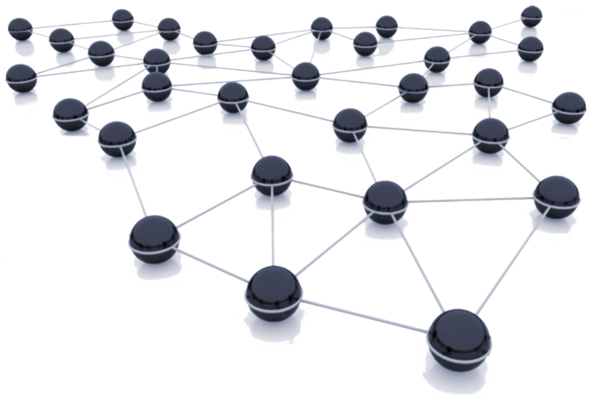
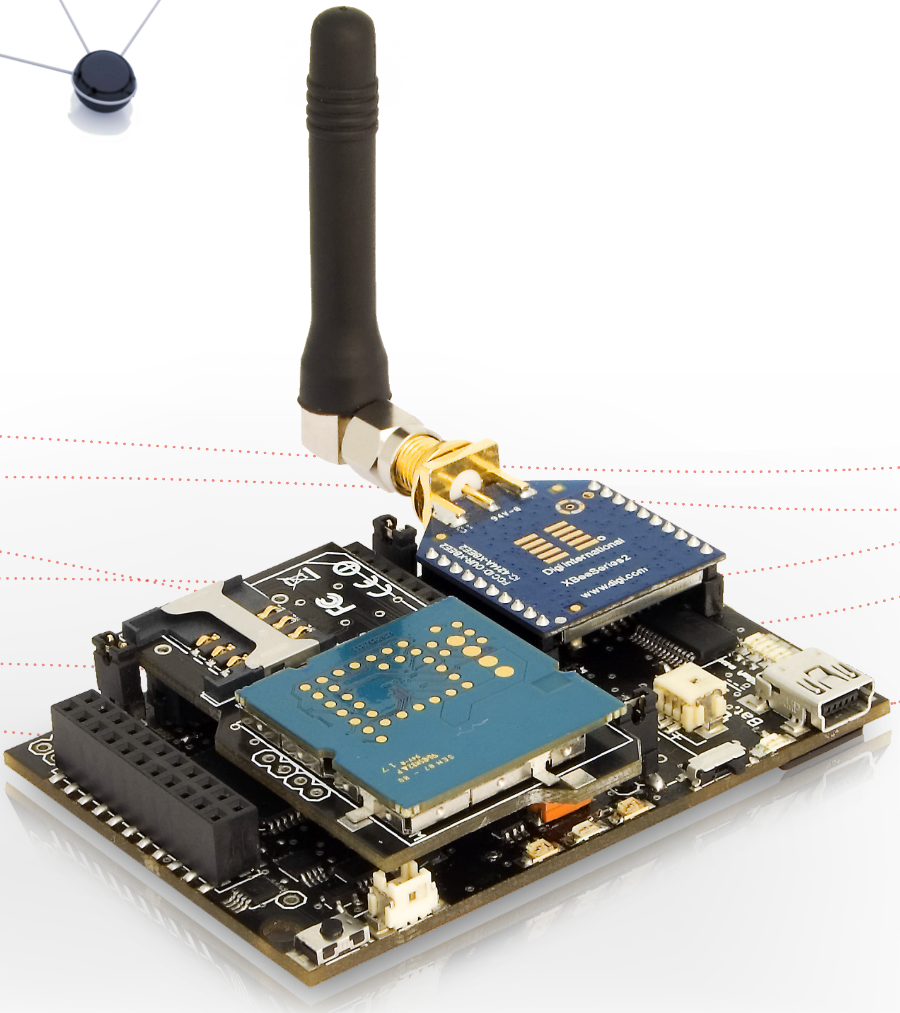
Waspmote Digimesh

Networking Guide





Document version: v0.4 - 07/2011

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1. General Considerations

1.1. Waspmote Libraries

1.1.1. Waspmote XBee Files

WaspXBeeCore.h ; WaspXBeeCore.cpp, WaspXBeeDM.h, WaspXBeeDM.cpp

1.1.2. Constructor

To start using the Waspmote XBee DigiMesh library, an object from class 'WaspXBeeDM' must be created. This object, called 'xbeeDM', is created inside the Waspmote XBee DigiMesh library and it is public to all libraries. It is used through the guide to show how Waspmote XBee DigiMesh library works.

When creating this constructor, some variables are defined with a value by default.

1.2. API Functions

Through the guide there are many examples of using parameters. In these examples, API functions are called to execute the commands, storing in their related variables the parameter value in each case.

Example of use

```
{
 xbeeDM.getOwnMacLow(); // Get 32 lower bits of MAC Address
 xbeeDM.getOwnMacHigh(); // Get 32 upper bits of MAC Address
}
```

Related Variables

xbeeDM.sourceMacHigh[0-3] → stores the 32 upper bits of MAC address
xbeeDM.sourceMacLow [0-3] → stores the 32 lower bits of MAC address

When returning from 'xbeeDM.getOwnMacLow' the related variable 'xbeeDM.sourceMacLow' will be filled with the appropriate values. Before calling the function, the related variable is created but it is empty.

There are three error flags that are filled when the function is executed:

- error_AT: it stores if some error occurred during the execution of an AT command function
- error_RX: it stores if some error occurred during the reception of a packet
- error_TX: it stores if some error occurred during the transmission of a packet

All the functions return a **flag** to know if the function called was successful or not. Available values for this flag:

- 0: Success. The function was executed without errors and the variable was filled.
- 1: Error. The function was executed but an error occurred while executing.
- 2: Not executed. An error occurred before executing the function.
- -1: Function not allowed in this module.

To store parameter changes after power cycles, it is needed to execute the writeValues function.

Example of use

```
{
 xbeeDM.writeValues(); // Keep values after rebooting
}
```

1.3. API extension

All the relevant and useful functions have been included in the Waspmote API, although any XBee command can be sent directly to the transceiver using the 'sendCommandAT' function.

Example of use

```
{
  xbeeDM.sendCommandAT("CH#"); // Executes command ATCH
}
```

Related Variables

xbeeDM.commandAT[0-100] → stores the response given by the module up to 100 bytes

1.4. Waspmote reboot

When Waspmote is rebooted or it wakes up from a deep sleep state (battery is disconnected) the application code will start again, creating all the variables and objects from the beginning.

1.5. Constants pre-defined

There are some constants pre-defined in a file called 'WaspXBeeConstants.h'. These constants define some parameters like the size of each fragment or maximum data size. The most important constants are explained next:

- MAX_DATA: it defines the maximum available data size for a packet. This constant must be equal or bigger than the data is sent on each packet. This size shouldn't be bigger than 1500.
- DATA_MATRIX: it defines the data size for each fragment. As the maximum payload is 100bytes, there is no reason to make it bigger.
- MAX_PARSE: it defines the maximum data that is received in each call to 'treatData'. If more data are received, they will be stored in the UART buffer until the next call to 'treatData'. However, if the UART buffer is full, the following data will be written on the buffer, so be careful with this matter.
- MAX_BROTHERS: it defines the maximum number of brothers that can be stored.
- MAX_FRAG_PACKETS: it defines the maximum number of fragments that can be received from a global packet. If a packet is divided in more fragments, when it is detected all the fragments will be deleted and the packet will be discarded.
- MAX_FINISH_PACKETS: it defines the maximum number of finished packets that can be stored.
- DATA_OFFSET: it is used as an input parameter in 'setDestinationParams'. It specifies that the data given as a parameter must be added at the end of the packet. It allows the generation of one packet from several calls to 'setDestinationParams' with different types of data.
- DATA_ABSOLUTE: it is used as an input parameter in 'setDestinationParams'. It specifies that the data given as a parameter are the data to send. It also sets the addresses to the packet.
- XBEE_LIFO: it specifies the LIFO replacement policy. If one packet is received and the finished packets array is full, this policy will free the previous packet received and it will store the data from the last packet.
- XBEE_FIFO: it specifies the FIFO replacement policy. If one packet is received and the finished packets array is full, this policy will free the first packet received and it will store the data from the last packet.
- XBEE_OUT: it specifies the OUT replacement policy. If one packet is received and the finished packets array is full, this policy will discard this packet.

1.6. XBee modules supported

DigiMesh can be used on two XBee modules: XBee 802.15.4 and XBee 900MHz. There are some differences between both modules as the frequency used (2.4GHz vs 900MHz) or the power transmission.

2. Initialization

Before starting to use a module, it needs to be initialized. During this process, the UART to communicate with the module has to be opened and the XBee switch has to be set on.

