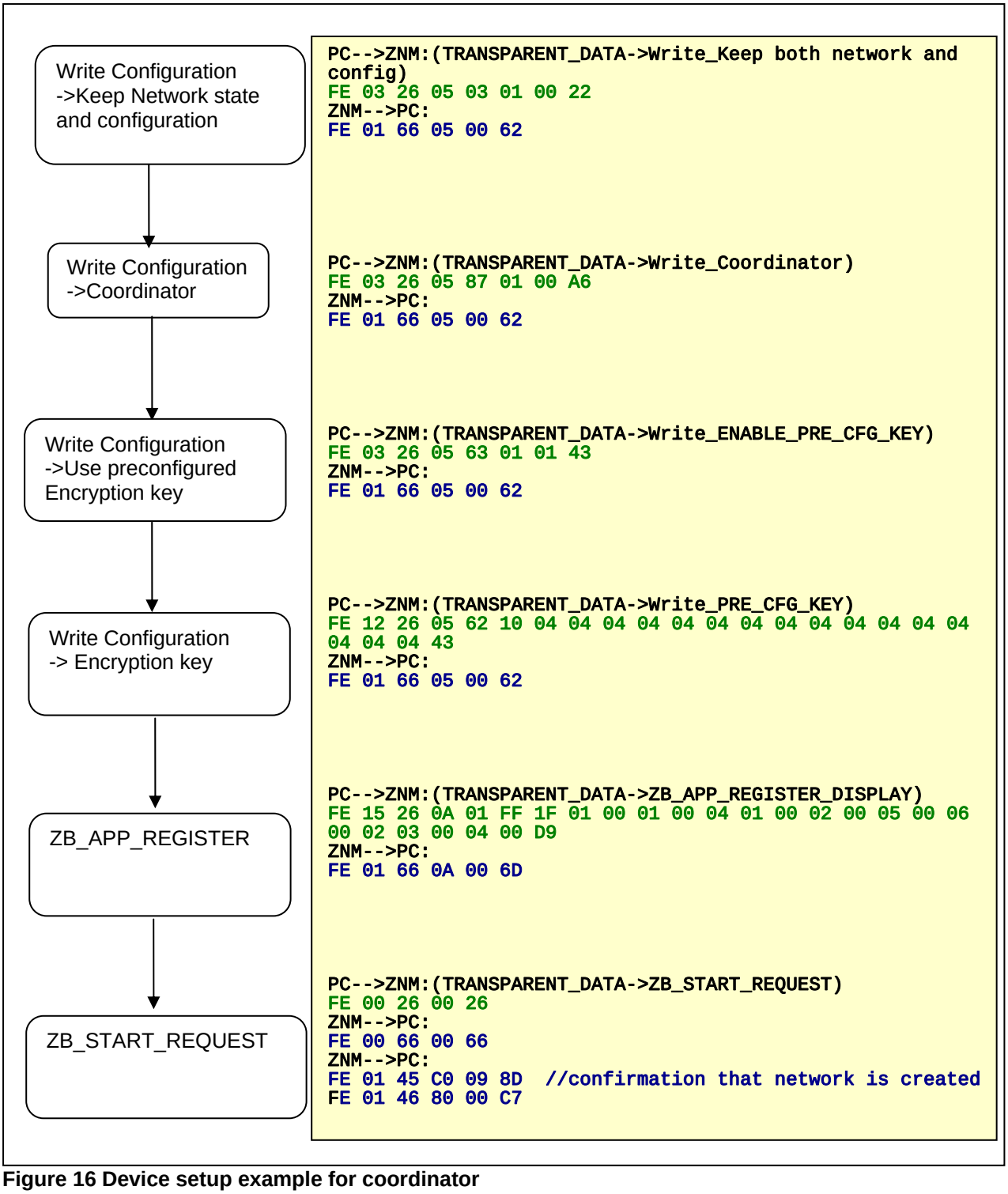


Figure 16 Device setup example for coordinator

Setting up the Routers

In Figure 17 it is shown the required setup for a Router, including network joining.
For controlling joining of new routers to the network, please see page 10

