The Analog Mixed Signal Company

User Manual

Rev. 1.20 / August 2012

ZWIR451x

Serial Command Interface

Contents

List of Figures

List of Tables

1 Introduction

This document describes the features and the usage of the ZWIR451x module with the Serial Command Interface (SCI) firmware. The SCI allows using ZWIR451x modules without programming the module. The ZWIR451x modules are delivered preprogrammed and tested and can be integrated into the application without programming. The module provides several serial interfaces that can be used independently to control the module.

The SCI module provides firmware over-the-air update (OTAU) capability, data encryption, and data authentication in addition to the normal User Datagram Protocol (UDP) communication. Integration into normal computer networks is possible without restrictions.

1.1. Organization of this Document

The following section gives a functional overview of the serial command interface firmware. The different interfaces, mechanisms, and functionalities are explained in this section. Section 3 documents all available commands.

In order to differentiate between decimal, hexadecimal, and binary number representations, this document uses the convention to subscript binary and hexadecimal numbers with a capital B or H, respectively.

In section 3, command argument fields and responses are explained in a table format. Interpret tables for command argument fields as a list: the first table row is the first command argument; the second row represents the second argument, and so on. For responses, the same rule applies if there is no code field in the table. Otherwise, the table is interpreted in the following way: The code is the first field contained in the response. All fields (second column of the table) in the same row as the code field follow the code in the response.

2 Functional Description

2.1. Interfaces

The module provides two UART and one SPI interface for communication with external hosts. The host can also execute commands over the network interface. Hosts can be computers, microcontrollers, or even single sensors that have an appropriate interface. It is possible to connect different devices to different interfaces. All communication interfaces are enabled in the SCI default configuration.

The SCI firmware allows sending incoming network data to any of the available interfaces. For this purpose, the Configure Receiver command expects a dispatch value that specifies to which of the serial interfaces incoming data is sent. Table 2.1 shows the dispatch numbers for the different interfaces.

Table 2.1 Interface Dispatch Numbers

Interface	Dispatch Value
UART1	0
UART2	1
SPI	2
Network	3

2.1.1. UART Interfaces

The module provides two UART interfaces. By default, both interfaces operate at a data rate of 115200 kBaud, have 8 data bits, one stop bit, no parity bit, and no flow control. The UART configuration can be changed at any time using one of the commands Configure UART1 or Configure UART2. Any interface can be used to change the UART configuration.

Table 2.2 UART Configuration and Pin Description

UART-Pin Name	Usage	Direction	Module Pin	
			UART1	UART2
Transmit (TX)	Mandatory	Output	13	6
Receive (RX)	Mandatory	Input	12	5
Request to send (RTS)	Optional	Output	17	7
Clear to send (CTS)	Optional	Input	16	8

Table 2.3 UART Configuration Options

Option	Default Configuration	Configuration Options
Data Transfer Rate	115200 Baud	61(1) baud – 256000(2) baud
Parity	Not enabled	Odd, Even
Number of Stop Bits	1	2
Flow-Control	Not enabled	Hardware Flow Control

(1) 61 baud can only be achieved on UART2. The minimum baud rate of UART1 is 122.

(2) The maximum rate of 256000 baud can only be achieved on UART1. The maximum rate of UART2 is 115200 baud.

2.1.2. SPI Interface

The module provides an SPI interface that is operating in slave mode. To control the SCI module via the SPI, the host computer must provide an SPI clock whenever data is to be sent or received. Availability of data from the SCI module is signaled by a dedicated line that is pulled low when data is available for read-out. If the host needs to receive data and no data is to be transmitted, sending zeros is recommended. The ZWIR451x will send zeros over its MISO line if the master is transmitting a frame and no data has to be transmitted to the host.

The default configuration uses the SSN pin to activate the SCI node. Data is only received and transmitted if the SSN pin is pulled to low. The SPI is configured for MSB first transmission and reception; the clock is low when idle; and the first clock transition is used as data capture edge.

Table 2.4 SPI Pin Description

SPI Pin Name	Direction	Usage	Module Pin
Master Out Slave In (MOSI)	Input	Mandatory	1
Master In Slave Out (MISO)	Output	Mandatory	2
Clock	Input	Mandatory	3
Slave Select	Input	Optional	4
Data Pending	Output	Optional	7

Table 2.5 SPI Configuration Options

Value	Default	Configuration Option
Clock Polarity	Low (clock is low when idle)	High
Clock Phase	First edge captures data	Second edge captures data
Pending Pin Mapping	Module pin 7	

2.1.3. Network Interface

The network interface allows executing commands remotely. Basically this works like the serial interfaces with the difference that command frames sent over the network interface do not have to carry the *START* byte and data escaping is not required. All available commands can be executed remotely. For some commands restrictions apply.

Each SCI node listens to UDP port 4 for incoming command frames. If a command is received, it is executed and if there is any response from the command, the response is sent back to the device that requested execution of the command.

The SCI also implements the Remote Execute command, which allows initiation of a remote execution over one of the serial interfaces.

2.2. Frame Format

Command and responses are sent over the different physical communication interfaces in data frames that have a special format that allows detecting communication errors and introduces low overhead. All frames have a common format.

The frame format is illustrated in Figure 2.1. Each frame starts with the START delimiter $7E_H$. The following two bytes determine the length of the frame payload. Length information is stored in Little Endian format; hence, the least significant byte is stored first. The third byte determines the command to be executed. The following N bytes

are the frame payload. At the end of the frame, a checksum byte is attached, which helps to detect communication errors.

Figure 2.1 Frame Format

START 1 byte	LENGTH 2 bytes	CMD 1 byte	PAYLOAD LENGTH bytes	CHKS 1 byte

2.2.1. Commands and Responses

The Serial Command Interface firmware distinguishes Command and Response Frames. Command Frames are sent in order to trigger a specific action at the receiver of the Command Frame. Response Frames contain status information sent in response to Command Frames. Typically Response Frames are only sent if an error was encountered in the last Command Frame.

A Command Frame has a Command Code in the range of 01_H to $7F_H$. The values 00_H, $1B_H$ and $7E_H$ are not allowed. An overview of all available commands and their command codes can be found in Table 3.1.

The Command Code of a Response Frame is the Command Code of the Command Frame that triggered the Response OR'ed with 80_H. The Response Frame with the Command Code 80_H is a special response frame that is sent when an invalid frame was received or another non-command-related error occurred.

Table 2.6 General Error Responses

Code	Field	Length	Description
1	Invalid Header	3	Message larger than the maximum allowed size or unknown command.
2	-		Invalid checksum.
3	Interface	1	A framing, parity, overflow, or noise error at the UART or SPI interface occurred.
	Command	1	
	Pos. of Last Valid Byte	2	
4	Internal Error Code	4	An internal error occurred.
5	-		Duplicate address detection failed.
30	Failing IPv6 Address	16	The address resolution for the address returned in the response failed. This error occurs sometime after attempting to send an unicast frame to a destination.

2.2.2. Checksum Computation

At the end of each packet a checksum is appended that helps to detect transmission errors on the physical transmission medium. The checksum is formed in such way that the sum of all transmitted bytes, excluding the Start character $7E_H$ is zero. If the sum of all received bytes of a packet does not result in zero, a Frame Error packet with its error code set to CHECKSUM_ERROR is sent over the same interface the erroneous packet was received on.

2.2.3. Escaping

If one of the characters $1B_H$ or $7E_H$ is contained in the data stream or one of the frame control fields, this character must be escaped by XOR'ing it with 80_H and prepending it with $1B_H$. This modification has no effect on the length field of the frame, even if it is done in the payload section of the frame. However, escaping must be considered for checksum calculation.

If the checksum of the device is one of ZMDI's two control characters, the checksum must be escaped as well. Escaping the checksum is done by sending the escape character $1B_H$ followed by the computed checksum value minus $1B_H$

The following examples illustrate how escaping must be performed:

```
7e 04 00 12 1a 1b 1c 1d 7c
7e 04 00 12 1a 1b 9b 1c 1d e1

7e 1b 00 01 ff 02 00 00 00 00 00 00 00 00 00 00 00 00 00 01 7e 03 01 02 03 04 05 06 07 08 09 34
7e 1b 9b 00 01 ff 02 00 00 00 00 00 00 00 00 00 00 00 00 00 01 1b fe 03 01 02 03 04 05 06 07 08 09 fe

7e 04 00 10 24 9f 32 79 7e
7e 04 00 10 24 9f 32 79 1b 63
```

2.3. Frame Buffering

Each communication interface maintains its own message queue. In situations of high load, messages are queued temporarily in the message queue. Each interface has its own message queue. The message queue distinguishes between command frames and response frames. Response frames are queued at the beginning of the queue, while command frames are queued at the end of the queue. This ensures that response frames are sent immediately after the triggering command frame. However, if a command frame is being sent when a response frame is queued, the transmission of the command frame is completed before the response frame is sent.

2.4. Resets

The SCI module provides two types of reset. One is System Reset; the other one is Network Reset. System Reset puts the device into the state that it has after a power-on. It executes the complete startup procedure of the microcontroller and the transceiver in order to put them into a defined state. All settings are restored to the fabric default values or to the configuration that was saved to the flash memory the last time. System Reset is also performed automatically in the event of an unrecoverable error. If System Reset is performed because of an error, an error message is sent over the interface the last instruction was received from. This message usually contains an error description. The most common error for System Reset is a memory allocation failure, which can appear after changing the network configuration or after configuring multicast. Refer to the documentation of the Configure Network and Configure Multicast commands.

Network Reset is used after changing the network configuration. It does not perform a System Reset. A Network Reset disconnects all open connections and applies changes in network parameters that have been applied before. The command Configure Network performs a reset automatically to apply the settings that have been made. Network Reset does not affect the physical parameter set with Configure PHY.

2.5. Addressing

Each SCI module has three types of addresses. The PAN Identifier, the PAN Address and the IPv6 Address(es) are described in the following sections.

2.5.1. PAN Identifier

This address identifies the network the device is operating in. All devices that are part of the same network must use the same PAN identifier. Devices with different PAN identifiers are not able to communicate with each other, even if they are in the physical range of each other and have the same PHY settings applied.

The PAN Identifier is a 16-bit number. Its default value is $ACCA_H$. This value is changed using the command Set PAN ID.

2.5.2. PAN Address

The PAN address is the hardware address of the device. The PAN address is also commonly known as the MAC address. The PAN address of the SCI module is a 64-bit number that is formed according to the EUI-64 rules. Each device in the network MUST have a unique PAN address. This address is used to generate locally and globally unique IPv6 addresses (see section 2.5.3.1). Usually applications do not have to process the PAN address directly.

ZMDI's ZWIR451x SCI Modules have a globally unique address preprogrammed. This enables generation of locally and globally unique IPv6 addresses without any need for initial configuration. ZMDI does not recommend changing the PAN address of the device. However, if the application requires this, it is supported by the command Set PAN Address.

2.5.3. IPv6 Addresses

The IPv6 addresses are the addresses the applications are dealing with. These addresses are 128-bit wide. Each device must have at least one IPv6 address in order to be able to communicate. Using IPv6 addresses, the application determines where packets are sent to and received from. How IPv6 addresses are set up and how they are presented is explained below.

IPv6 addresses are 128-bit, thus 16-byte wide. As it would be impractical to use the byte-wise notation known from the old IPv4, IPv6 introduces a new notation. IPv6 addresses are represented by eight 16-bit hexadecimal numbers that are separated by colons. An example for such address is

2001:0db8:0000:0000:1b00:0000:0ae8:52f1

Leading zeros of segments can be omitted as they do not carry information. The IPv6 notation allows omitting a sequence of zero-segments and representing it as double colon. With these rules, the above address can be written as

2001:db8::1b00:0:ae8:5211 or **2001:db8:0:0:1b00::ae8:52f1.**

However, replacing multiple zero segments is not allowed. Thus the address

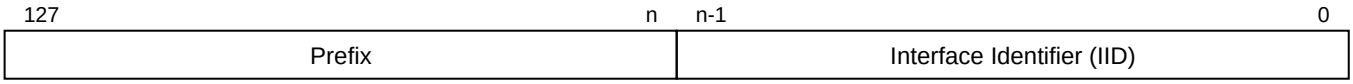
2001:db8::1b00::ae8:5211

is invalid.