2.1. Initializing

It initializes all the global variables that will be used later.

It returns nothing.

The initialized variables are:

- **protocol**: specifies the protocol used (DigiMesh in this case).
- **freq**: specifies the frequency used (2,4GHz or 900MHz in this case).
- **model**: specifies the model used. XBee Series I has two possible models: Normal(2mW) or PRO(50mW) and XBee 900MHz has one model(50mW)
- **totalFragmentsReceived**: specifies the number of fragments expected from a packet
- **pendingPackets**: specifies the packets pending of fragments to be completed
- **pos**: specifies the position to use in received packets
- **discoveryOptions**: specifies the options in Node Discovery
- **awakeTime**: specifies the time to be awake before go sleeping
- **sleepTime**: specifies the time to be sleeping
- **scanChannels**: specifies the channels to scan
- **scanTime**: specifies the time to scan each channel
- **timeEnergyChannel**: specifies the time the channels will be scanned
- **encryptMode**: specifies if encryption mode is enabled
- **powerLevel**: specifies the power transmission level
- **timeRSSI**: specifies the time RSSI LEDs are on
- **sleepOptions**: specifies the options for sleeping
- **networkHops**: specifies the maximum number of hops expected to be seen in a network route
- **netDelaySlots**: specifies the maximum random number of network delay slots before rebroadcasting a network packet
- **netRouteRequest**: specifies the maximum number of route discovery retries allowed to find a path to the destination node
- **meshNetRetries**: specifies the maximum number of network packet delivery attempts

Example of use

```
{
  xbeeDM.init(DIGIMESH,FREQ2_4G,NORMAL); // initializes the variables
}
```

2.2. Setting ON

It opens the UART and switches the XBee ON. The baud rate used to open the UART is defined on the library (38400bps by default).

Example of use

```
{
  xbeeDM.ON(); // Opens the UART and switches the XBee ON
}
```

2.3. Setting OFF

It closes the UART and switches the XBee OFF.

Example of use

```
{
  xbeeDM.OFF(); // Closes the UART and switches the XBee OFF
}
```

3. Node Parameters

When configuring a node, it is necessary to set some parameters which will be used lately in the network, and some parameters necessary for using the API functions.

3.1. MAC Address

A 64-bit RF module's unique IEEE address. It is divided in two groups of 32 bits (High and Low).

It identifies uniquely a node inside a network due to it can not be modified and it is given by the manufacturer.

Example of use

```
{
 xbeeDM.getOwnMacLow(); // Get 32 lower bits of MAC Address
 xbeeDM.getOwnMacHigh(); // Get 32 upper bits of MAC Address
}
```

Related Variables

xbeeDM.sourceMacHigh[0-3] → stores the 32 upper bits of MAC address
xbeeDM.sourceMacLow [0-3] → stores the 32 lower bits of MAC address

3.2. PAN ID

A 16-bit number that identifies the network. It must be unique to differentiate a network. All the nodes in the same network should have the same PAN ID.

Example of use

```
{
 panid={0x33,0x31}; // array containing the PAN ID
 xbeeDM.setPAN(panid); // Set PANID
 xbeeDM.getPAN(); // Get PANID
}
```

Related Variables

xbeeDM.PAN_ID[0-7] → stores the 16-bit PAN ID. It is stored in the two first positions.

3.3. Node Identifier

A max 20-character ASCII string which identifies the node in a network. It is used to identify a node in the application level. It is also used to search a node using its NI.

Example of use

```
{
 xbeeDM.setNodeIdentifier("forrestnode-01#"); // Set 'forrestnode-01' as NI
 xbeeDM.getNodeIdentifier(); // Get NI
}
```

Related Variables

xbeeDM.nodeID[0-19] → stores the 20-byte max string Node Identifier

3.4. Channel

This parameter defines the frequency channel used by the module to transmit and receive.

When working on 2,4GHz band, DigiMesh defines 16 channels to be used:

- 2.40-2.48GHz : 16 channels

2.4GHz Band

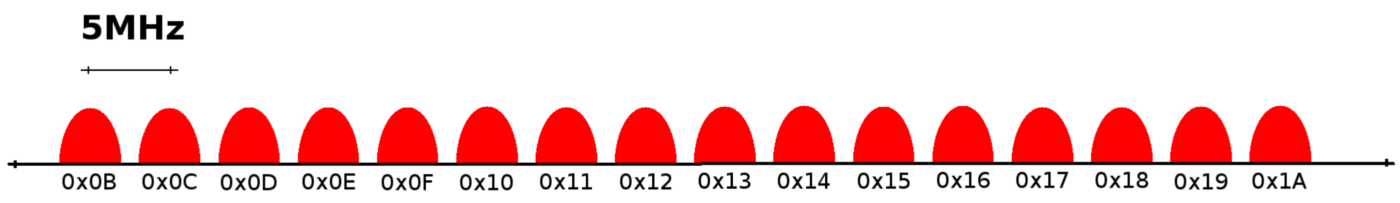

Figure 3.1: Operating Frequency Bands on 2,4GHz

However, 900MHz band can also be used with DigiMesh, defining 12 channels:

- 902-926MHz : 12 channels

902 - 928 MHz Band

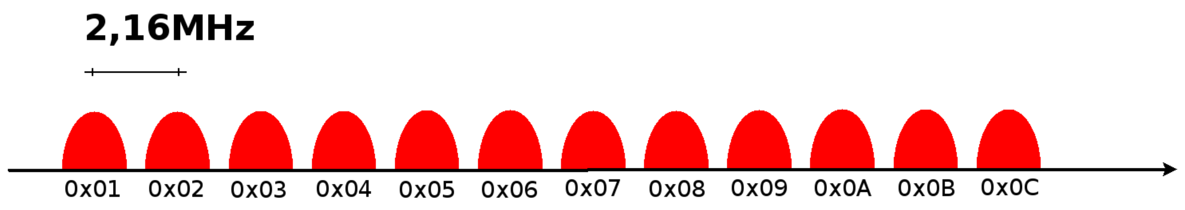

Figure 3.2: Operating Frequency Bands on 2,4GHz

Channel Number	Frequency	Supported by
0x0B – Channel 11	2,400 – 2,405 GHz	Normal
0x0C – Channel 12	2,405 – 2,410 GHz	Normal / PRO
0x0D – Channel 13	2,410 – 2,415 GHz	Normal / PRO
0x0E – Channel 14	2,415 – 2,420 GHz	Normal / PRO
0x0F – Channel 15	2,420 – 2,425 GHz	Normal / PRO
0x10 – Channel 16	2,425 – 2,430 GHz	Normal / PRO
0x11 – Channel 17	2,430 – 2,435 GHz	Normal / PRO
0x12 – Channel 18	2,435 – 2,440 GHz	Normal / PRO
0x13 – Channel 19	2,440 – 2,445 GHz	Normal / PRO
0x14 – Channel 20	2,445 – 2,450 GHz	Normal / PRO
0x15 – Channel 21	2,450 – 2,455 GHz	Normal / PRO
0x16 – Channel 22	2,455 – 2,460 GHz	Normal / PRO
0x17 – Channel 23	2,460 – 2,465 GHz	Normal / PRO
0x18 – Channel 24	2,465 – 2,470 GHz	Normal
0x19 – Channel 25	2,470 – 2,475 GHz	Normal
0x1A – Channel 26	2,475 – 2,480 GHz	Normal

Figure 3.3: Channel Frequency Numbers on 2,4GHz

Channel Number	Frequency
0x01 – Channel 1	902 – 904,16 GHz
0x02 – Channel 2	904,16 – 906,32 GHz
0x03 – Channel 3	906,32 – 908,48 GHz
0x04 – Channel 4	908,48 – 910,64 GHz
0x05 – Channel 5	910,64 – 912,80 GHz
0x06 – Channel 6	912,80 – 914,96 GHz
0x07 – Channel 7	914,96 – 917,12 GHz
0x08 – Channel 8	917,12 – 919,28 GHz
0x09 – Channel 9	919,28 – 921,44 GHz
0x0A – Channel 10	921,44 – 923,6 GHz
0x0B – Channel 11	923,6 – 925,76 GHz
0x0C – Channel 12	925,76 – 928 GHz

Figure 3.4: Channel Frequency Numbers on 902MHz

Example of use

```
{
  xbeeDM.setChannel(0x0C); // Set channel
  xbeeDM.getChannel(); // Get Channel
}
```

Related Variables

xbeeDM.channel → stores the operating channel

3.5. Network Hops

It specifies the maximum number of hops expected to be seen in a network route.