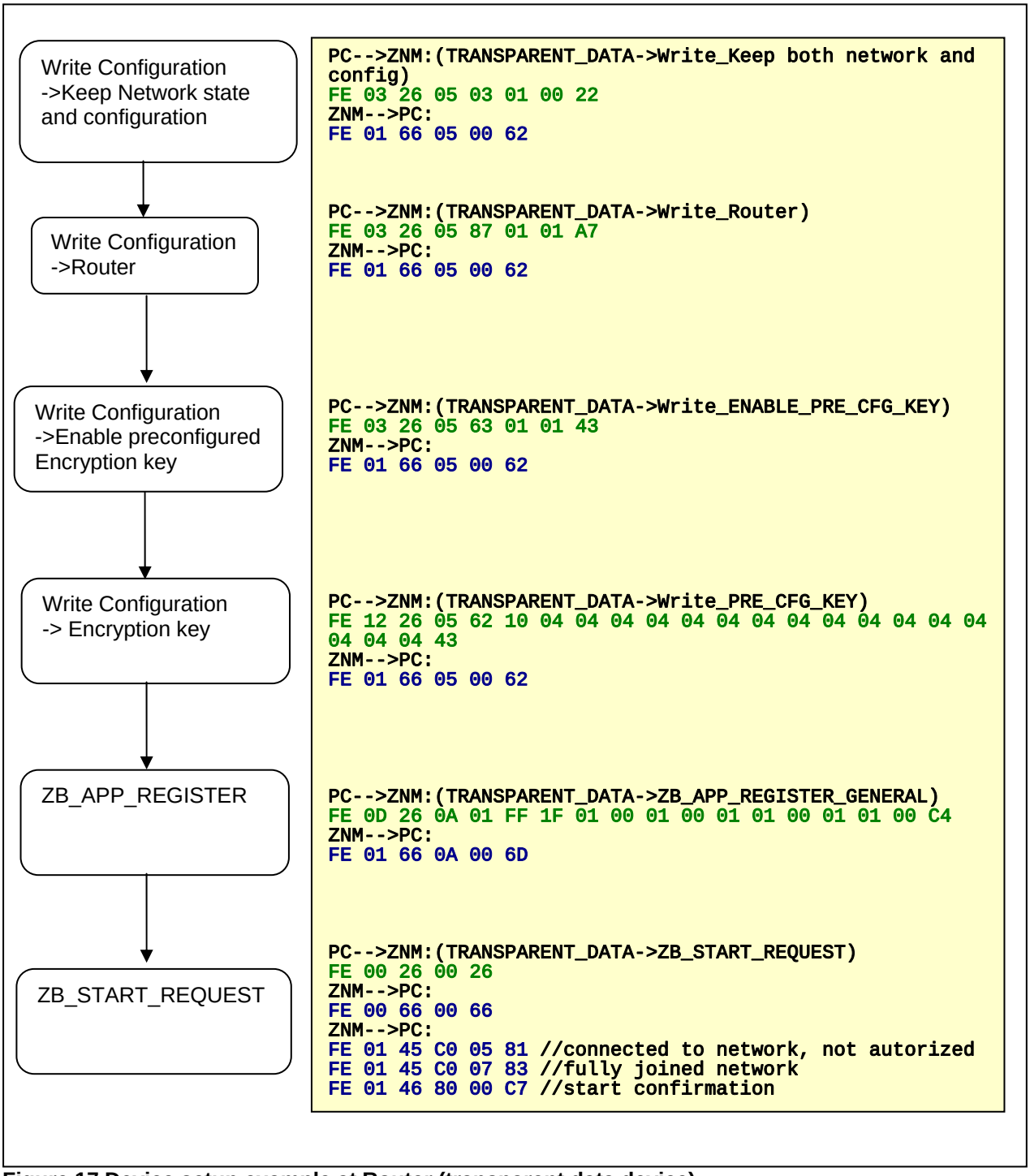


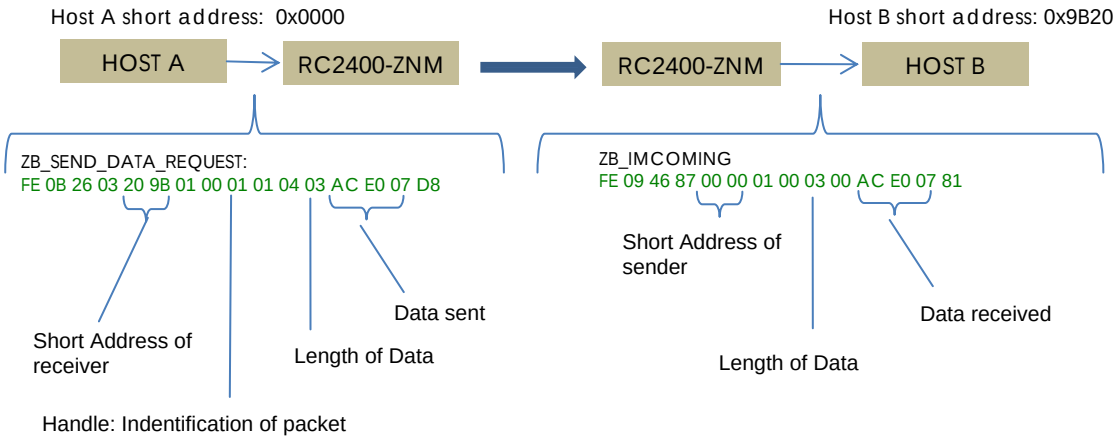
Figure 17 Device setup example at Router (transparent data device)

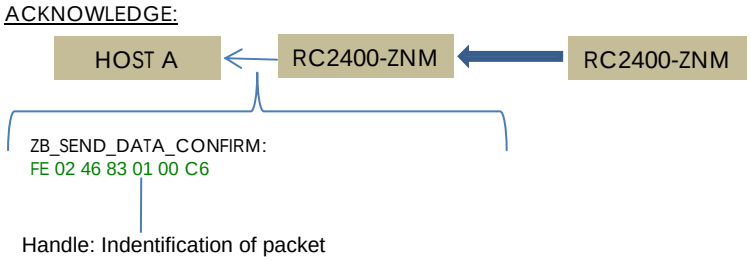
Identifying/finding nodes

For how to find devices in a network based on the IEEE address see page 12.

Sending and receiving transparent data.

When all nodes know the short address of the devices they shall communicate with, the network is completely set up and data can be sent and received with the *ZB_SEND_DATA_REQUEST* and the *ZB_RECEIVE_DATA_INDICATION*. Example of communication of the three bytes "AC E0 07" is illustrated below:





In order for the host controllers to identify the payload in both directions they must discard the overhead bytes added before- and after the Data field. The overhead bytes give valuable address- and information data which can be used for addressed communication.

Remarks

This application note has given a brief introduction to ZigBee and showed how easy it can be to build a ZigBee network with RC2400-ZNM. However it has only revealed a small part of the powerful functionality within RC2400-ZNM and ZigBee PRO. For more detailed information and complete overview of the features within RC2400-ZNM see the RC24xx-ZNM User Manual and the CC2530-ZNP interface specification.

Document Revision History

Document Revision	Changes
1.0	First release

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