In order to explain IPv6 addresses, the term "link" must be defined. Nodes are said to be on the same link when they are able to communicate with each other without requiring any routers. Nodes on the same link are able to communicate on the MAC level.

An IPv6 address consists of two components: a prefix and an interface identifier. The prefix specifies the network a device is part of while the interface identifier specifies the interface of a device. The size of the prefix varies for different address types. In the IPv6 address notation, the prefix length can be appended to the address with a slash followed by the number of prefix bits. Thus the notation 2001:db8::/64 represents a network containing the addresses from 2001:db8:: to 2001:db8::ffff:ffff:ffff:ffff.

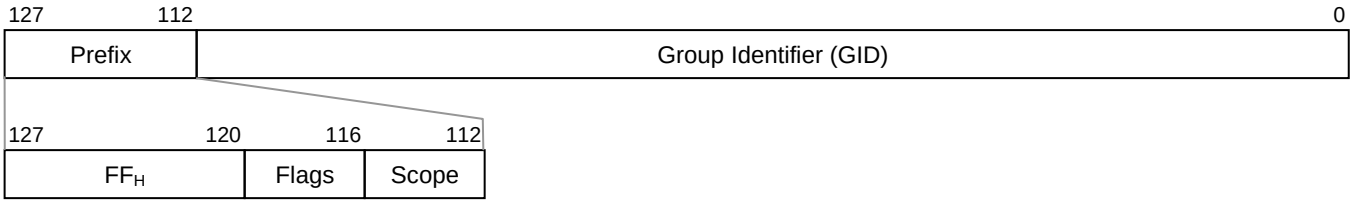
Figure 2.2 General IPv6 Address Layout



IPv6 supports three kinds of addressing methodologies: unicast addressing, multicast addressing, and anycast addressing. Unicast addressing is used to communicate to well defined remote nodes. Using multicast addressing packts may be sent to multiple addresses at the same time. Anycast addressing is used to reach any node out of a group of nodes which share the same anycast address. ZMDI's SCI firmware doesn't allow nodes to have anycast addresses. However, remote anycast nodes (e.g. compuers in the network) can be reached. A network node may have multiple interfaces; e.g. it may incorporate multiple radio nodes or multiple Ethernet cards. Unicast addresses are used to address a single interface in the network. The prefix of the address determines the scope of the unicast address. This may be link-local or global. All unicast addresses with a prefix starting with 0b000 (bits 125 to 127) have a 64-bit interface identifier. If the prefix equals fe80::/64, this is a link-local unicast address. Link local addresses are valid only on the link the interface is connected to. The prefix of global unicast addresses is typically received from a router via address autoconfiguration. If the router is not connected to the internet, the node will not get a global address, only a local one. Besides local and global prefixes, there are further prefix configurations with limited scope that are not covered by this documentation. Refer to RFC 4291 for more detailed information about alternative prefix configurations.

Multicast allows sending packets to multiple receivers at the same time. For this purpose, IPv6 provides multicast addresses. This class of addresses must only be used as destination address. It MUST NOT be used as a source address in IPv6 packets. Figure 2.3 shows the layout of multicast addresses. They have a 16-bit prefix with the most significant eight bits set to ff_H, followed by two 4-bit fields for flags and the scope of the multicast packet. The lower 112 bits specify the multicast group id. A device checks if it is part of a multicast group depending on the multicast group ID.

Figure 2.3 IPv6 Multicast Address Layout



For the flags field, ZMDI's IPv6 stack only supports the values 0000_B and 0001_B. The first version specifies that the multicast address is a well-known address (an address that has been assigned by the IANA). The second one marks the address as a temporarily assigned address that is not specified by internet standards. Custom multicast addresses MUST use the latter version of multicast addresses!

For the scope field, any allowed value is supported. However values above 0010_B require appropriately configured routers.

Two addresses are of special interest, as they are used very often.

1. The unspecified address :: - All segments of this address are zero. It is used by receivers to listen to any sender. This address must never be used as destination address.
2. The link-local all nodes multicast address ff02::1 – Packets sent to this address are received by all nodes on the link. Thus this multicast address is equivalent to link-local broadcasting.

For further information about IPv6 addressing, refer to RFC 4291 – "IP Version 6 Addressing Architecture."

2.5.3.1. IPv6 Address Autoconfiguration

In order to make node configuration and setup as easy as possible, IPv6 provides a stateless autoconfiguration mechanism for IPv6 addresses. Using this algorithm, IPv6 unicast addresses are generated automatically from information statically available on the interface and information provided by routers on the link. If no router is present, only an IPv6 address with link-local scope is generated. Global addresses are generated if the router advertises prefix information. Thus, no manual address assignment is required and no server-based address assignment technology, such as DHCP, needs to be provided.

The stateless address autoconfiguration mechanism uses the PAN address (refer to section 2.5.2) of the interface to generate the device's IPv6 addresses. For both address scopes, link-local and global scope, this is done by putting a 64-bit prefix in front of the modified 64-bit PAN address of the interface. The modification of the PAN address refers to toggling the universal/local bit of the interface identifier. This method is described in Appendix A of RFC 4291. Assuming a PAN address of 0**0**:11:7d:00:00:12:34:56 and a prefix 2001:db8::/64, this would result in the global IPv6 address 2001:db8::**2**11:7d00:12:3456. Accordingly the link-local address would be generated by using the link-local prefix fe80::/64 and result in the IPv6 address fe80::**2**11:7d00:12:3456. Note that in both cases, the modification coming from the modified PAN address is highlighted in red.

IPv6 requires that addresses that are assigned to an interface are checked for their uniqueness on the link. This is done using the Duplicate Address Detection (DAD) algorithm. DAD is not required if the universal/local bit in the interface identifier of the IPv6 address is set to 1 (like in the example above). The DAD algorithm is described in more detail in section 2.5.3.3.

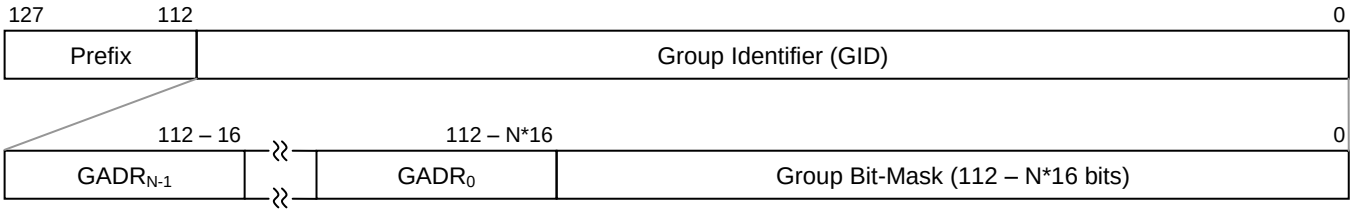
2.5.3.2. Multicast

IPv6 Multicast allows sending packets to multiple receivers at the same time. Sending packet to multiple receivers is done by simply using a multicast address as the destination address. All devices that want to receive packets sent to a particular multicast address must join the appropriate multicast group before they are able to receive packets. The receiver must be configured appropriately to receive packets from the sender. Refer to section 2.7 for more detailed information on configuring devices for data reception.

The ZWIR451x SCI firmware provides a flexible multicast implementation supporting up to 16384 (2^{14}) groups. Depending on the multicast configuration of the device, 7 to 112 groups can be accessed simultaneously. When multicast is configured, a bit-field is allocated in the devices with each bit representing the status of a certain group membership status of the device. Joining a certain group will set the corresponding bit in the bit-field internally, while leaving that group will delete the bit. Each device can join as many groups as it wishes.

In order to send data to one or multiple groups, the destination address must be formed appropriately according to the selected multicast configuration. ZMDI's multicast implementation allows flexible configuration of the way multicast groups are addressed in the network. The multicast GID basically is divided into two sections. The lower bits are interpreted as a bit mask that is logically AND'ed with the internally stored bit-field of a receiving device in order to determine if the device is part of the requested multicast group. The remaining bits that are not in the bit-mask are interpreted as 16-bit group addresses. Each multicast device MUST configure multicast. During the multicast configuration, specify how many of the upper 16 fields of an IPv6 multicast address are interpreted as the group address. The remaining bits are interpreted as bit-field. The general layout of the multicast GID is shown in Figure 2.4. Parameter N is the configured number of group address fields. Note that all devices in the network must use the same multicast configuration.

Figure 2.4 Multicast Addressing: Group ID Configuration



2.5.3.3. Validation of IPv6 Address Uniqueness

Duplicate address detection (DAD) is performed to check if an IPv6 address is unique on the link. For this purpose, a node starts to send neighbor solicitation (NS) messages to the address to be checked. If another node replies to one of those messages or if another node also sends neighbor solicitation messages to this address, the assigned address is not unique and must not be used. In such cases, a system reset is performed, and an error message is sent to the interface that the last command was received from. Note that this error can only happen if some of the devices in the application use manually configured IPv6 addresses or PAN addresses. Therefore, it is recommended that manually configured addresses not be used!

2.6. The UDP Protocol

The User Datagram Protocol (UDP) is used for data transmission in ZWIR451x devices. UDP is a connectionless and lightweight protocol, introducing minimal communication and processing overhead. No connection has to be created, and no network traffic is required before data transmission between nodes can be started. Instead, communication is possible immediately. UDP does not guarantee that packets that have been sent are reaching the receiver. If reliable transmission is required, acknowledges must be implemented on the application level. It is also possible that the same UDP packet is received multiple times. Furthermore, it is not guaranteed that the receive order of packets at the destination is the same as the send-order at the source. This must be considered by the application programmer.

UDP uses the concept of ports to differentiate different data streams to a node. A port can be seen as the address of a service running on the receiver of a packet. Depending on the destination port of a packet, the network stack decides to which network service the packet is routed. UDP distinguishes 65636 ports. The SCI firmware on ZWIR451x simply transmits data that have been received on a certain connection to one of its interfaces. It is possible to assign different interfaces to different ports.

The SCI firmware opens three UDP connections automatically. These connections are required for the remote-execution of commands, the Internet Key Exchange protocol, and the Over-the-Air firmware update feature. The ports allocated for these services are listed below. They must not be used by the application.

- Port 4: Remote Execution
- Port 500: Internet Key Exchange version 2
- Port 1357: Over-the-Air Update

2.7. Data Transmission and Reception

Data transmission is requested with the Transmit Data command. This command allows specification of the destination IPv6 address and the UDP port that the packet should be sent to. The source port of the transmission is selected randomly.

In order to receive packets from a remote device, the receiver must be configured appropriately. For that purpose, the command Configure Receiver is provided. It allows configuring the source address of the device that data should be received from and the UDP port that data should be received on. It is possible to determine to which

interface that data traffic received on the particular connection is sent to. The source address argument SHOULD be a unicast address, if data reception from a particular device is expected. Alternatively it is possible to use the unspecified address that will accept data from any sender.

For successful data transmission, the UDP port configured at the receiver must match the UDP port that data is sent to.

2.8. Network Configuration

ZWIR451x network parameters are configurable to match the needs of the application. Especially for large installations with mesh routing, adjusting settings for optimal performance is strongly recommended.

2.8.1. Physical Parameters

ZWIR451x's SCI firmware allows configuring the radio channel, the signal modulation, and the transmission power. In order to be able to communicate, all devices must use the same channel and modulation settings. All physical parameters are changed with the command Configure PHY.

Note that the European Union restricts the output power of devices in the SRD extension band (865 MHz – 868 MHz) to 1 mW. For that reason, it is not possible to select an output power of more than 0dBm for these bands. Otherwise an error message is returned.

2.8.2. Software Parameters

The software parameters control the behavior of the network stack. All of these parameters are changed using the command Configure NET.