Example of use

```
{
  xbeeDM.setNetworkHops(0x07); // Set network hops
  xbeeDM.getNetworkHops(); // Get network hops
}
```

Related Variables

xbeeDM.networkHops → stores the number of hops selected

3.6. Network Delay Slots

It specifies the maximum random number of network delay slots before rebroadcasting a network packet.

Example of use

```
{
  xbeeDM.setNetworkDelaySlots(0x03); // Set network delay slots
  xbeeDM.getNetworkDelaySlots(); // Get network delay slots
}
```

Related Variables

xbeeDM.netDelaySlots → stores the number of delay slots

3.7 Network Route Requests

It specifies the maximum number of route discovery retries allowed to find a path to the destination node.

Example of use

```
{
  xbeeDM.setNetworkRouteRequests(0x03); // Set network route requests
  xbeeDM.getNetworkRouteRequests(); // Get network route requests
}
```

Related Variables

xbeeDM.netRouteRequest → stores the number of route requests

3.8. Mesh Network Retries

It specifies the maximum number of network packet delivery attempts.

Example of use

```
{
  xbeeDM.setMeshNetworkRetries(0x01); // Set mesh network retries
  xbeeDM.getMeshNetworkRetries(); // Get mesh network retries
}
```

Related Variables

xbeeDM.meshNetRetries → stores the number of network packet delivery attempts

3.9. Node type

It determines the node networking type. A module set as an "end device" will not propagate broadcasts and won't become an intermediate node on a route. Possible values are:

- 0: Router
- 2: End Device

Example of use

```
{
   xbeeDM.setNodeType(0x00); //set node as router
   xbeeDM.getNodeType(); //get node type
}
```

Related Variables

xbeeDM.routingMode → stores the routing mode

4. Packet Parameters

4.1. Structure used in packets

Packets are structured in API libraries using a defined structure called 'packetXBee'. This structure has many fields to be filled by the user or the application:

```
/************ IN ***********/
   uint8_t macDL[4];         // 32b Lower Mac Destination
   uint8_t macDH[4];         // 32b Higher Mac Destination
   uint8_t mode;             // 0=unicast ; 1=broadcast ; 2=cluster ; 3=synchronization
   uint8_t address_type;     // 0=16B ; 1=64B
   uint8_t naD[2];           // 16b Network Address Destination
   char data[MAX_DATA];      // Data of the sent message. All the data here, even when > Payload
   uint16_t data_length;     // Data sent length. Real used size of vector data[MAX_DATA]
   uint16_t frag_length;     // Fragment length. Used to send each fragment of a big packet
   uint8_t SD;               // Source Endpoint
   uint8_t DE;               // Destination Endpoint
   uint8_t CID[2];           // Cluster Identifier
   uint8_t PID[2];           // Profile Identifier
   uint8_t MY_known;         // 0=unknown net address ; 1=known net address
   uint8_t opt;              // options: 0x08=Multicast transmission

/******** APLICATION *******/
   uint8_t packetID;         // ID for the packet
   uint8_t macSL[4];         // 32b Lower Mac Source
   uint8_t macSH[4];         // 32b Higher Mac Source
   uint8_t naS[2];           // 16b Network Address Source
   uint8_t macOL[4];         // 32b Lower Mac Origin Source
   uint8_t macOH[4];         // 32b Higher Mac Origin Source
   uint8_t naO[2];           // 16b Network Address origin
   char niO[20];             // Node Identifier Origin. To use in transmission, it must finish  "#".
   uint8_t RSSI;             // Receive Signal Strength Indicator
   uint8_t address_typeS;    // 0=16B ; 1=64B
   uint8_t typeSourceID;     // 0=naS ; 1=macSource ; 2=NI
   uint8_t numFragment;      // Number of fragment to order the global packet
   uint8_t endFragment;      // Specifies if this fragment is the last fragment of a global packet
   uint8_t time;             // Specifies the time when the first fragment  was received

/******** OUT **************/
   uint8_t deliv_status;     // Delivery Status
   uint8_t discov_status;    // Discovery Status
   uint8_t true_naD[2];      // Network Address the packet has been really sent to
   uint8_t retries;          // Retries needed to send the packet
```

- **macDL & macDH**
  64-bit destination address. It is used to specify the MAC address of the destination node. It is used in 64-bit unicast transmissions.

- **mode**
  Transmission mode chosen to transmit that packet. Available values:
  - 0: Unicast transmission
  - 1: Broadcast transmission
  - 2: Application binding transmission, using clusters and endpoints(Not used in this protocol)
  - 3: Synchronization packet

- **address_type**
  Address type chosen, between 16-bit and 64-bit addresses.

  - 0: 16-bit address
  - 1: 64-bit address

- **naD**
  16-bit Destination Network Address. It is used in 16-bit unicast transmissions.

- **data**
  Data to send in the packet. It is used to store the data to send in unicast or broadcast transmissions to other nodes.

  All the data to send must be stored in this field. The API function responsible for sending data will take care of fragmenting the packet if it exceeds the maximum payload.

  Its max size is defined by 'MAX_DATA', a constant defined in API libraries.

- **data_length**
  Data really sent in the packet. Due to 'data' field is an array of max defined size, each packet could have a different size.

- **frag_length**
  Fragment data length. It is used by the API function responsible for sending data in the internal process of fragmenting packets.

- **SD**
  Not used in DigiMesh.

- **DE**
  Not used in DigiMesh.

- **CID**
  Not used in DigiMesh.

- **PID**
  Not used in DigiMesh.

- **MY_known**
  Not used in DigiMesh.

- **opt**
  Options for the transmitted packet. Options available in DigiMesh are:

  0x08: Enables Multicast transmission.

- **packetID**
  ID used in the application level to identify the packet. It is filled by the transmitter and it is used by the receiver to manage the received packet and the pending fragments.

- **macSL & macSH**
  64-bit Source MAC Address. It is filled by the receiver, and it specifies the address of the node which has delivered the message. It is useful in multi-hops networks to know which node has delivered the message.

- **naS**
  16-bit Source Network Address. It is filled by the receiver, and it specifies the address of the node which has delivered the message. It is useful in multi-hops networks to know which node has delivered the message.

- **macOL & macOH**
  64-bit Origin MAC Address. It is filled by the receiver, and it specifies the address of the node which has sent originally the packet. It is useful in multi-hops networks to know which node has created and sent the message.

- **naO**
  16-bit Origin Network Address. It is filled by the receiver, and it specifies the address of the node which has sent originally the packet. It is useful in multi-hops networks to know which node has created and sent the message.

- **niO**
  Origin Node Identifier. It is filled by the receiver, and it specifies the node identifier of the node which has sent originally the packet. It is useful in multi-hops networks to know which node has created and sent the message.
- **RSSI**
  Received Signal Strength Indicator. It specifies in dBm the RSSI of the last received packet via RF. In a fragmented packet, it contains the average of all received fragments RSSI.
- **address_typeS**
  Address type used to send the packet by the transmitter.
  - 0: 16-bit transmission
  - 1: 64-bit transmission
- **typeSourceID**
  Source ID type used to send the packet. It is filled by the transmitter and it specifies the ID at application level.
  - 0: 16-bit Network Address ID
  - 1: 64-bit MAC Address ID
  - 2: Node Identifier ID
- **numFragment**
  Number of the fragment indicating the position in the fragmented packet to order them at receiver.
- **endFragment**
  Specifies if the sent fragment is the last fragment of a packet. It is filled by the transmitter.
- **time**
  Specifies the time when the first fragment was received.
- **deliv_status**
  Delivery status returned when transmitting a packet. It specifies the success or failure reason of the last packet sent:
  - 0x00: Success
  - 0x02: CCA failure
  - 0x15: Invalid Destination Endpoint
  - 0x21: Network ACK failure
  - 0x22: Not Joined to the Network
  - 0x23: Self-addressed
  - 0x24: Address not found
  - 0x25: Route not found
- **discov_status**
  Discovery stats returned when transmitting a packet. It specifies the processes executed to find the destination node:
  - 0x00: No Discovery Overhead
  - 0x01: Address Discovery
  - 0x02: Route Discovery
  - 0x03: Address and Route Discovery
- **true_naD**
  16-bit Network Address the packet was delivered to (if success). If not success, this address matches the 16-bit address given in the transmission packet.
- **retries**
  The number of application transmission retries that took place.

4.2. Maximum payloads

Depending on the way of transmission, a maximum data payload is defined:

	Unicast	**Broadcast**
Encrypted	73Bytes	73Bytes
Un-Encrypted	73Bytes	73Bytes

Figure 4.1: Maximum Payloads Size

5. Power Gain and Sensibility

When configuring a node and a network, one important parameter is related with power gain and sensibility.

5.1. Power Level

Power level(dBm) at which the RF module transmits conducted power.

This command is only valid using XBee 802.15.4, not in XBee 900MHz. XBee 802.15.4 are divided in Normal model and PRO model. Its possible values are:

Parameter	XBee	XBee-PRO	XBee-PRO International
0	-10dBm	10dBm	PL=4 : 10dBm
1	-6dBm	12dBm	PL=3 : 8dBm
2	-4dBm	14dBm	PL=2 : 2dBm
3	-2dBm	16dBm	PL=1 : -3dBm
4	0dBm	18dBm	PL=0 : -3dBm

Figure 5.1: Power Output Level on XBee Series I module

NOTE: dBm is a standard unit to measure power level taking as reference a 1mW signal.

Values expressed in dBm can be easily converted to mW using the next formula:

mW = 10^(value dBm/10)

Graphics about transmission power are exposed next:

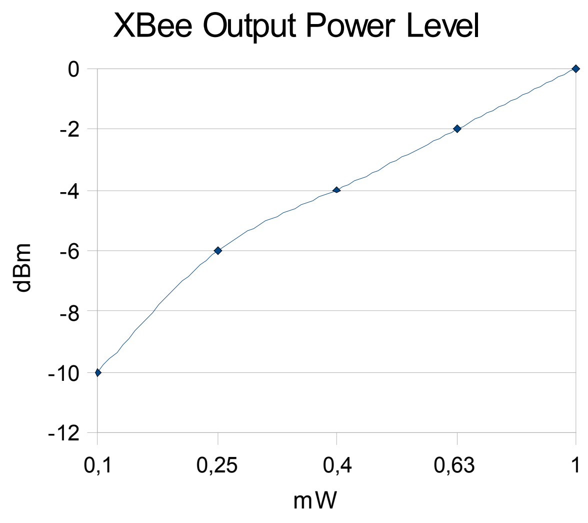

Figure 5.2: XBee Output Power Level

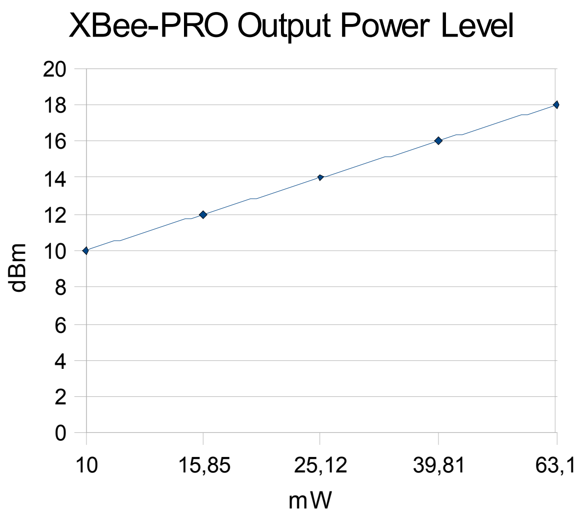

Figure 5.3: XBee-PRO Output Power Level

Example of use

```
{
  xbeeDM.setPowerLevel(0); // Set Power Output Level to the minimum value
  xbeeDM.getPowerLevel(); // Get Power Output Level
}
```

Related Variables

xbeeDM.powerLevel → stores the power output level selected

5.2. Received Signal Strength Indicator

It reports the Received Signal Strength of the last received RF data packet. It only indicates the signal strength of the last hop, so it does not provide an accurate quality measurement of a multihop link.

Example of use:

```
{
  xbeeDM.getRSSI(); // Get the Receive Signal Strength Indicator
}
```

Related Variables

xbeeDM.valueRSSI→ stores the RSSI of the last received packet

The ideal working mode is getting maximum coverage with the minimum power level. Thereby, a compromise between power level and coverage appears. Each application scenario will need some tests to find the best combination of both parameters.

6. Connectivity

6.1. Topologies

DigiMesh provides different topologies to create a network:

- **Peer-to-Peer (p2p)**: networks can form arbitrary patterns of connections, and their extension is only limited by the distance between each pair of nodes.

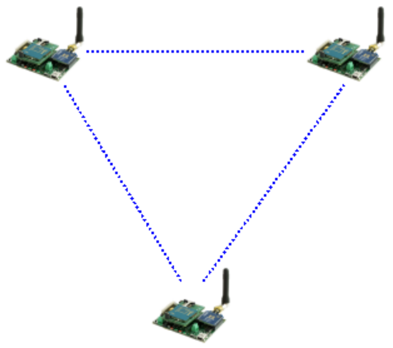

Figure 6.1: Peer-to-Peer Topology

- **Mesh**: all the nodes are connected among them. DigiMesh provides a Network Layer to route packets among nodes out of sight.

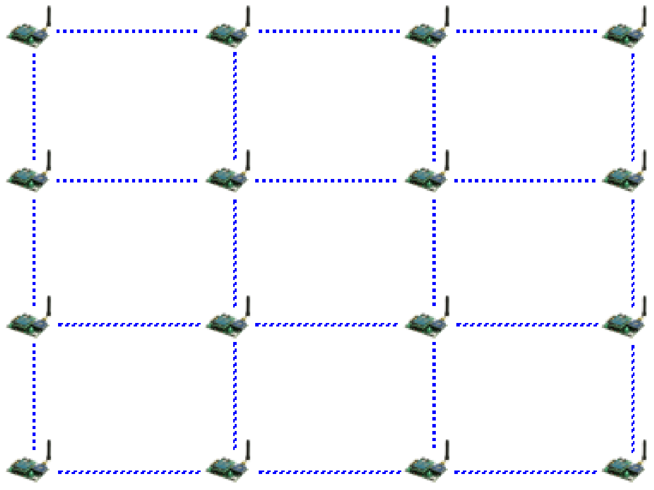

Figure 6.2: Mesh Topology

6.2. DigiMesh Architecture

Mesh networking allows messages routing through several different nodes to a final destination. In the event that one RF connection between nodes is lost (due to power-loss, environmental obstructions, etc.) critical data can still reach its destination due to the mesh networking capabilities embedded inside the modules.

DigiMesh contains the following features

- **Self-healing**: any node may enter or leave the network at any time without causing the network as a whole to fail.
- **Peer-to-peer architecture**: no hierarchy and no parent-child relationships are needed.
- **Quiet Protocol**: routing overhead will be reduced by using a reactive protocol similar to AODV.
- **Route Discovery**: rather than maintaining a network map, routes will be discovered and created only when needed.
- **Selective acknowledgments**: only the destination node will reply to route requests.
- **Reliable delivery**: reliable delivery of data is accomplished by means of acknowledgements.
- **Sleep Modes**: low power sleep modes with synchronized wake up are supported, with variable sleep and wake up times.

6.2.1. Routing

A module within a mesh network is able to determine reliable routes using a routing algorithm and table. The routing algorithm uses a reactive method derived from AODV (Ad-hoc On-demand Distance Vector). An associative routing table is used to map a destination node address with its next hop. By sending a message to the next hop address, either the message will reach its destination or be forwarded to an intermediate node which will route the message on to its destination. A message with a Broadcast address is broadcast to all neighbors. All receiving neighbors will rebroadcast the message and eventually the message will reach all corners of the network. Packet tracking prevents a node from resending a broadcast message twice.

6.2.2. Route Discovery Process

If the source node doesn't have a route to the requested destination, the packet is queued to await a route discovery (RD) process. This process is also used when a route fails. A route fails when the source node uses up its network retries without ever receiving an ACK. This results in the source node initiating RD.

RD begins by the source node broadcasting a route request (RREQ). Any node that receives the RREQ that is not the ultimate destination is called an intermediate node. Intermediate nodes may either drop or forward an RREQ, depending on whether the new RREQ has a better route back to the source node. If so, information from the RREQ is saved and the RREQ is updated and broadcast. When the ultimate destination receives the RREQ, it unicasts a route reply (RREP) back to the source node along the path of the RREQ. This is done regardless of route quality and regardless of how many times an RREQ has been seen before.

This allows the source node to receive multiple route replies. The source node selects the route with the best round trip route quality, which it will use for the queued packet and for subsequent packets with the same destination address.

6.3. Connections

Every RF data packet sent over-the-air contains a Source Address and Destination Address field in its header. DigiMesh supports long 64-bit addresses. A unique 64-bit IEEE source address is assigned at the factory and can be read with the functions explained in chapter 2.

DigiMesh supports Unicast and Broadcast transmission.

6.3.1. Unicast

When transmitting in Unicast communications, reliable delivery of data is accomplished using retries and acknowledgements. The number of retries is determined by the Network Retries (NR) parameter (explained in chapter 3). RF data packets are sent up to NR + 1 times and ACKs (acknowledgements) are transmitted by the receiving node upon receipt. If a network ACK is not received within the time it would take for a packet to traverse the network twice, a retransmission occurs.