2.8.2.1. IPv6 Network Parameters

The **Neighbor Cache Size** determines how many neighbor cache entries are allocated by the network. Neighbor cache entries are required for each remote endpoint a device wishes to communicate via unicast to. Considering an example network topology as shown in Figure 2.5, the devices must have the following number of neighbor cache entries:

D1 → 1 entry

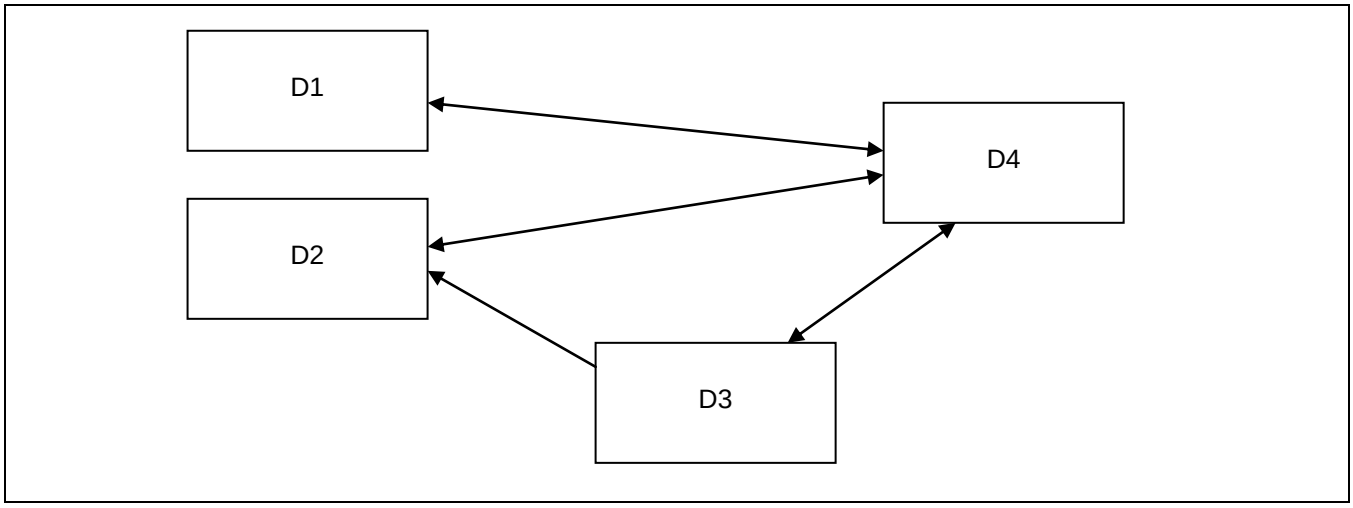
D2 → 1 entry

D3 → 2 entries

D4 → 3 entries

Thus for each outgoing connection (arrow is pointing away from device), a neighbor cache entry is required.

Figure 2.5 Example of Network Topology 1



The **Maximum Socket Count** parameter determines how many sockets may be open at the same time. This is important for concurrent reception of different data streams.

The **Neighbor Reachable Time** parameter determines the time a neighbor cache entry is considered as reachable before reachability is verified by the network stack automatically. Usually this parameter is configured by routers present in the network. Thus, if a router is present, the configured value is overwritten with the value received from router advertisements.

The **Duplicate Address Detection Enable** flag determines if duplicate address detection (DAD) is performed during interface initialization or when a new address is assigned to the interface. Duplicate address detection is used to verify that no other device in the network is using the same address as the address verified. DAD causes one broadcast packet to be sent during interface initialization. The interface is not available for user communication before the DAD packet is sent and some delay to receive an answer has passed. The time before availability of the interface or a newly assigned IPv6 address is between one and two seconds if DAD is enabled. If DAD is disabled, the interface or newly assigned addresses are available immediately and no packet is sent out by the device. However, leaving DAD enabled is recommended for protection from network failures caused by duplicate addresses. A device that is unable to initialize its interface correctly will report an error and go to Standby Mode until it is being reset.

The **Router Solicitation Enable** flag determines if the device sends router solicitations to the network. This is typically done to obtain network configuration information such as address lifetimes and reachable times as well as global network prefixes. If there will never be a router on the network, this option can be disabled. Otherwise the option should be left enabled. Usually routers send configuration information autonomously at a certain time interval. If delayed reception of router information is acceptable, the Router Solicitation Enable flag may be unset. However, care must be taken to ensure that the router information advertised on a regular basis contains the same amount of information as the solicited advertisements.

2.8.2.2. Mesh Routing Parameters

The mesh routing mechanism used in the ZWIR451x network stack is configurable to control the behavior of nodes during the establishment of routes and to get better reliability of the whole network and single connections.

The first item that is configurable is the **Maximum Hop Count**. This parameter is applicable during the reception of multicast packets. If the received packets' Hop Count is greater or equal to the value configured in this parameter, the packet is not forwarded again. Thus, a multicast packet is only forwarded when the packet's Hop Count is lower than the configured value. If this value is set to zero, the device will never work as a mesh network relay. If not set to zero, the value should be set to the maximum hop count expected to be occurring in the network. Setting the value to a much larger value is not recommended as this value is also required to stop the circulation of packets in the network. Circulating packets could occur very rarely under special circumstances. The larger the Maximum Hop Count value of a packet is, the longer a circulating packet will travel through the network.

In networks having many devices with direct mutual reachability, limiting the number of devices that may serve as mesh relays is strongly recommended. Otherwise the network might tend to be unreliable, especially during the startup phase. The level of unreliability increases with the number of devices with mutual reachability acting as a mesh relay. A good rule of thumb is having a maximum of five to ten mesh relays with mutual reachability.

It has to be noted that devices with the **Maximum Hop Count** parameter set to zero are still able to send data to remote devices that are multiple hops away! Also reception of data is possible from a node that is multiple hops away. The parameter only controls whether the device is allowed to act as a network relay.

Each device in the network maintains a routing table storing the link-layer address of the next hop to be taken to a certain destination. The **Routing Table Size** parameter determines how many routing table entries are available in the device. A routing table entry is required for each endpoint that a device is communicating to in the network. For relay enabled nodes, this includes the communication endpoints of the nodes using the nodes relay service.

Figure 2.6 Example of Network Topology 2

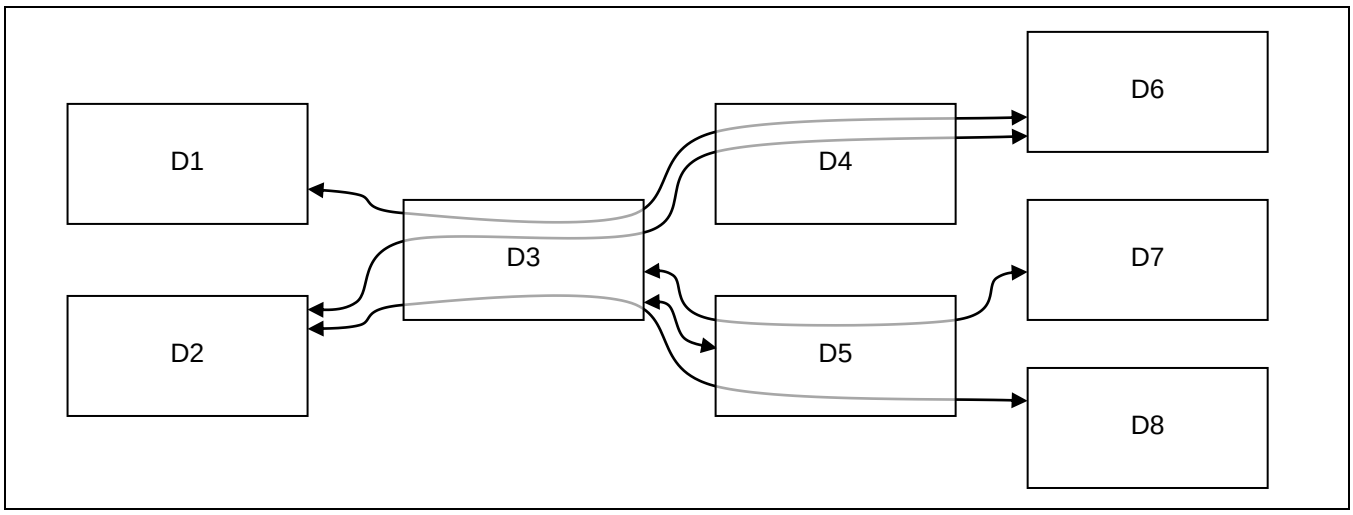


Figure 2.6 shows an example network topology with different communication paths. The lines going through D3, D4 and D5 symbolize multi-hop communication paths. For demonstration, the list below shows how many routing table entries are required as a minimum at each node:

D1 → 1 entry (D6)

D2 → 2 entries (D6, D8)

D3 → 6 entries (D1, D2, D5, D6, D7, D8)

D4 → 3 entries (D1, D2, D6)

D5 → 4 entries (D2, D3, D7, D8)

D6 → 2 entries (D1, D2)

D7 → 1 entry (D3)

D8 → 1 entry (D2)

Once a route has been set up, the routing table entry persists until one of the two following events occurs:

(1) The route is not used for **Route Timeout** seconds

(2) **Route Max Fail Count** attempts of using the route have been failing

The first case will simply remove the route from the routing table and will reestablish the route when it is required again. Thus if rare usage of a route is anticipated, the **Route Timeout** parameter can be increased accordingly. In contrast, for networks with frequently changing topologies, it may be advantageous to reduce the Route Timeout parameter to avoid failing attempts at using a broken route and instead reestablish the route on demand. In these networks, it might be advantageous to reduce the **Route Max Fail Count** parameter, as the probability of a hop being gone is high and therefore the route can be reestablished faster.

The reliability of transmissions can be increased using the **Route Discovery Minimum Link RSSI** parameter. This parameter puts constraints on the route discovery process. Only paths with a RSSI value equal to or greater than the configured value are considered for route setup. If a route cannot be established using the configured Route Discovery Minimum Link RSSI, the next attempt to setup the route is made with the previously used value reduced by the amount of **Route Discovery Minimum Link RSSI Reduction**. There are **Route Discovery Attempts** made to setup the route. If RSSI constraints have been put on route discovery, the resulting routes might choose a longer route (more hops). However, if the network is static, the route is more likely to succeed than the shorter route with higher probability of communication failures on single segments of a route.

By default, the Route Discovery Minimum Link RSSI is set to a value of -128dBm and the reduction value is set to zero. The transceiver is capable of reporting a minimum value of -100dBm. Thus, the initial value allows any connection. In order to generate a very reliable route, an initial **Route Discovery Minimum Link RSSI** value of -80dBm could be chosen with a **Route Discovery Minimum Link RSSI Reduction** value of 1 and a **Route Discovery Attempts** value of 20. If possible, the route with an overall RSSI of -80dBm is chosen if these settings are applied. However, if no such route exists, this will take a very long time to determine. Therefore, typical RSSI reduction values are chosen higher.

Note that the route discovery process is typically initiated by the receiver of a unicast packet! The reason for this is that during address resolution, the receiver of the packet must send a unicast neighbor advertisement message.

2.9. Network Discovery

The Discover Network command requests all devices in the PAN to send a network discover reply message to the requesting device. For each answer received, the requesting device sends an informational message to the interface that the Discover Network command was received on. The message contains information about all assigned IPv6 addresses, the link quality, and how may hops the device is away from the requester.

Network discovery must be used rarely and carefully! Each call to Discover Network causes a multicast packet to be sent to all nodes in the network. Each node receiving the request will try to answer it with a unicast message back to the device that the network discovery request was received from. Receiving nodes must wait for a random time up to a configured limit before they send their response. This helps to avoid too many devices trying to send their response at the same time and blocking each other. Depending on the size of the network, the upper time limit must be adjusted appropriately. As a “rule of thumb,” the number of nodes in the network divided by the time limit must not exceed a value of 5. The opportunity to receive a response from each device in the network increases with lowering the quotient.

2.10. Security

Security has become one of the most discussed topics in wireless sensor networks. Most applications need some amount of security. Each application has different requirements. A well-designed security system should be able to support data confidentiality, data authentication, data integrity, and protection against replay attacks. Depending on the type of application, one or more of these concepts need to be supported.

The ZWIR451x supports all of these security concepts with the IPSec (IPSec=Internet Protocol Security) protocol suite. This protocol suite is already widely used in Virtual Private Networks (VPNs) today. Additionally, ZMDI provides an implementation of the Internet Key Exchange protocol version 2 (IKEv2). Using this protocol, it is possible to generate shared keys for different IPSec links. Both protocols are open standards developed by the Internet Engineering Task Force (IETF).

Both, IPSec and IKEv2 are supported by all major operating systems and therefore allow end-to-end secure communication between ZWIR45xx devices and computers anywhere on the world.