6.3.2. Broadcast

Broadcast transmissions will be received and repeated by all nodes in the network. Because ACKs are not used the originating node will send the broadcast four times. Essentially the extra transmissions become automatic retries without acknowledgments. This will result in all nodes repeating the transmission four times as well. In order to avoid RF packet collisions, a random delay is inserted before each node relays the broadcast message. This time is specified by Network Delay Slots, explained in chapter 3.

6.4. Sending Data

Sending data is a complex process which needs some special structures and functions to carry out. Due to the limit on maximum payloads (see chapter 3) it is usual the packet fragmentation, so an application header has been created to deal with this process. This application header is sent inside RF Data, following the API Frame Structure.

6.4.1. API Frame Structure

The structure used to transmit packets via RF is specified by the used modules. The application header has been added to that defined structured as shown below:

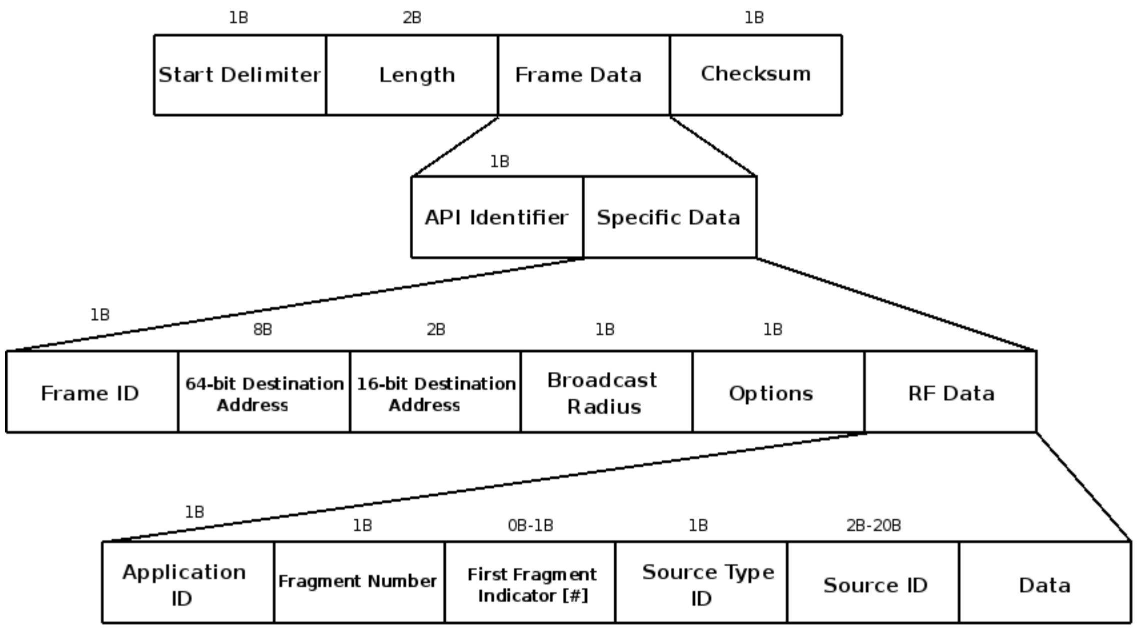

Figure 6.3: 64-bit API Frame Structure

6.4.2. Application Header

This application header is filled by the transmitter (internal Waspmote operation) and it is used by the receiver to treat the packet or fragment. It is sent in data field, so the maximum payload is reduced in a variable length (depending on the source ID type chosen).

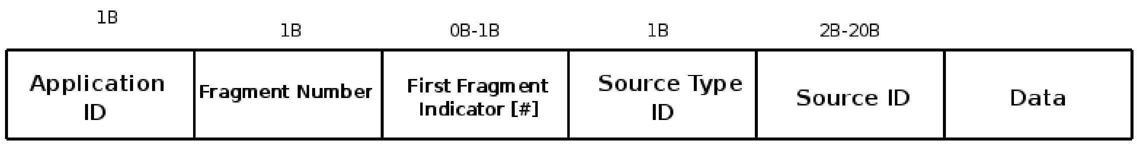

Figure 6.4: Data field in an API frame

To add some application level features to the receiver, some fields have been added like ID or Source ID. Source ID identifies the origin node which created the packet. It is useful in multi-hops networks, to identify the origin node to answer. To identify this node, three ID can be chosen:

- MAC Address: 64-bit MAC Source Address
- Network Address: 16-bit Network Address
- Node Identifier: 20-byte max string NI

The different fields of this header and its structure inside the data field used in an API frame is represented in figure 6.4.

- ID: specifies the ID at application level. It allows to identify the packet among various packets in the receiver.
- Frag Num: specifies the position of the fragment in its packet. The first fragment shows the total number of fragments of the packet.
- [#]: optional field that is included in the first fragment to indicate it is the first fragment.
- Source Type: specifies the source ID type chosen. The possibilities are MAC, 16-bit or NI.
- Source ID: specifies the source ID of the origin node. It is related with the previous field.
- Data: stores the data sent in each fragment or packet.

6.4.3. Fragmentation

When the data length of a packet exceeds the maximum payload, the packet has to be fragmented to reach the destination. If the packet is not fragmented, the module will discard it without even transmitting the packet.

NOTE: Due to restricted memory in Waspmote, the maximum recommended data in a packet is **1500 Bytes (to be fragmented).**

6.4.4. Structure packetXBee

It is the structure used for the packet to send. It was explained in chapter 3.

The process to send a packet is explained next:

1. A structure 'packetXBee' is created to contain the packet to send.
2. That structure is filled with the correct data into the corresponding fields.
3. The API function responsible of sending data is called, using the previously created structure as the input.

The API function takes care of the rest of the process, returning the process successful or failure.

6.4.5. Sending without API header

There is a function to send raw data without the API header. This mode has been designed to send simple data to a gateway when the API features are not necessary.

Broadcast and Unicast transmissions are supported, as well as encryption.

6.4.6. Examples

To simplify the examples and make them easy to read, there are some lines doesn't work exactly in C/C++

- **Sending a packet of 50 bytes without API header.**

```
{
 char* data;
        for(int c=0;c<50;c++) // Set the data
        {
               data[c]='A';
        }
 xbeeDM.send("0013A2004030F66A",data);
}
```

- **Sending a packet of 50 bytes. Unicast 64-bit Mode. 16-bit NA Source ID.**

```
{
 packetXBee* paq_sent; // create packet to send
 char* data;
 paq_sent->mode=UNICAST; // set Unicast mode
 paq_sent->packetID=0x52; // set ID application level
 paq_sent->opt=0x00; // set options. No option selected.
        for(int c=0;c<50;c++) // Set the data
        {
               data[c]='A';
        }
 xbeeDM.setOriginParams(paq_sent, "1221", MY_TYPE); // sets Origin Parameters
 xbeeDM.setDestinationParams(paq_sent, "0013A2004030F686", data, MAC_TYPE, DATA_ABSOLUTE);
        state=xbeeDM.sendXBee(paq_sent); // Call function responsible to send data
}
```

The data field in the API frame generated by the function 'sendXBee' will be:

Application ID	Fragment Number	First Fragment Indicator [#]	Source Type ID	Source ID	Data
0x52	1	#	0	0x12 0x21	A A A ... A A (50 Bytes)

Figure 6.5: API Application Header

- **Sending a 50-bytes packet. Unicast 64-bit Mode. 64-bit MAC Source ID.**

```
{
  packetXBee* paq_sent; // create packet to send
  char* data;
  paq_sent->mode=UNICAST; // set Unicast mode
        paq_sent->packetID=0x52; // set ID application level
  paq_sent->opt=0x00; // set options. No option selected.
        for(int c=0;c<50;c++) // Set the data
        {
               data[c]='A';
        }
  xbeeDM.setOriginParams(paq_sent, "0013A2004030F66A", MAC_TYPE);
  xbeeDM.setDestinationParams(paq_sent, "0013A2004030F686", data, MAC_TYPE, DATA_ABSOLUTE);
        state=xbeeDM.sendXBee(paq_sent); // Call function responsible to send data
}
```

The data field in the API frame generated by the function 'sendXBee' will be:

Application ID	Fragment Number	First Fragment Indicator [#]	Source Type ID	Source ID	Data
0x52	1	#	2	forrestNode-01	A A A ... A A (50 Bytes)