2.10.1. Internet Protocol Security (IPSec)

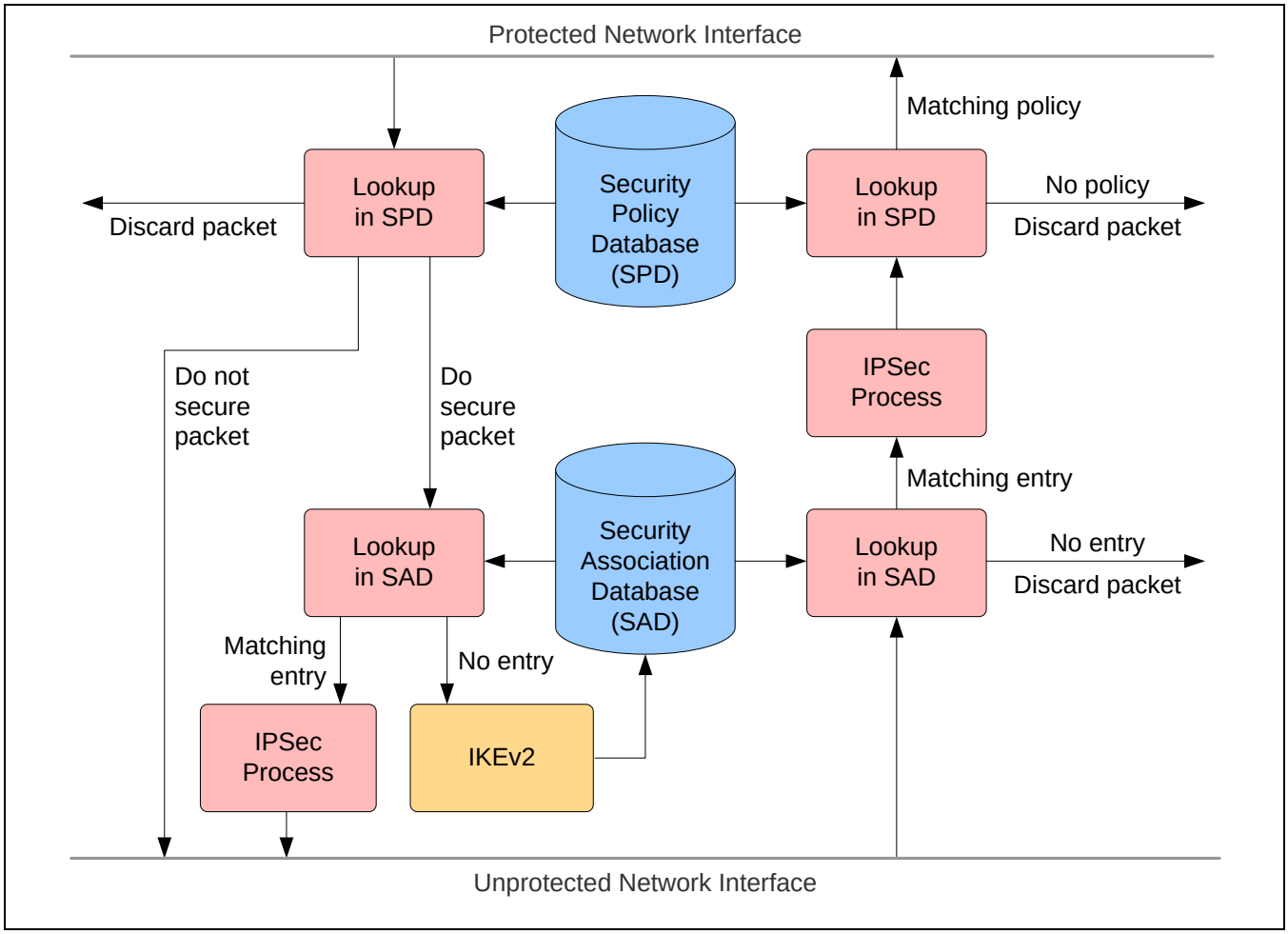
IPSec is a protocol suite for encryption and authentication of data sent over an IP network. IPSec is supported by virtually all modern operating systems running on normal PCs. ZMDI’s IPSec implementation supports the Encapsulating Security Payload (ESP) and Authentication Header (AH) protocols. ESP provides data encryption, data integrity, and protection against replay attacks. AH is applied if authentication of the packet sender is required in addition to the previously mentioned security services.

The basic working principle is depicted in Figure 2.7. Two databases are the central elements of IPSec: the Security Policy Database (SPD) and the Security Association Database (SAD). These databases must be configured appropriately to enable secure communication. This is done using the commands Add Security Policy and Add Security Association. The latter is not required if IKEv2 is used for generating keying material (see section 2.10.2).

The information about how traffic to different destinations must be handled is stored in the Security Policy Database. Each policy entry applies for a remote address (range) with a port (range) and one or more protocols. Each packet that is going to be sent or received is compared to the different security policies stored in the SPD. If the packet does not match any of the policies, the packet is silently dropped. Thus, there MUST be rules for all types of traffic that need to be sent or received by the application. Such rules are added using the command Add Security Policy. If the application does not use IKEv2 for the automatic generation of keying material, a SAD entry must be available before the generation of a new security policy.

In addition to the remote device and protocol information, each SPD entry is linked to an entry in the Security Association Database. The SAD stores the keying material for encryption, decryption, and authentication as well as the encryption and authentication method to be used. The SAD can be administrated manually, or it will be filled automatically by the IKEv2 daemon. It is also possible to use a mixture of these two methods. In order to generate entries manually, use the command Add Security Association.

Figure 2.7 IPSec Working Principle



ZWIR451x SCI modules are delivered with default settings that allow any incoming and outgoing traffic to pass. Thus, if the application does not need security features, there is no need to re-configure. If security is required, the first call to the Add Security Policy command will remove the default policy of allowing all traffic to pass unsecured. The newly configured policy will apply instead. Subsequent calls to Add Security Policy will add additional policies.

Note: Security policies are matched in the order of their generation! Therefore the rule with the most general traffic matching filter must be added as the last rule to avoid hiding other rules. A maximum of 10 security policies may be generated.

2.10.2. Internet Key Exchange (IKEv2)

The Internet Key Exchange version 2 protocol is provided to enable automatic exchange of keying material for IPSec. In this case, security associations are generated automatically on demand. If network traffic is generated on a connection that requires some kind of security processing but there is no security association assigned, IKEv2 automatically initiates the key exchange procedure in order to establish a security association.

The need to establish a security association has two effects on the device:

1. The UDP packet that initiates the key exchange is not delivered to the receiver. Instead, an error message is returned to the host, reporting that the packet could not be delivered.
2. The key exchange procedure requires complex mathematical computations that take some time. For this reason, the internal clock frequency will be increased for the required time of about four seconds. During this time, the device is not able to execute commands. However, incoming data on the serial interfaces is buffered and executed after completion of the key exchange procedure.

In order to authenticate the communicating parties that wish to establish a security association using IKEv2, the application must register appropriate authentication entries with the IKEv2 daemon. These authentication entries consist of an identifier that is transmitted with the IKEv2 message and a 16-byte pre-shared key. This is done using the command Add IKEv2 Authentication Entry. Up to five different IKEv2 authentication entries can be created.

2.10.3. Important Security Considerations and Recommendations

ZMDI strongly recommends using security in almost any kind of application that is installed in the field. It is absolutely mandatory in applications for remote control, in applications that transmit confidential data, and in applications that transfer data that are used for billing purposes.

Applications requiring security MUST be designed in such way that no keying material is transferred over one of the serial links or over an unsecured wireless link. Otherwise it would be easy to break the security mechanisms. Thus, keying material of manually configured security associations and IKEv2 pre-shared keys must not be stored on the host processor but must be stored in the wireless module instead.

Getting these values into the module without giving attackers the chance of obtaining these sensitive data is one of the most critical points in security sensitive systems. How this can be handled must be considered in the starting phase of the project and must be reviewed carefully. A security system is never stronger than its weakest component!

2.11. Firmware Over-the-Air Update (OTAU)

The SCI firmware on the ZWIR451x may be updated using the over-the-air (OTAU) update mechanism. This mechanism allows firmware updates for bug-fixes and feature extensions even if the product is already installed in the field. The firmware over-the-air daemon is permanently running on the device. It listens to UDP port 1357 for incoming firmware packets. Therefore this port must not be used by the application.

Refer to *ZWIR45xx Application Note—Enabling Firmware Over-the-Air Updates* for information on how to distribute a new firmware version to the ZWIR451x via OTAU.

Important Recommendation: Put an IPSec security policy on UDP port 1357 for all remote IPv6 addresses. Otherwise, attackers might be able to install malicious software on the device, using the over-the-air update mechanism. Refer to section 2.10 and *ZWIR45xx Application Note—Using IPSec and IKEv2 in 6LoWPANs*.

2.12. General Purpose I/Os

ZWIR45xx devices provide up to 19 general purpose input and output (GPIOs) pins. GPIO pins can be used in different modes as shown in Table 2.7. In the default settings, some of these GPIOs are allocated for the different serial interfaces. However, if an interface is disabled, the pins that had been allocated are freed and available as GPIO.

Table 2.7 GPIO Operating Modes

Mode	Behavior	Configuration Options
Interface	The pin is controlled by hardware; however, inputs can be used as a wakeup pin.	None
Wakeup	The pin is configured as an input. The device is awakened from low-power mode on the configured activity.	Floating input or input with pull-up or pull-down [1)]
LED Driver	The pin is configured as an output. The SCI firmware controls output value.	Push/pull or open drain output with configurable driving strength
GPIO	The pin is freely configurable for use by the application. Inputs can be used as a wakeup pin.	Floating or pull-up/ pull-down input Push/pull or open-drain output
Unused	All input and output circuitry is disabled for minimal power consumption	None
[1] Wakeup pins cannot be configured directly. When an I/O pin that is already configured as an input is used as a wakeup pin, the configuration is retained. If an unconfigured pin is selected as a wakeup pin, the pin is configured as a floating input.		

In order to meet the needs of the application, all GPIOs are configurable easily and flexibly. Unconfigured devices only have pins configured if they belong to one of the serial interfaces. All other pins are in the unconfigured state to consume minimal power. Table 2.8 shows the default GPIO configuration of all preconfigured pins.

Table 2.8 Default I/O Configuration of Preconfigured Pins

Pin Number	Interface	Function	Default Configuration
1	SPI	Master Out Slave In (SPI_MOSI)	Input
2	SPI	Master In Slave Out (SPI_MISO)	Push-pull output with high driving strength
3	SPI	Clock (SPI_SCK)	Input
4	SPI	Slave Select (SPI_SSN)	Input
5	UART 2	Receive (UART2_RX)	Input
6	UART 2	Transmit (UART2_TX)	Push-pull output with medium driving strength
7	SPI	Data Pending	Push-pull output with medium driving strength
12	UART 1	Receive (UART1_RX)	Input
13	UART 1	Transmit (UART1_TX)	Push-pull output with medium driving strength

The I/O pin configuration is changed with different commands. The following commands could affect I/O pin settings: Configure UART1, Configure UART2, Configure SPI, Configure Wakeup, Configure LEDs, and Configure GPIO. These commands are only executed successfully if changes to the I/O configuration can be performed without possibly changing the behavior of the application. For instance, it is not possible to set pin 4 operating mode to GPIO when the SPI is configured to be active. Configure GPIO will report an I/O conflict in this case. The same would happen in the opposite direction. If pin 4 is configured as GPIO, it will not be possible to enable the SPI interface. The only possibility for dual use of an I/O pin is configuring an already configured input as a wakeup source.

LED driver and GPIO pins permit the configuration of the pin settings. The SCI firmware uses an 8-bit field describing the pin configuration. This 8-bit field is passed to the corresponding configuration function. The layout of the bit-field is shown in Figure 2.8 below.

Figure 2.8 Layout of the Pin Configuration Bit-Field

7	6	5	4	3	2	1	0
CONF				Reserved		IAV	AL

The **AL** bit determines whether the pin is active HIGH or LOW.
- 0 the pin is active LOW
- 1 the pin is active HIGH

The **IAV** bit determines the initial activity value of the pin. This value only applies to outputs. The logical level at the pin output depends on the setting of AL.
- 0 the initial value is inactive
- 1 the initial value is active

CONF determines the pin configuration.
- 0 Disabled
- 1 Floating input
- 2 Pull-down input
- 3 Pull-up input
- 4 Push/pull output: medium driving strength
- 5 Open drain output: medium driving strength
- 6 Push/pull output: low driving strength
- 7 Open drain output: low driving strength
- 8 Push/pull output: high driving strength
- 9 Open drain output: high driving strength

2.13. Watchdog Timer

The serial command interface firmware allows enabling the hardware watchdog timer of the module's micro-controller. This watchdog timer automatically restarts the module upon detection of a software deadlock. A deadlock is detected if the firmware does not execute its internal main loop for at least five seconds.

Using the watchdog timer in conjunction with the module's low-power modes is only possible if the low power interval is significantly shorter than 5 seconds. If one of the low-power modes is required for a longer timer, the watchdog must not be used.

By default, the watchdog timer is disabled after startup and any type of system reset. In order to enable the watchdog timer in any situation, the host device should enable the watchdog timer and store the configuration to the device's internal flash memory. After this configuration, the watchdog is always enabled after system or power-on reset. In this case, the only way of disabling the watchdog is setting the watchdog enable bit to zero and again storing the configuration or by execution of the Restore Fabric Settings command.

2.14. Persistent Parameter Storage

The SCI allows storing the configuration of the device at any time. Stored parameters are restored automatically after the following events:

- Power-on
- Wakeup from Standby Mode
- System reset, triggered by activation of reset-pin, execution of command Reset, or software reset caused by an internal error

If the Store Configuration command is called, all configuration parameters that are in effect at this time are stored to the module's internal flash memory. The following parameters are stored by the persistent parameter storage mechanism:

- All parameters set with the Configure PHY command
- All parameters set with the Configure NET command
- SPI, UART1 and UART2 configuration
- GPIO configuration
- Wakeup configuration
- LED configuration
- PAN ID and PAN address configuration
- Receiver settings (all connections that have been opened for listening)
- All configured security policies
- All configured security associations
- All configured IKEv2 authentication entries
- Full multicast configuration including the group-mask
- Watchdog configuration

The status of the neighbor cache and the routing tables of the device is not stored or restored, respectively.

3 Command Reference

This section describes the available commands for SCI modules. Table 3.1 gives an overview of available commands. Detailed descriptions are given in the subsections.

Table 3.1 Command Overview

Name	Code	Description	Section
Command Frames Accepted by the SCI Node			
Transmit Frame	01_H	Sends a data packet to a single or multiple remote locations.	3.1
Configure Receiver	02_H	Configures the reception of data and where the data should be sent.	3.2
Get TRX Statistic	03_H	Returns information about transmitted and received data and about transmission duty cycle.	3.3
Reset TRX Statistic	04_H	Resets all TRX statistics.	3.4
Configure Wakeup	05_H	Configures the wakeup sources for the different power modes.	3.5
Power Down	06_H	Puts the device into a low power mode.	3.6
Get Address Configuration	07_H	Requests the MAC address and the IPv6 addresses of the device.	3.7
Set PAN Address	08_H	Sets the PAN address of the device.	3.8
Set PAN ID	09_H	Sets the PAN ID of the PAN in which the device is operating.	3.9
Configure PHY	$0A_H$	Configures PHY parameters (channel, modulation, TX-power).	3.10
Configure NET	$0B_H$	Configures network parameters.	3.11
Discover Network	$0C_H$	Detects other devices in the network.	3.12
Remote Execute	$0D_H$	Executes command on a remote device.	3.13
Get Firmware Version	$0E_H$	Requests the firmware version running on the module.	3.14
Reset	$0F_H$	Resets the module.	3.15
Network Reset	10_H	Resets the network stack on the module.	3.16
Store Configuration	11_H	Stores the current configuration of the module to be restored during startup.	3.17
Test	12_H	Requests immediate response (useful for alive checking).	3.18
Configure LEDs	13_H	Configures the ports at which indicator LEDs for indicating transmission and reception of data are connected.	3.19
Configure GPIO	14_H	Configures a module pin as GPIO pin.	3.20
Write GPIO	15_H	Sets a value on a GPIO pin.	3.21
Read GPIO	16_H	Reads the value of a GPIO pin.	3.22
Toggle GPIO	17_H	Toggles a GPIO pin.	3.23
Configure UART1	18_H	Configures parameters of UART interface 1.	3.24
Configure UART2	19_H	Configures parameters of UART interface 2.	3.25
Configure SPI	$1A_H$	Configures parameters of the SPI interface.	3.26
Restore Fabric Settings	$1C_H$	Restores all module default settings.	3.27

Name	Code	Description	Section
Command Frames Accepted by the SCI Node			
Configure Multicast	$1D_H$	Configures multicast settings.	3.28
Join Multicast Group	$1E_H$	Joins a multicast group.	3.29
Leave Multicast Group	$1F_H$	Leaves a multicast group.	3.30
Add Security Policy	20_H	Adds a new IPSec security policy.	3.31
Add Security Association	21_H	Adds a new IPSec security association.	3.32
Add IKEv2 Authentication Entry	22_H	Registers the IKE daemon for automatic generation of missing security associations.	3.33
Enable Watchdog Timer	23_H	Enables or disables the watchdog timer.	3.34
Get Current Interface	24_H	Requests the interface identifier of an interface.	3.35
Get PHY Configuration	26_H	Requests the PHY parameters (channel, modulation, tx-power).	3.36
Get NET Configuration	27_H	Requests the Network parameters.	3.37
Get FCC ID	28_H	Requests the FCC ID of the module	3.38
Command Frames Sent by the SCI Node			
Receive Packet	50_H	Sent to the host upon reception of a data packet.	3.39
Remote Response	51_H	Sent to a host to inform about the response of a remotely executed command.	3.40

3.1. Transmit Frame Command

This command is used to transmit data frames to one or multiple destinations. Data transmission is based on the User Datagram Protocol (UDP) over Internet Protocol version 6 (IPv6). The destination IP address determines which node(s) will receive the packet.

Table 3.2 Transmit Frame Command Fields

Field	Width	Description
Destination IP Address	16	This is the address of the destination node of the packet. Address can be of any type available in IPv6. Depending on the address type, one or multiple destinations are selected as receiver of the packet. Refer to section 2.5.3 for further information on IPv6 addressing. The address is transmitted in big endian format. Thus, the address ff02::1 would be transmitted as ff 02 00 00 00 00 00 00 00 00 00 00 00 00 00 01.
Destination UDP Port	2	This is the port number that the target device should be listening on. Use the RX Setup command to configure the listening port on ZWIR451x SCI nodes. The port field is transmitted in little endian format. Thus, port 1000 would be transmitted as e8 03.
Payload Data	1 - 1232	This is the payload data to be transmitted. Packets must be in the documented range. Otherwise an error message will be returned and the packet is dropped at the sender.

Table 3.3 Transmit Frame Command Responses

Code	Description
1	The packet that should be sent is too big (the frame payload is larger than 1250 bytes).
2	The packet that should be sent is too small (the frame payload is smaller than 19 bytes).
27	The packet could not be sent. This error has typically temporary reasons – try to send the packet again. **Note:** If this response is not received, it does not automatically mean that the packet was delivered successfully to the receiver!

3.2. Configure Receiver Command

This command enables data reception on a device. It configures the device that data should be received from and the UDP port that is used for this communication. Furthermore, it allows selecting the communication interface to which incoming data should be sent.

Table 3.4 RXSetup Command Fields

Field	Width	Description
Source IPv6 Address	16	The address from which packets should be received. If the IPv6 Unspecified Address [::] is selected, packets from all nodes are accepted. Specifying a multicast address is not allowed. The address is transmitted in big endian format. Thus, the address fe80::1 would be transmitted as `fe 80 00 00 00 00 00 00 00 00 00 00 00 00 00 01`.
Local UDP Port	2	This is the port on which data should be received. The UDP port allows distinguishing different connections. The port field is transmitted in little endian format. Thus, port 1000 ($3e8_H$) would be transmitted as `e8 03`.
Dispatch Interface	1	This option specifies the interface to which received data shall be dispatched.

Table 3.5 RXSetup Command Responses

Code	Field	Length	Description
1	-		The request was too short.
2	-		The request was too long.
5	-		The request was dropped as an internal error occurred. Try to perform a full system reset to fix the problem.
20	IID	1	A connection with the same configuration already existed with another dispatch interface. The old entry was overwritten with the new one. The response contains an option filed which specifies the former IID which has been replaced with the new value.
21	-		The request was dropped as the maximum number of connections is already in use. The number of connections can be increased using the Configure Network command.

3.3. Get TRX Statistics

This command requests a Response Frame containing the current network statistics. Network statistics consist of the number of transmitted and received packets, the number of transmitted and received bytes, the number of failing transmissions, and the transmission duty cycle.

Note that the transmission duty cycle in European countries is limited in the different frequency bands. It is up to the application to ensure that these limitations are met. This command helps to monitor the transmission duty cycle of the device. Present duty cycle limitations are listed in Table 3.7.

The Get TRX Statistics command does not expect any additional arguments in the command frame. However, if data is transmitted in the payload section of the command frame, this data is ignored. There are no error responses sent by this command.

Data returned is always counted from the last device reset, network reset, reset of the TRX statistics, or from the last wakeup from Standby Mode. The values returned also consider traffic that is forwarded automatically to other nodes and is not visible to the application.

Table 3.6 Get TRX Statistics Response Format

Code	Field	Length	Comment
0	TX Bytes	4	Number of bytes transmitted.
	TX Packets	4	Number of packets sent.
	RX Bytes	4	Number of bytes received.
	RX Packets	4	Number of packets received.
	TX Fail	4	Number of lost packets due to transmission failures; e.g., due to an occupied channel.
	Duty Cycle	4	The transmission duty-cycle in percent, multiplied with a factor of 1000; e.g., a value of 1000 corresponds to a duty-cycle of 1 %.

Table 3.7 Transmission Duty-Cycle Requirements of Sub-GHz Devices in the European Union

Frequency Band	Corresponding Channels	Required Duty-Cycle
868.0 – 868.6 MHz	0	1%
863.0 – 870.0 MHz	100, 101, 102	0.1%

3.4. Reset TRX Statistics

This command resets the transmission and reception statistics. All values are set to 0. The command does not expect any fields. However, if data is transmitted in the payload section of the Command Frame, this data is ignored. There are no responses sent by this command.

3.5. Configure Wake-up Command

This command configures how the device is awakened from low-power modes. The settings applied here are used for each power mode. However, for all low-power modes, only a limited set of wakeup sources is accepted. Table 3.8 lists the possible wakeup sources for the different low-power modes.

For wakeup from Sleep Mode, any of the wakeup options except pin 8 are valid. Thus, it is possible to wake up from activity on one of the serial interfaces, on any but one GPIO pin, on reception of a packet, and on timeout of the Sleep Timer. It is also possible to use a combination of these wakeup sources.

From Stop Mode it is possible to wake up on any except one GPIO pin (see Table 3.8), on reception of a packet, or if the Sleep Timer timed out.

In Standby Mode only the Sleep Timer or one GPIO pin is available as a wakeup source (see Table 3.8).

Table 3.8 Wakeup Sources

Wakeup Source	Sleep	Stop	Standby	Comment
UART1	X	-	-	An incoming data transfer wakes the device.
UART2	X	-	-	An incoming data transfer wakes the device.
SPI	X	-	-	An incoming data transfer wakes the device.
Sleep Timer	X	X	X	The device sleeps for the time that is specified in the Power Down command (see section 3.6).
Transceiver	X	X	-	The device is awakened when the transceiver receives a packet.
Pin 1	X	X	-	
Pin 2	X	X	-	Only usable if SPI interface is disabled.
Pin 3	X	X	-	
Pin 4	X	X	-	1 ms before starting the SPI clock, pull down pin 4 to wake up from Stop Mode using the SPI.
Pin 5	X	X	-	
Pin 6	X	X	-	Only usable if UART2 interface is disabled.
Pin 7	X	X	-	Only usable if UART2 interface is disabled or if UART2 is used without flow-control.
Pin 8	-	-	X	Selecting this pin as a wakeup source is accomplished by setting the WKUP bit in the peripheral field. Only rising edges can be detected!
Pin 9	X	X	-	
Pin 12	X	X	-	
Pin 13	X	X	-	Only usable if UART1 interface is disabled.
Pin 16	X	X	-	
Pin 17	X	X	-	Only usable if UART1 interface is disabled or if UART1 is used without flow-control.
Pin 19	X	X	-	
Pin 20	X	X	-	
Pin 21	X	X	-	
Pin 22	X	X	-	
Pin 23	X	X	-	
Pin 24	X	X	-	

Table 3.9 Configure Wakeup Command Fields

Field	Width	Description
Peripheral	1	Bit-mask controlling which peripheral is used to wake the device.
GPIO Falling Edge	3	Bit-mask that selects the falling edge on a GPIO as a wakeup event.
GPIO Rising Edge	3	Bit-mask that selects the rising edge on a GPIO as a wakeup event.