Figure 6.6: API Application Header

- **Sending a 50-bytes packet. Broadcast Mode. Node Identifier Source ID Type.**

```
{
  packetXBee* paq_sent; // create packet to send
  char* data;
  paq_sent->mode=BROADCAST; // set Broadcast mode
        paq_sent->packetID=0x52; // set ID application level
  paq_sent->opt=0x00; // set options. No option selected.
        for(int c=0;c<50;c++) // Set the data
        {
               data[c]='A';
        }
  xbeeDM.setOriginParams(paq_sent, "forrestNode-01", NI_TYPE);
  xbeeDM.setDestinationParams(paq_sent, "000000000000FFFF", data, MAC_TYPE, DATA_ABSOLUTE);
        state=xbeeDM.sendXBee(paq_sent); // Call function responsible to send data
}
```

The data field in the API frame generated by the function 'sendXBee' will be:

Application ID	Fragment Number	First Fragment Indicator [#]	Source Type ID	Source ID	Data
0x52	1	#	1	0x00 0x13 0xA2 0x00 0x40 0x30 0xF6 0x86	A A A ... A A (50 Bytes)

Figure 6.7: API Application Header

- **Sending a 200-bytes packet. Unicast 64-bit Mode. 16-bit Source ID Type.**

```
{
  packetXBee* paq_sent; // create packet to send
  char* data;
```

```
        paq_sent->mode=UNICAST; // set Broadcast mode
                paq_sent->packetID=0x52; // set ID application level
        paq_sent->opt=0x00; // set options. No option selected.
                for(int c=0;c<200;c++) // Set the data
                {
                         data[c]='A';
                }
        xbeeDM.setOriginParams(paq_sent, "1221", MY_TYPE);
        xbeeDM.setDestinationParams(paq_sent, "0013A2004030F686", data, MAC_TYPE, DATA_ABSOLUTE);
                state=xbeeDM.sendXBee(paq_sent); // Call function responsible to send data
      }
```

Due to the amount of data, the packet needs to be fragmented before being sent. The maximum data payload is 73Bytes (see chapter 3) and the application header will occupy a maximum of 6 Bytes (in the first fragment), so there will be three fragments, sending 67Bytes(data) in the first fragment, 68Bytes(data) in the second fragment and 65Bytes(data) in the third fragment.

First Fragment

Application ID	Fragment Number	First Fragment Indicator [#]	Source Type ID	Source ID	Data
0x52	3	#	0	0x12 0x21	A A A ... A A (67 Bytes)

Second Fragment

Application ID	Fragment Number	Source Type ID	Source ID	Data
0x52	2	0	0x12 0x21	A A A ... A A (68 Bytes)

Third Fragment

Application ID	Fragment Number	Source Type ID	Source ID	Data
0x52	1	0	0x12 0x21	A A A ... A A (65 Bytes)

Figure 6.8: API Application Header

6.5. Receiving Data

Receiving data is a complex process which needs some special structures to carry out. These operations are transparent to the API user, so it is going to be explained the necessary information to be able to read properly a received packet.

Before any packet has been received, a multidimensional array of 'matrix' structures pointers, an array of 'index' structures pointers and an array of 'packetXBee' structures pointers are created. The size of these arrays is defined by some constants in compilation time, so it is necessary to adequate its value to each scenario before compile the code:

- MAX_FINISH_PACKETS: max number of finished packets pending of treatment. It specifies the size of the array of finished packets.
- MAX_FRAG_PACKETS: max number of fragments per packet. It specifies the number of columns in the multidimensional array of pending fragments. The number of rows is specified by MAX_FINISH_PACKETS.

When a packet or fragment is received, the algorithm used in reception API function is:

1. Check if the fragment is a new packet or belongs to an existing packet. If it is a new packet, an structure 'index' is created and linked to the array index previously created. The application level information is stored in that structure. If it belongs to an existing packet, it doesn't store any information.
2. Create an structure 'matrix' and link it to the corresponding position in the multidimensional matrix array. The position is calculated basing on the information stored in the 'index' array.
3. Store the data in the corresponding position of the matrix.
4. Check if the packet is complete. If the packet is complete, a 'packetXBee' structure is created and linked to the corresponding position in the array of finished packets. The different fragments are ordered and copied to this structure, as the application level information. The 'index' and row of 'matrix' are released, to free memory. If the packet is not complete, goes to next step.
5. Exit the function.

When a packet is received via RF, the module will send the data via UART, so it is recommended to check periodically if data is available. The API function responsible of reading packets can read more than one fragment, but the XBee module may overflow its buffer, so it is recommended to read packets one by one.

When a packet is completed, it will be stored in a finished packets array called 'packet_finished'. This array should be used by the application to read the received packet. A variable called 'pos' is used to know if there are pending received packets: if 'pos'=0, there is no packet available; if 'pos'>0, there will be as many pending packets as its value (pos=3, 3 pending packets).

6.5.1. Examples

- **Received 50-byes data packet. Unicast. 16-bit NA Source ID Type**

```
{
 state=xbeeDM.treatData(); // Read a packet when XBee has noticed it to us
 if( xbeeDM.pos>0 )
 {
        /* Available info: (there are more available information) */
        network_address[0]=packet_finished[xbeeDM.pos-1]->naS[0];
        network_address[1]=packet_finished[xbeeDM.pos-1]->naS[1];
 }
}
```

Available Information

packet_finished[xbeeDM.pos-1]->naS: stores the 16-bit network address of the sender.

packet_finished[xbeeDM.pos-1]->macSH: stores the 32 upper bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->macSL: stores the 32 lower bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->naO: stores the 16-bit network address of the origin sender.

packet_finished[xbeeDM.pos-1]->mode: stores the transmission mode. Unicast in this case.

packet_finished[xbeeDM.pos-1]->data: stores the data received. Max size 'MAX_DATA'.

packet_finished[xbeeDM.pos-1]->packetID: stores the packet ID of the received message. 0x52 in this case.

packet_finished[xbeeDM.pos-1]->typeSourceID: stores the source type ID used in the message.

After receiving the packet, due to there is only one fragment, it will be completed, so variable 'pos' will be greater than zero. This variable is used to index the array where the received packet is stored. The information that has been stored is indicated in the example.

- **Received 50-bytes data packet. Unicast. 64-bit MAC Address Source ID Type**

```
{
 state=xbeeDM.treatData(); // Read a packet when XBee has noticed it to us
 if( xbeeDM.pos>0 )
 {
        /* Available info: (there are more available information) */
        source_address[0]=packet_finished[xbeeDM.pos-1]->macSH[0];
        ...
        source_address[3]=packet_finished[xbeeDM.pos-1]->macSH[3];
 }
}
```

Available Information

packet_finished[xbeeDM.pos-1]->naS: stores the 16-bit network address of the sender.

packet_finished[xbeeDM.pos-1]->macSH: stores the 32 upper bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->macSL: stores the 32 lower bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->macOH: stores the 32 upper bits of MAC origin sender address.

packet_finished[xbeeDM.pos-1]->macOL: stores the 32 lower bits of MAC origin sender address.

packet_finished[xbeeDM.pos-1]->mode: stores the transmission mode. Unicast in this case.

packet_finished[xbeeDM.pos-1]->data: stores the data received. Max size 'MAX_DATA'.

packet_finished[xbeeDM.pos-1]->packetID: stores the packet ID of the received message. 0x52 in this case.

packet_finished[xbeeDM.pos-1]->typeSourceID: stores the source type ID used in the message.

After receiving the packet, due to there is only one fragment, it will be completed, so variable 'pos' will be greater than zero. This variable is used to index the array where the received packet is stored. The information that has been stored is indicated in the example.

- **Received 50-bytes data packet. Broadcast. Node Identifier Source ID Type**

```
{
 state=xbeeDM.treatData(); // Read a packet when XBee has noticed it to us
 if( xbeeDM.pos>0 )
 {
        /* Available info: (there are more available information) */
        source_address[0]=packet_finished[xbeeDM.pos-1]->macSH[0];
        ...
        source_address[3]=packet_finished[xbeeDM.pos-1]->macSH[3];
 }
}
```

Available Information

packet_finished[xbeeDM .pos-1]->naS: stores the 16-bit network address of the sender.

packet_finished[xbeeDM.pos-1]->macSH: stores the 32 upper bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->macSL: stores the 32 lower bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->niO: stores 20-byte max string used to Node Identifier of the origin sender

packet_finished[xbeeDM.pos-1]->mode: stores the transmission mode. Unicast in this case.

packet_finished[xbeeDM.pos-1]->data: stores the data received. Max size 'MAX_DATA'.

packet_finished[xbeeDM.pos-1]->packetID: stores the packet ID of the received message. 0x52 in this case.

packet_finished[xbeeDM.pos-1]->typeSourceID: stores the source type ID used in the message.

After receiving the packet, due to there is only one fragment, it will be completed, so variable 'pos' will be greater than zero. This variable is used to index the array where the received packet is stored. The information that has been stored is indicated in the example.