Figure 3.1 Configure Wakeup - Peripheral Field Format

7	6	5	4	3	2	1	0
Reserved		SPI	UART2	UART1	WKUP	TRX	RTC

RTC determines if the wakeup timer is used as a wakeup source:
- 0 Do not use the wakeup timer.
- 1 Wakeup on wakeup timer timeout.

TRX determines if the transceiver is used as a wakeup source:
- 0 Do not use the transceiver (transceiver is in Standby Mode).
- 1 Use the transceiver (transceiver remains in receive mode).

WKUP determines if the wakeup pin (pin 8) is used as a wakeup source:
- 0 Do not use the wakeup pin.
- 1 Wakeup on rising edge on wakeup pin.

UART1 determines if the device is awakened on data reception on the UART1 interface:
- 0 Do not use UART1 as wakeup source.
- 1 Wakeup on reception of data on UART1.

UART2 determines if the device is awakened on data reception on the UART2 interface:
- 0 Do not use UART2 as wakeup source.
- 1 Wakeup on reception of data on UART2.

SPI determines if the device is awakened on reception of data on the SPI interface:
- 0 Do not use SPI as wakeup source.
- 1 Wakeup on reception of data on SPI.

Table 3.10 Configure Wakeup Command Responses

Code	Field	Length	Description
1	-		The Command Frame is too short.
2	-		The Command Frame is too long.
8	Pin-Nr.	1	The pin specified in the response field is not a GPIO
9	Pin-Nr.	1	The pin specified in the response field is already configured as output pin, and therefore cannot be used as wakeup pin.
12	-		At least two pins cannot be used together as wakeup source.

3.6. Power-Down Command

This command sends the device to one of the low power modes. The power mode is specified in the first option field. The duration of the power down state is specified in the second field. The Configure Wakeup command (see section 3.5) specifies on which events the low power mode is exited. The duration field has no effect if the sleep timer is not selected as wakeup source.

For the power mode three values are available:

0 – Sleep Mode

2 – Stop Mode

4 – Standby Mode

Table 3.11 Power Down Command Fields

Field	Length	Description
Mode	1	This field specifies the low power mode to be entered.
Duration	4	This field specifies how long the device remains in the low power mode. This field is ignored, if the sleep timer is not selected as wakeup source.

Table 3.12 Power Down Command Responses

Code	Field	Length	Description
1	-		The Command Frame is too short.
2	-		The Command Frame is too long.
3	-		Invalid low-power mode.

3.7. Get Address Configuration Command

This command requests the current address configuration of the device. The EUI64 address and all IPv6 addresses of the device are returned in the response. This command does not require additional fields. Extra fields in the Command Frame are ignored.

The number of IPv6 addresses (N_{IPv6}) returned by the command must be computed from the length field of the response frame. This is done using the following formula:

$$N_{IPv6} = \frac{Length - 9}{16}$$

Table 3.13 Get Address Configuration Response Fields

Code	Field	Length	Description
0	EUI64	8	The EUI64 address of the device. If not changed manually, this function will return the factory programmed, globally unique EUI64. The address is returned in big endian format.
	IPv6 [1]	16	The first IPv6 address of the device. The address is returned in big endian format. If this field is not present, the device is unable to communicate.
	IPv6 [2]	16	The second IPv6 address of the device (optional). The address is returned in big endian format.
	…		
	IPv6 [N]	16	IPv6 address N (optional). The address is returned in big endian format.

3.8. Set PAN Address

This command sets the PAN address of the device. The PAN address must be unique in the network. Changing this address is not recommended as the module has a unique preprogrammed PAN address. The addresses 0 and $FFFFFFFFFFFFFFFF_H$ must not be used as PAN addresses.

Performing a network reset is required after changing the PAN address. For this purpose, the Set PAN Address command has one optional field that allows performing a network reset immediately after changing the address. If the optional field is set to a value other than 0, the network reset is performed. If the field is set to 0 or not included in the message, the network reset is not performed.

Table 3.14 Set PAN Address Command Fields

Field	Width	Description
PAN Address	8	The new PAN address to be assigned to the device.
Reset [Optional]	1	Performs a network reset immediately after changing the PAN address if this field is set to a value other than 0. If set to 0 or omitted, no reset is performed.

Table 3.15 Set PAN Address Command Responses

Code	Field	Length	Description
1	-		The message is too short.
2	-		The message is too long.
19	-		The PAN Address is invalid.

3.9. Set PAN ID

This command sets the PAN identifier of the node. The PAN identifier is a 16-bit number that is used to differentiate networks. Nodes that wish to communicate must use the same PAN ID. Otherwise they will not be able to communicate even if they can physically reach each other. The PAN identifier is set immediately after calling this command. No network reset is required. The command accepts only one single argument field. This field specifies the new PAN ID. The PAN Identifier $FFFF_H$ must not be used!

Note: If the PAN ID is set after some packets have already been sent, it is possible that packets that have been queued using the old PAN ID setting might be sent to the network with the new PAN ID.

Table 3.16 Set PAN ID Command Fields

Field	Width	Description
PAN ID	2	The new PAN identifier to be set.

Table 3.17 Set PAN ID Command Responses

Code	Field	Length	Description
1	-		The message is too short.
2	-		The message is too long.
3	-		The PAN ID is invalid.

3.10. Configure PHY

Using this command it is possible to change the physical communication channel, the modulation scheme, and the output power of the module. For successful communication between two nodes, both nodes must have the same channel and the same modulation scheme selected. All parameters are configured using one command.

Table 3.18 shows the command format. Table 3.19 lists the possible error responses.

If one of the fields contains an invalid value, the whole command is not executed. Invalid parameters are reported by a command response. Note that for different channels the output power is limited.

Table 3.18 Configure PHY Command Fields

Field	Width	Description
Channel	1	This is the channel number to be selected. Possible values include ▪ Europe 0 and 100 to 102 ▪ North America 1 to 10 Note that regulations do not allow selecting a channel that does not correspond to the location of the installation of the application. Default value: 0
Modulation	1	This is the modulation scheme to be used. BPSK modulation is selected using the value 0; any other value will result in selecting O-QPSK. Default value: 0
TX-Power	1	This value determines the output power of the device. Depending on the channel being selected, the maximum output power may vary from 0 to 10 dBm. All US channels (0 < channel < 11) allow 10dBm to be selected. For the European channel 0, a maximum of 5dBm is allowed, and for the remaining European channels, 0dBm may be selected as maximum. Default value: 0

Table 3.19 Configure PHY Command Responses

Code	Field	Length	Description
1	-		The message is too short.
2	-		The message is too long.
24	-		Invalid channel.
25	-		Invalid power.

3.11. Configure Network

This command is used to configure the network parameters of the device. All parameters are set at the same time. The execution of this command automatically performs a network reset as this is required for the parameters to take effect.

Table 3.20 Configure Network Command Fields

Nr.	Field	Width	Description
0	Max Socket Count	1	This value determines how many RX sockets may be open at the same time. Default value: 8
1	Neighbor Cache Size	1	This value determines the size of the neighbor cache. The neighbor cache must have at least one entry. Default value: 4
2	Neighbor Reachable Time	2	This value determines how long a neighbor is considered to be reachable before reachability detection is performed by the network stack. Default value: 3600 s
3	Max Hop Count	1	This number determines how many hops a packet may take through the network. Setting this value to zero disables mesh networking. Default value: 8
4	Routing Table Size	2	This number determines the maximum number of entries in the routing table. The minimum Routing Table Size is 1. Default value: 8
5	Route Timeout	2	This number determines how long a routing table entry stays valid. If a route is not validated by network traffic for this amount of time, the route entry is removed from the routing table. Default value: 3600 s
6	Route Max Fail Count	1	This number determines how many times routing a packet over an existing route may fail before the route is considered as broken and the entry is removed from the routing table. Default value: 3
7	Route Min RSSI	1	During route discovery, this number determines the minimum RSSI that must be achieved during route discovery. If one link on the route has an RSSI below this value, the route is not established. Default value: -128
8	Route RSSI Reduction	1	This value determines by which value the Route Min RSSI value is decreased in the event of failing route setup due to RSSI constraints. Default value: 0
9	Route Request Attempts	1	This number determines how many attempts are made to establish a route before the request is reported to be failing. Default value: 3
10	Do Duplicate Address Detection	1	This Boolean value determines if the device performs Duplicate Address Detection when being powered on or awakened from Standby Mode. Default value: true
11	Do Router Solicitation	1	This Boolean value determines if the device performs Router Solicitations when being powered on or awakened from Standby Mode. Default value: true

Table 3.21 Response Codes of the Configure Network Command

Code	Field	Length	Description
1	-		The message is too short.
2	-		The message is too long.
26	-		Socket count too high. 251 sockets can be used as maximum.
29	Parameter Mask	2	At least one given parameter is out of range. Each enabled bit at the returned parameter mask represents the adjacent failed parameter. Note that all invalid parameters were ignored.

3.12. Discover Network

This command initiates a network discovery. Network discovery is used to identify other ZWIR45xx in the network. Each device that receives a network discovery request responds with a message containing information about the IPv6 addresses of the device, the hop distance of the remote device, and a link indicator. Refer to section 2.8 for more detailed information about network discovery.

The only argument that is passed to the Discover Network command is the upper time limit by which nodes must respond to the network discovery request. If this parameter is omitted, a default value of 3 is assumed for the time limit. If 0 is passed as the time limit, the default value of 3 is used as well.

3.13. Remote Execute

The remote execute command allows executing a command on a remote device. The first argument is the IPv6 device of the remote node that a command should be executed on. The second argument is the command frame that shall be executed on the remote device. Figure 3.2 shows the general layout of a Remote Execute command frame. The whole command frame that is requested to be executed remotely must not be longer than 1232 bytes.

Figure 3.2 Remote Execute Command Frame Layout

Table 3.22 Remote Execute Response Codes

Code	Field	Length	Description
1	-		The message is too short.
2	-		The message is too long.
27	-		Failed to send out the remote command over the network interface. **Note:** if this response is not received, it does not automatically mean that the command was successfully delivered to the remote host.

If the command executed remotely generates a response message, this message is delivered through the command Remote Response.

3.14. Get Firmware Version

This command requests the SCI to send a firmware Version String to the host. The command does not require any argument fields. Any argument field present in the command frame is ignored.

Table 3.23 Get Firmware Version Command Responses

Field	Width	Description
Status	1	This field should always contain a value of 0. If a non-zero value is returned in this field, the response must be ignored.
Product ID	2	This is the Product ID of the ZMDI Product.
SCI Major Version	1	This is the major version of the SCI.
SCI Minor Version	1	This is the minor version of the SCI.
SCI VCS Version	2	This is the VCS version of the SCI.
Stack Major Version	1	This is the major stack version.
Stack Minor Version	1	This is the minor stack version.
Stack VCS Version	2	This is the VCS version.

3.15. Reset

This command performs a System Reset. After the System Reset, the stack loads the default parameters from the flash and configures the device accordingly.

This command does not accept any parameters. If extra fields are present in the command frame, the device returns error code 2.

3.16. Network Reset

This command performs a Network Reset. This operation disconnects all network sockets and reinitializes the network stack with the configured parameters. The device will send out Router Solicitation and Duplicate Address Detection messages if enabled.

The command does not accept any parameters. If extra fields are present in the command frame, the device returns error code 2.

3.17. Store Configuration

This command stores the current device configuration to the device's flash memory. During the next startup phase, the stack is configured using the stored parameters. Refer to section 2.14 to find out which parameters can be stored continuously in the device's flash memory.

In order to prevent accidental storage of the current settings, transmitting a four byte validation string is required. If the string is incorrect, nothing is stored and an error message is returned.

Table 3.24 Store Configuration Command Fields

Field	Width	Description
Validation String	4	This field must contain the number $681c51ab_H$. The number must be transmitted in little endian byte order (least significant byte first).

Table 3.25 Store Configuration Command Responses

Code	Field	Length	Description
1	-		The message is too short.
2	-		The message is too long.
7	-		Invalid validation string.
27	-		Failed to write parameters to the flash.

3.18. Test

This command causes the device to reply with the same packet immediately (with the command field set to Test response). This is typically used for alive testing.

Table 3.26 Test Command Fields

Field	Width	Description
Data	0 – 1250	This field contains arbitrary data.

Table 3.27 Test Command Responses

Field	Width	Description
Data	0 – 1250	This field contains exactly the same data that have been sent to the device.

3.19. Configure LEDs Command

Using this command it is possible configure several indicator LEDs. There are indicator LEDs available for incoming and outgoing network data, incoming and outgoing serial data, and the power state. Each LED output can be configured separately using the I/O configuration byte described in section 2.12. The IAV bit in the I/O configuration byte is ignored. LED pins must be configured as output. The selected I/O pin must be unconfigured.

Table 3.28 Configure LEDs Command Fields

Field	Width	Description
Network RX LED Pin	1	Pin number at which the Network RX LED is attached. Set to 0 if network RX indication is disabled.
Network RX LED Config[1]	1	The I/O configuration of the Network RX LED pin.
Network TX LED Pin	1	Pin number at which the Network TX LED is attached. Set to 0 if network TX indication is disabled.
Network TX LED Config[1]	1	The I/O configuration of the Network TX LED pin.
Serial RX LED Pin	1	Pin number at which the Serial RX LED is attached. Set to 0 if network RX indication is disabled.
Serial RX LED Config[1]	1	The I/O configuration of the Serial RX LED pin.
Serial TX LED Pin	1	Pin number at which the Serial TX LED is attached. Set to 0 if network TX indication is disabled.
Serial TX LED Config[1]	1	The I/O configuration of the Serial TX LED pin.
Active LED Pin	1	Pin number at which the Active LED is attached. Set to 0 if active LED is disabled.
Active LED Config[1]	1	The I/O configuration of the Active LED pin.
[1] Refer to section 2.12 for a description of the configuration byte. The IAV bit in the configuration byte is ignored.		

Table 3.29 Configure LEDs Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
8	Pin-Nr.	1	The pin specified in the response field cannot be used as LED driver.
9	Pin-Nr.	1	The pin specified in the response field is already used for another purpose.
18	-		Invalid GPIO configuration.

3.20. Configure GPIO

This command configures an I/O pin to be used as application programmable GPIO. The pin to be configured must be in the unused operating mode before configuration can be successful. Trying to configure an already configured pin will cause the stack to send an error message and leave the pin configuration in the previous state. Refer to section 2.12 for a detailed description of available GPIO configurations.

Table 3.30 Configure GPIO Command Fields

Field	Width	Description
Pin Nr.	1	The pin number of the GPIO to be configured.
Configuration	1	The intended GPIO configuration (refer to Table 2.8).

Table 3.31 Configure GPIO Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
8	Pin-Nr.	1	The pin specified in the response field cannot be used as GPIO.
9	Pin-Nr.	1	The pin specified in the response field is already used for another purpose.
18	-		Invalid GPIO Configuration.

3.21. Write GPIO

The output value of a GPIO pin is set using this command. This command can only be executed on pins that are outputs in GPIO operating mode.

Table 3.32 Write GPIO Command Fields

Field	Width	Description
Pin Nr.	1	The pin number of the GPIO to be written.
Configuration	1	The intended GPIO value (0 or 1).

Table 3.33 Write GPIO Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
8	Pin-Nr.	1	The pin specified in the response is not a GPIO pin.
22	Pin-Nr.	1	The pin specified in the response is not configured as GPIO output.

3.22. Read GPIO

This command reads a value from a GPIO port. The command can be executed on any GPIO pin regardless of whether it is configured as input or output. Also interface, wakeup, and LED pins can be read.

Table 3.34 Read GPIO Command Fields

Field	Width	Description
Pin Nr.	1	The pin number of the GPIO to be configured.

Table 3.35 Read GPIO Command Responses

Code	Field	Length	Description
0	Value	1	If the command is successful, the response code is 0 and the value is returned in the first field of the response.
1	-		Message too short.
2	-		Message too long.
8	Pin-Nr.	1	The pin specified in the response is not a GPIO pin.
23	Pin-Nr.	1	The pin specified in the response is unconfigured.

3.23. Toggle GPIO

This command toggles the output value of a GPIO pin. This command can only be executed on pins that are outputs in GPIO operating mode.

Table 3.36 Toggle GPIO Command Fields

Field	Width	Description
Pin Nr.	1	The pin number of the GPIO to be configured.

Table 3.37 Toggle GPIO Command Responses

Code	Field	Length	Description
1	-		Message too short
2	-		Message too long.
8	Pin-Nr.	1	The pin specified in the response is not a GPIO pin.
22	Pin-Nr.	1	The pin specified in the response is not configured as GPIO output.

3.24. Configure UART1

This command configures the settings of UART1. The first argument field contains a configuration bit-field controlling the parity bit, stop bit, and flow-control settings as well as the enable status of the UART. The second field is a three-byte number controlling the baud-rate settings. The layout of the configuration field is shown in Figure 3.3. If the ENBL field of the configuration bit-field is set to zero, the baud-rate field may be omitted.

Table 3.38 Configure UART Command Fields

Field	Width	Description
Configuration	1	This byte controls the behavior of the module.
Baud Rate	3	Baud-rate in bits per second. This field can be omitted if the ENBL bit in the configuration field is set to zero. The number is required to be in little endian format (least significant byte first).

Figure 3.3 UART Configuration Bit-Field Layout

7	6	5	4	3	2	1	0
FLCTL	STOP	PARITY		Reserved			ENBL

The **ENBL** bit selects whether the interface is enabled or disabled.
- 0 The interface is disabled
- 1 The interface is enabled

The **PARITY** bits control transmission of parity bits with UART frames.
- 0 Parity is disabled
- 2 Even parity
- 3 Odd Parity

The **STOP** bit controls the transmission of stop bits.
- 0 One stop bit
- 1 Two stop bits

The **FLCTL** bit controls whether flow control is enabled or disabled.
- 0 Flow control is disabled
- 1 Flow control is enabled

Table 3.39 Configure UART Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
9	Pin-Nr.	1	Pin is already configured.

3.25. Configure UART2

This command is used to configure the UART2 interface. Refer to the previous section for a description of the command.

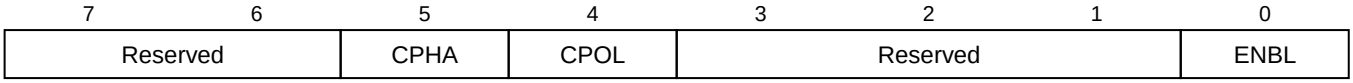
3.26. Configure SPI

This command is used to configure the SPI interface. The first argument field is a configuration bit-field that controls the clock polarity and clock edge of the SPI as well as the enable status. The second field specifies which pin is used as pending data indicator pin. The pending pin field may be omitted if the ENBL field of the configuration bit-field is set to zero.

Table 3.40 Configure SPI Command Fields

Field	Width	Description
Configuration	1	Bit-field configuring SPI behavior and enable status. Refer to Figure 3.4 for the layout of the bit-field.
Pending Pin	1	Specifies which GPIO pin is used as the pending data indicator. This field can be omitted if the ENBL bit in the configuration bit-field is set to zero.

Figure 3.4 SPI Configuration Bit-Field Layout



The **ENBL** bit selects whether the interface is enabled or disabled.

2 The interface is disabled.
3 The interface is enabled.

The **CPOL** bit controls the clock polarity.

0 Clock input is low when idle.
1 Clock input is high when idle.

The **CPHA** bit controls the clock phase

0 Data are sampled on the first clock edge.
1 Data are sampled on the second clock edge.

Table 3.41 Configure SPI Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
8	Pin-Nr.	1	Pin is not an GPIO.
9	Pin-Nr.	1	Pin is already configured.

3.27. Restore Fabric Settings

This command deletes all settings stored in the flash memory and restores the original settings instead. The command does not expect any arguments, but to avoid accidental execution of the command, passing a four-byte validation string is required.

Table 3.42 Restore Fabric Settings Command Fields

Field	Width	Description
Validation String	4	This field must contain the number $f85a23e1_H$. The number must be transmitted in little endian byte order (least significant byte first).

Table 3.43 Restore Fabric Settings Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
7	-		Invalid validation string.

3.28. Configure Multicast

This command configures the multicast settings. It configures how many multicast groups are present in the system and how many 16-bit fields of the IPv6 multicast address group identifier are used as full group ID fields. Refer to section 2.5.3.2 for a general description of IPv6 multicast and its implementation in the ZWIR451x.

Note that the memory for the internal bit-field storing group membership is allocated dynamically at runtime. SCI allocates one byte per 8 groups. For example, a configuration with 1024 groups requires 128 bytes of memory. If sufficient memory is not available, the ZWIR451x will be reset and the stored settings will be restored. After the reset, the corresponding error response is returned.

Table 3.44 Configure Multicast Command Fields

Field	Width	Description
Group Count	2	Specifies the number of maximally available groups.
Group Address Count	1	Specifies how many Group Address fields are in an IPv6 address.

Table 3.45 Configure Multicast Command Fields

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
5	-		Memory exhaustion.
10	-		Maximum group count exceeded.
11	-		Invalid group address number.

3.29. Join Multicast Group

This command is used to join a multicast group. The device will receive multicast messages that are sent to Group Address immediately after executing this command.

Table 3.46 Join Multicast Group Command Fields

Field	Width	Description
Group Address	2	Specifies the address of the group the device should join.

Table 3.47 Join Multicast Field Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
10	-		Group Address is larger than configured group count.

3.30. Leave Multicast Group

This command is used to leave a multicast group. The device will no longer receive multicast messages that are sent to Group Address immediately after executing this command.

Table 3.48 Leave Multicast Group Command Fields

Field	Width	Description
Group Address	2	Specifies the address of the group the device should leave.

Table 3.49 Leave Multicast Group Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
10	-		Group Address is larger than configured group count.

3.31. Add Security Policy

This command adds a security policy to the security policy database. Outgoing and incoming traffic is matched with the Remote Address, Prefix, Protocol, and Lower and Upper Port. If a rule is found in the security policy database, the traffic is processed by IPSec according to the specified security association. For manual administration of security associations, a security association must be generated before executing this command. The response value received from the Add Security Association has to be passed as the last parameter. If automatic generation of security associations is desired, the last parameter must be zero. Refer to the ZMDI document *ZWIR45xx Application Note—Using IPSec and IKEv2 in 6LoWPANs* for further information about security processing.

Without a call to this command, a default rule is in effect that allows all outgoing and incoming traffic to pass unsecured. The first call to Add Security Policy will disable this rule and install the new one instead. Subsequent calls will add further rules.

ZMDI's SCI firmware allows the generation of a maximum of ten security policies. Policy matching is done in the order that the policies have been generated. If multiple policy matching parameters are overlapping, ensure that the most general rule is inserted last.

Table 3.50 Add Security Policy Command Fields

Field	Width	Description
Type	1	Defines the type of the rule: 11_H Output Secure 12_H Output Bypass 13_H Output Drop 21_H Input Secure 22_H Input Bypass 23_H Input Drop
Remote Address	16	The remote address that this rule applies to. Note: Only the *Prefix* number of higher bits are used in the matching algorithm.
Prefix	1	Defines how many of the upper bits of *Remote Address* are considered for matching traffic. This value may be in the range of 0 to 128.
Protocol	1	This field defines the protocol the rule applies to: 00_H Policy applies to any protocol 17_H Policy applies to UDP traffic only 58_H Policy applies to ICMPv6 traffic only
Lower Port	2	Defines the lower port of port-based protocols that the policy applies to
Upper Port	2	Defines the upper port of port-based protocols that the policy applies to.
SA Handle	4	Security Association handle returned by command Add Security Association.

Table 3.51 Add Security Policy Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
4	-		No more space in the SPD.
13	-		Invalid type.
14	-		Invalid prefix length.