- **Received 200-bytes data packet. Unicast. 16-bit NA Source ID Type**

```
{
 state=xbeeDM.treatData(); // Read a packet when XBee has noticed it to us
 if( xbeeDM.pos>0 )
 {
        /* Available info: (there are more available information) */
        network_address[0]=packet_finished[xbeeDM.pos-1]->naS[0];
        network_address[1]=packet_finished[xbeeDM.pos-1]->naS[1];
 }
}
```

Available Information

packet_finished[xbeeDM .pos-1]->naS: stores the 16-bit network address of the sender.

packet_finished[xbeeDM.pos-1]->macSH: stores the 32 upper bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->macSL: stores the 32 lower bits of MAC sender address.

packet_finished[xbeeDM.pos-1]->naO: stores the 16-bit network address of the origin sender.

packet_finished[xbeeDM.pos-1]->mode: stores the transmission mode. Unicast in this case.

packet_finished[xbeeDM.pos-1]->data: stores the data received. Max size 'MAX_DATA'.

packet_finished[xbeeDM.pos-1]->packetID: stores the packet ID of the received message. 0x52 in this case.

packet_finished[xbeeDM.pos-1]->typeSourceID: stores the source type ID used in the message.

After receiving the first packet, due to there are three fragments, it will not be completed, so variable 'pos' will be zero. It is recommended to set a delay in the transmitter so as to the receiver doesn't receive more than one packet at once. When the three fragments have been received, variable 'pos' will change its value and the information in the 'packet_finished' array will be available.

NOTE: Due to memory restrictions, it is recommended when a pending packet is treated and it is not necessary to store it any more, to release this pointer. If don't, memory may overflow and crash the application. It is not possible having in a receiver node more than 1500Bytes. It is referred to a single big packet or many smaller packets in parallel.

6.6. Discovering and Searching Nodes

As explained in chapter 3, an extra Digi header enables some features discovering and searching nodes.

6.6.1. Structure used in Discovery

Discovering nodes is used to discover and report all modules on its current operating channel and PAN ID.

To store the reported information by other nodes, an structure called 'Node' has been created. This structure has the next fields:

```
uint8_t MY[2];      // 16b Network Address
uint8_t SH[4];      // 32b Lower Mac Source
uint8_t SL[4];      // 32b Higher Mac Source
char NI[20];        // Node Identifier
uint8_t PMY[2];     // Parent 16b Network Address
uint8_t DT;         // Device Type: 0=End 1=Router 2=Coord
uint8_t ST;         // Status: Reserved
uint8_t PID[2];     // Profile ID
uint8_t MID[2];     // Manufacturer ID
uint8_t RSSI;       // Receive Signal Strength Indicator
```

- **MY**
  16-bit Network Address of the reported module.
- **SH & SL**
  64-bit MAC Source Address of the reported module.
- **NI**
  Node Identifier of the reported module
- **PMY**
  Parent 16-bit network address. It specifies the 16-bit network address of its parent.
- **DT**
  Device Type. It specifies if the node is a Coordinator, Router or End Device.
- **ST**
  Status. Reserved by DigiMesh.
- **PID**
  Profile ID. Profile ID used to application layer addressing.
- **MID**
  Manufacturer ID. ID set by the manufacturer to identify the module.
- **RSSI**
  Not returned in DigiMesh.

To store the found brothers, an array called 'scannedBrothers' has been created. It is an array of structures 'Node'. To specify the maximum number of found brothers, it is defined a constant called 'MAX_BROTHERS'. It is also defined a variable called 'totalScannedBrothers' that indicates the number of brothers have been discovered. Using this variable as index in the 'scannedBrothers' array, it will be possible to read the information about each node discovered.

Example of use:

```
{
 xbeeDM.scanNetwork(); // Discovery nodes
}
```

Related variables

xbeeDM.totalScannedBrothers → stores the number of brothers have been discovered.

xbeeDM.scannedBrothers → 'Node' structure array that stores in each position the info related to each found node. For example, xbeeDM.scannedBrothers[0].MY should store the 16-bit Network Address of the first found node.

6.6.2. Searching specific nodes

Another possibility for discovering a node is searching for a specific one. This search is based on using the Node Identifier. The NI of the node to discover is used as the input in the API function responsible of this purpose.

Example of use

```
{
 packetXBee* paq_sent;
 xbeeDM.nodeSearch("forrestNode-01",14,paq_sent); // '14' is string length
}
```

Related variables

paq_sent → Stores the 16-bit and 64-bit addresses of the searched. For example

paq_sent->MY[0] & paq_sent->MY[1] → stores the 16-bit NA of the searched node.

6.6.3. Node discovery to a specific node

When executing a Node Discovery all the nodes respond to it. If its Node Identifier is known, a Node Discovery using its NI as an input can be executed.

Example of use

```
{
 xbeeDM.scanNetwork("forrestNode-01"); // Performs a ND to that specific node
}
```

Related variables

xbeeDM.totalScannedBrothers → stores the number of brothers have been discovered. In this case its value will be '1'

xbeeDM.scannedBrothers → Node' structure array that stores in each position the info related to each found node. It will store in the first pos

7. Starting a Network

To create a network only two parameters are necessary: channel and PAN ID. These parameters are the base of a network and we need to be careful choosing them. There are more parameters used to create a network like security parameters, which are not necessary but recommended (see chapter 11).

Two nodes are in the same network if they are using the same channel and PAN ID.

7.1. Choosing a channel

As explained in chapter 3, there are different channels to choose. In XBee Series 1, a random value between '0x0B'-'0x1A' (XBee-PRO values are 0x0C-0x17) should be chosen. However, if XBee 900 is used, a random value between '0x01'-'0x0C' should be chosen. This value will be used as the input parameter in the API function responsible of setting the channel.

Example of use

```
{
  xbeeDM.setChannel(0x0C); // Set channel
}
```

7.2. Choosing a PAN ID

A network must have an unique PAN ID. This PAN ID is a 16-bit number which values are comprised among 0-0xFFFF.

To set a valid PAN ID it is necessary to select a random number and use the API function responsible of setting this parameter. Any value comprised between 0-0xFFFF could be valid, but it should be used only by one network to avoid conflicts between them.

Example of use

```
{
  PANID={0x33,0x31}; // array containing the PAN ID
  xbeeDM.setPAN(PANID); // Set PANID
}
```

NOTE: if two different networks are using the same PAN ID, it doesn't mean there will be interferences between them. Interferences will appear if both networks are transmitting in the same channel. If that happens, it will mean the two different networks will become the same network because both are using same PAN ID and channel frequency.

8. Joining an Existing Network

Joining an existing network process requires some knowledge about the network to join. Three parameters are needed: channel, PAN ID and security (explained in chapter 11).

8.1. Network parameters are known

When these three parameters are known, the process is reduced to set the parameters in the node.

8.1.1. Channel

To set channel, use the API function responsible of that matter.

Example of use

```
{
  xbeeDM.setChannel(0x0C); // Set Channel the network is working on
}
```

8.1.2. PAN ID

To set PAN ID, use the API function responsible of that matter.

Example of use

```
{
  PANID={0x33,0x31}; // array containing PAN ID the network is using
  xbeeDM.setPAN(PANID); // Set PANID
}
```

Once these two parameters are set in the node, it will be part of the network, receiving messages from other nodes.

8.2. Network parameters are unknown

If channel or PANID are not known, it is not possible to join a DigiMesh network. The unique solution if channel is not known is launching ND in all the channels waiting for an answer, selecting the channel where it occurs.

8.3. Node Discovery

Once these parameters have been set, the node is part of the network, so now we can discover other nodes in the network.

Some parameters are involved in a node discovery process.

8.3.1 Node Discovery Function

Performs a node discovery returning the found brothers in the network stored in an array of structures that contain information about the nodes as explained in chapter 6.

Example of use:

```
{
  xbeeDM.scanNetwork(); // Discovery nodes
  if(xbeeDM.totalScannedBrothers>0)
  {
        /* Available info (There are more available information) */
        network_address[0]=scannedBrothers[totalScannedBrothers-1].MY[0];
        network_address[1]=scannedBrothers[totalScannedBrothers-1].MY[1];
  }
}
```

Available Information

scannedBrothers[totalScannedBrothers-1].MY → stores 16-bit NA of each module
scannedBrothers[totalScannedBrothers-1].SH → stores the 32 upper bits of MAC address
scannedBrothers[totalScannedBrothers-1].SL → stores the 32 lower bits of MAC address
scannedBrothers[totalScannedBrothers-1].NI →stores the Node Identifier
scannedBrothers[totalScannedBrothers-1].PMY → stores the 16-bit NA of its parent
scannedBrothers[totalScannedBrothers-1].DT→ stores the device type(C, R or E)
scannedBrothers[totalScannedBrothers-1].ST → stores the status. Reserved by module.
scannedBrothers[totalScannedBrothers-1].MID→ stores the 16-bit manufacturer ID
scannedBrothers[totalScannedBrothers-1].PID → stores the 16-bit Profile ID

8.3.2. Node Discovery Time

It is the amount of time a node will wait for responses from other nodes when performing a ND.