3.32. Add Security Association

This command manually adds a security association to the security association database. On successful completion of this operation, the command returns a security index that must be passed to the Add Security Policy command to link the security association to a certain security policy. A security association may be assigned to multiple security policies.

Each security association requires a unique identifier that is passed with the first argument field. A maximum of ten security associations may be generated. If an item is added that has a security parameter ID that is already stored in the SAD, then the SAD entry is overwritten with the new security association.

Note that if no encryption is selected, packets are still sent with encryption headers. However, packets are not encrypted in this case. This feature can be used for debug purposes.

Table 3.52 Add Security Association Command Fields

Field	Width	Description
Security Parameter ID	4	A value identifying the security association.
Encryption Algorithm	1	Selects the encryption algorithm: 11 No Encryption 13 AES128, Counter Mode
Encryption Key	16	This is the 128-bit key used for encryption—must be the same for all communicating parties.
Encryption Nonce	4	This is a 32-bit value used for encryption. Must be the same for all communicating parties.
Authentication Algorithm	1	This determines the authentication algorithm: 0 No Authentication 5 AES XCBC96 Authentication
Authentication Key	16	This is the 128-bit key used for authentication—must be the same for all communicating parties.

Table 3.53 Add Security Association Command Responses

Code	Field	Length	Description
0	SA Handle	4	Handle of the newly generated security association
1	-		Message too short.
2	-		Message too long.
4	-		No more space in the SAD.
15	-		Invalid Encryption Algorithm.
16	-		Invalid Authentication Algorithm.

3.33. Add IKEv2 Authentication Entry

This command generates a new IKEv2 authentication entry. These entries are used to authenticate the device in the process of key negotiation for an IPSec security association. A maximum of 5 IKEv2 authentication entries may be created on each device.

Table 3.54 Add IKEv2 Authentication Entry Command Fields

Field	Width	Description
Remote Address	16	The remote address that this rule applies to. Note: Only the *Prefix* number of higher bits are used in the matching algorithm.
Prefix	1	Defines how many of the upper bits of *Remote Address* are considered for matching traffic. This value may be in the range of 0 to 128.
Pre-Shared Key	16	This is the pre-shared key that is used for authentication.
ID-Length	1	Determines the size of the ID.
ID	ID-Length	This is the unique identifier of the IKEv2 authentication entry. It must not exceed a size of 16 bytes.

Table 3.55 Add IKEv2 Authentication Entry Command Responses

Code	Field	Length	Description
1	-		Message too short.
2	-		Message too long.
4	-		No more space in the IKEv2 authentication database.
14	-		Invalid Prefix Length.
17	-		Invalid ID Length.

3.34. Enable Watchdog Timer

This command is used to enable the watchdog timer or to prepare disabling it. Enable requests are performed immediately on reception of this command. Disabling the watchdog is done by a simple system reset when the watchdog is not enabled permanently (stored configuration does not have the watchdog enable bit set) or by resetting the watchdog enable bit, storing the new configuration, and resetting the device. It is not possible to disable a permanently configured watchdog without changing the present configuration. For more information about the watchdog timer, refer to section 2.13.

Table 3.56 Enable Watchdog Timer Command Fields

Field	Width	Description
Enable Status	1	Watchdog is disabled when set to zero, otherwise it is enabled.
Validation String	4	The local UDP port over which the packet has been received

3.35. Get Current Interface

This command returns the interface identifier of the interface that this command was issued over. For example, if the module receives this command over the UART1 interface, it returns the interface identifier byte 00_H. This command does not expect any parameters.

3.36. Get PHY Configuration

This command returns the current PHY configuration. This command does not expect any parameters.

Table 3.57 Get PHY Command Response

Code	Field	Length	Description
0	Values	3	If the command is successful, the response code is 0 and the PHY configuration is returned in the response. See the table in section 3.10 for the structure of the returned PHY parameter configuration.

3.37. Get NET Configuration

This command returns the current NET configuration. This command does not expect any parameters.

Table 3.58 Get NET Command Response

Code	Field	Length	Description
0	Values	15	If the command is successful, the response code is 0 and the NET configuration is returned in the response. See the table in section 3.11 for the structure of the returned NET parameter configuration.

3.38. Get FCC ID

This command requests the FCC-ID of the module. The command returns an ASCII-encoded byte array representing the module's FCC-ID.

Code	Field	Length	Description
0	FCC-ID	Varialbe	ASCII-encoded FCC-ID of the module

3.39. Receive Packet Command

This command is sent by the SCI device when a data packet has been received over one of the configured receive sockets. The packet is sent to the interface that has been configured using the Configure Receiver command.

Table 3.59 Receive Packet Command Fields

Field	Width	Description
Source IPv6 Address	16	The address from which the packet has been received.
Local UDP Port	2	The local UDP port over which the packet has been received.
Data	1 - 1232	The data payload that has been received with the packet.

3.40. Remote Response Command

This command is sent by the SCI device when a reply of a remotely executed command is received. The packet is sent to the interface over which the triggering command had been sent.

Table 3.60 Remote Response Command Fields

Field	Width	Description
Source IPv6 Address	16	The address from which the packet has been received.
Response Frame	1 - 1232	The command response that has been received.

4 Certification

4.1. European R&TTE Directive Statements

The ZWIR4512 module has been tested and found to comply with Annex IV of the R&TTE Directive 1999/5/EC and is subject of a notified body opinion. The module has been approved for Antennas with gains of 4 dBi or less.

4.2. Federal Communication Commission Certification Statements

4.2.1. Statements

This equipment has been tested and found to comply with the limits for a **Class B digital device**, pursuant to Part 15 of the FCC Rules. These limits are designed to provide reasonable protection against harmful interference in a residential installation. This equipment generates, uses and can radiate radio frequency energy and, if not installed and used in accordance with the instructions, may cause harmful interference to radio communications. However, there is no guarantee that interference will not occur in a particular installation. If this equipment does cause harmful interference to radio or television reception, which can be determined by turning the equipment off and on, the user is encouraged to try to correct the interference by one or more of the following measures:

- Reorient or relocate the receiving antenna.
- Increase the separation between the equipment and receiver.
- Connect the equipment into an outlet on a circuit different from that to which the receiver is connected.
- Consult the dealer or an experienced radio/TV technician for help.

This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

Modifications not expressly approved by ZMD AG could void the user's authority to operate the equipment.

The internal / external antennas used for this mobile transmitter must provide a separation distance of at least 20 cm from all persons and must not be co-located or operating in conjunction with any other antenna or transmitter.

4.2.2. Requirements

The ZWIR4512 complies with Part 15 of the FCC rules and regulations. In order to retain compliance with the FCC certification requirements, the following conditions must be met:

1. Modules must be installed by original equipment manufacturers (OEM) only
2. The module must only be operated with antennas …i
3. The OEM must place a clearly visible text label on the outside of the end-product containing the text shown in Figure 8-1, below.

Figure 4.1 FCC Compliance Statement to be printed on Equipment Incorporating ZWIR4512 Devices

Contains FCC ID: COR-ZWIR4512AC1
This device complies with part 15 of the FCC Rules. Operation is subject to the following two conditions: (1) This device may not cause harmful interference, and (2) this device must accept any interference received, including interference that may cause undesired operation.

4.2.3. Accessing the FCC ID

ZWIR451x modules are capable of showing their FCC ID electronically. Host applications may read the modules FCC-ID through the command Get FCC ID. Due to space constraints the FCC ID is not printed on the module. Host devices incorporating this module must be marked according to above guidelines.

4.3. Supported Antennas

The FCC compliance testing of the ZWIR4512 has been carried out using the MEXE902RPSM antenna from PCTEL Inc. This antenna has an omnidirectional radiation pattern at an antenna gain of 2 dBi. In order to be allowed to use the module without re-certification, the product incorporating the ZWIR4512 module must either use the antenna mentioned above or must use an antenna with an omnidirectional radiation pattern and a gain being less than or equal to 2 dBi.

5 Abbreviations

Term	Description
6LoWPAN	IPv6 over Low Power Wireless Personal Area Networks
AES	Advanced Encryption Standard
AH	Authentication Header
API	Application Programming Interface
ARP	Address Resolution Protocol
CBC	Cyclic Block Cipher
DAD	Duplicate Address Detection
DHCP	Dynamic Host Configuration Protocol
ESP	Encapsulating Security Payload
GPIO	General Purpose Input/Output
IETF	Internet Engineering Task Force
IKEv2	Internet Key Exchange version 2
IPSec	Internet Protocol Security
IPv4	Internet Protocol version 4
IPv6	Internet Protocol version 6
MAC	Media Access Control
LAN	Local Area Network
MCU	Micro-Controller Unit
NDP	Neighbor Discovery Protocol
NA	Neighbor Advertisement
NS	Neighbor Solicitation
OSI	Open Systems Interconnection
PAN	Personal Area Network
PLL	Phase-Locked Loop
PSK	Pre-Shared Key
RA	Router Advertisement
RS	Router Solicitation

Term	Description
RSSI	Receive Signal Strength Indicator
SA	Security Association
SAD	Security Association Database
SCI	Serial Command Interface
SP	Security Policy
SPD	Security Policy Database
TRX	Transceiver
UART	Universal Asynchronous Receiver Transmitter
UDP	User Datagram Protocol
WAN	Wide Area Network
WPAN	Wireless Personal Area Network

6 Related Documents

Document Name	Source
Public Documents	
Internet Protocol, Version 6 (IPv6) Specification	*RFC 2460, http://tools.ietf.org/html/rfc2460*
IP Version 6 Addressing Architecture	*RFC 4291, http://tools.ietf.org/html/rfc4291*
Security Architecture for the Internet Protocol	*RFC 4301, http://tools.ietf.org/html/rfc4301*
Internet Key Exchange (IKEv2) Protocol	*RFC 5996, http://tools.ietf.org/html/rfc5996*
Neighbor Discovery for IP Version 6 (IPv6)	*RFC 4861, http://tools.ietf.org/html/rfc4861*
IPv6 Stateless Address Auto-configuration	*RFC 4862, http://tools.ietf.org/html/rfc4862*
Transmission of IPv6 Packets over IEEE 802.15.4 Networks	*RFC 4944, http://tools.ietf.org/html/rfc4944*
ZMDI Documents	
ZWIR4512 Data Sheet	*ZWIR4512_Data_Sheet_revX.xy.pdf*
ZWIR451x Programming Guide	*ZWIR451x_ProgGuide_revX.xy.pdf*
ZWIR451x Application Note: Using IPSec and IKEv2 in 6LoWPANs	*ZWIR45xx_AN_Security_revX.xy.pdf*
ZWIR451x Application Note: Using Over-the-Air Updates in 6LoWPANs	*ZWIR451x_AN_OTAU_revX.xy.pdf*

7 Document Revision History

Revision	Date	Description
1.00	May 9, 2012	Initial public release. Added documentation of configurable network parameters. Added over-the-air update security notice.
1.10	July 17, 2012	Added documentation for new commands in firmware version 1.1 (Get PHY Configuration and Get NET Configuration).
1.11	July 30, 2012	Clarified documentation of security configuration command Minor edits
1.20	August 31, 2012	Added documentation for command Get FCC ID Added R&TTE & FCC conformity statements

Sales and Further Information www.zmdi.com wpan@zmdi.com

Zentrum Mikroelektronik Dresden AG
Grenzstrasse 28
01109 Dresden
Germany

Phone +49.351.8822.7476
Fax +49.351.8822.87476

ZMD America, Inc.
1525 McCarthy Blvd., #212
Milpitas, CA 95035-7453
USA

Phone +855-ASK-ZMDI
(+855.275.9634)

Zentrum Mikroelektronik Dresden AG, Japan Office
2nd Floor, Shinbashi Tokyu Bldg.
4-21-3, Shinbashi, Minato-ku
Tokyo, 105-0004
Japan

Phone +81.3.6895.7410
Fax +81.3.6895.7301

ZMD FAR EAST, Ltd.
3F, No. 51, Sec. 2,
Keelung Road
11052 Taipei
Taiwan

Phone +886.2.2377.8189
Fax +886.2.2377.8199

Zentrum Mikroelektronik Dresden AG, Korean Office
POSCO Centre Building
West Tower, 11th Floor
892 Daechi, 4-Dong,
Kangnam-Gu
Seoul, 135-777
Korea

Phone +82.2.559.0660
Fax +82.2.559.0700