Example of use:

```
{
 uint8_t time[2]={0x19,0x00};// In DigiMesh is only used first array position
 xbeeDM.setScanningTime(time); //  Set Scanning Time in ND
 xbeeDM.getScanningTime(); // Get Scanning Time in ND
}
```

Available Information

xbeeDM.scanTime → stores the time a node will wait for responses.

9. Sleep Options

9.1. Sleep Modes

All the nodes in a DigiMesh network can sleep, entering in a low power consumption mode.

There are several sleep modes characterized as either asynchronous or synchronous. Asynchronous sleeping modes should not be used in a synchronous sleeping network, and vice versa.

9.1.1. Asynchronous Cyclic Sleep

Asynchronous sleep modes can be used to control the sleep state on a module by module basis. Modules operating in an asynchronous sleep mode should not be used to route data.

9.1.2. Synchronous Cyclic Sleep

A node in synchronous cyclic sleep mode sleeps for a programmed time, wakes up in unison with other nodes, exchanges data and synchronization messages, and then returns to sleep. All synchronized cyclic sleep nodes enter and exit a low power state at the same time. This forms a cyclic sleeping network. While asleep, it cannot receive RF messages, neither will it read commands from the UART port.

9.2. Sleep Parameters

There are some parameters involved in setting a node to sleep.

9.2.1. Sleep Mode

Sets the sleep mode for a module. Its available values are:

- 0: Normal Mode. The node will not sleep. Normal mode modules are not compatible with nodes configured for sleep. Excepting the case of adding a new node to a sleep-compatible network, a network should consist of either only normal nodes or only sleep-compatible nodes.
- 1: Asynchronous Pin Sleep Mode: Pin sleep allows the module to sleep and wake according to the state of the Sleep_RQ pin (pin 9). When Sleep_RQ is set high, the module will finish any transmit or receive operations and enter a low-power state. The module will wake from pin sleep when the Sleep_RQ pin is set low.
- 4: Asynchronous cyclic sleep. In this mode, the module periodically sleeps and wakes based on the SP and ST commands.
- 5: Asynchronous cyclic sleep with pin wake-up. In this mode, the module acts in the same way as asynchronous cyclic sleep with the exception that the module will prematurely terminate a sleep period when a falling edge of the SLEEP_RQ line is detected.
- 7: Synchronous Sleep Support Mode. The node will synchronize itself with a sleeping network but will not sleep . They are especially useful when used as preferred sleep coordinator nodes and as aids in adding new nodes to a sleeping network.
- 8: Synchronous Cyclic Sleep Mode. The node sleeps for a programmed time, wakes in unison with other nodes, exchanges data and sync messages, and then returns to sleep.

Example of use:

```
{
  xbeeDM.setSleepMode(8); //  Set Sync Cyclic Sleep Mode
  xbeeDM.getSleepMode(); // Get the Sleep Mode used
}
```

Related Variables

xbeeDM.sleepMode → stores the sleep mode in a module

9.2.2. Sleep Period

It determines how long a node will sleep per period, with a maximum 4 hours. In the parent, it determines how long it will buffer a message for the sleeping device. Time in units of 10ms represented in hexadecimal.

Example of use:

```
{
 uint8_t asleep[3]={0x15,0xF9,0x00};
 xbeeDM.setSleepTime(asleep); //  Set Sleep period to 4 hours
}
```

Related Variables

xbeeDM.sleepTime → stores the sleep period the module will be sleeping

9.2.3. Time Before Sleep

It determines the time a module will be awake waiting before sleeping. It resets each time data is received via RF or serial. Once the timer expires, the device will enter low-power state. Time in units of ms represented in hexadecimal.

Example of use:

```
{
 uint8_t awake[3]={0x36,0xEE,0x80};
 xbeeDM.setAwakeTime(awake); //  Set time the module remains awake: 1hour
}
```

Related Variables

xbeeDM.awakeTime → stores the time the module remains awake

9.2.4. Sleep Options

It configures options for sleeping modes. Possible values are read as a bitmask (Bit 0 and Bit 1 cannot be set at the same time).

For synchronous sleep modules, the following sleep options are defined:

- bit 0: Preferred sleep coordinator. The node always acts as sleep coordinator
- bit 1: Non-sleep coordinator. Node never acts as a sleep coordinator
- bit 2: Enable API sleep status messages
- bit 3: Disable early wake-up for missed synchronizations
- bit 4: Enable node type equality
- bit 5: Disable coordinator rapid synchronization deployment mode. For asynchronous sleep modules, the following sleep options are defined:
- bit 8: Always wake for ST time

Example of use:

```
{
 xbeeDM.setSleepOptions(0x01); //  Set the node to be the preferred sleep coordinator
}
```

Related Variables

xbeeDM.sleepOptions → stores the sleep option chosen

9.2.5. Sleep Status

It queries a number of Boolean values describing the status of the module. Possible values are read as a bitmask:

- Bit 0: If it is true, the network is in its wake state
- Bit 1: If it is true, the node is currently acting as a network sleep coordinator
- Bit 2: If it is true, the node has ever received a valid sync message
- Bit 3: If it is true, the node has received a sync message in the current wake cycle
- Bit 4: If it is true, the user has altered the sleep settings on the module so that the node will nominate itself and send a sync message with the new settings at the beginning of the next wake cycle
- Bit 5: This bit will be true if the user has requested that the node nominate itself as the sleep coordinator (using the commissioning button or the CB2 command).
- bit 6: This bit will be true if the node is currently in deployment mode.
- All other bits: Reserved - All non-documented bits can be any value and should be ignored.

Example of use:

```
{
  xbeeDM.getSleepStatus();
}
```

Related Variables

xbeeDM.sleepStatus → stores the sleep status of the module

9.2.6. Missed synchronizations count

It determines the number of syncs that have been missed. This value can be reset to 0. When the value reaches 0xFFFF it will not be incremented anymore.

Example of use:

```
{
  xbeeDM.getMissedSyncCount();
}
```

Related Variables

xbeeDM.missedSyncs → stores the missed synchronizations

9.2.7. Operational sleep period

It determines the sleep period that the node is currently using. This number will oftentimes be different from the SP parameter if the node has synchronized with a sleeping router network.

Example of use:

```
{
  xbeeDM.getOpSleepPeriod();
}
```

Related Variables

xbeeDM.opSleepPeriod → stores the current sleep period

9.2.8. Operational wake period

It determines the wake period that the node is currently using. This number will oftentimes be different from the ST parameter if the node has synchronized with a sleeping router network.

Example of use:

```
{
  xbeeDM.getOpWakePeriod();
}
```

Related Variables

xbeeDM.opWakePeriod → stores the current wake period

9.3. ON/OFF Modes

In addition to the XBee sleep modes, Waspmote provides the feature of controlling the power state with a digital switch. This means that using one function included in the Waspmote API, any XBee module can be powered up or down (0uA).

Example of use:

```
{
  Xbee.setMode(XBEE_ON); // Powers XBee up
  XBee.setMode(XBEE_OFF); // Powers XBee down
}
```

10. Synchronizing the Network

Sleeping routers under DigiMesh allow to all nodes in the network to synchronize their sleep and wake up times. All synchronized nodes enter and exit into low power state at the same time. This forms a cyclic sleeping network. Nodes synchronize by receiving an special RF packet called 'synch' message which is sent by a sleep coordinator. Any node in the network can become an sleep coordinator through a process called nomination. The sleep coordinator will send one synch message at the beginning of each wake up period. The synch message to broadcast category is repeated by each node in the network, since it belongs.

10.1. Operation

One node in a sleeping network acts as the sleeping coordinator. At the beginning of a wake cycle the sleep coordinator will send a sync message as a broadcast to all nodes in the network. This message contains synchronization information and the wake and sleep times for the current cycle. All cyclic sleep nodes receiving a sync message will remain awake for the wake time and then sleep for the sleep period specified.

10.1.1. Synchronization Messages

Nodes which have not been synchronized or that have lost sync will send messages requesting sync information. Synchronized nodes which receive one of these messages will respond with a synchronization packet.

Deployment mode (set by default) is used by sleep compatible nodes when they are first powered up and the sync message has not been relayed. A sleep coordinator in deployment mode will rapidly send sync messages until it receives a relay of one of those messages. If a node which has exited deployment mode receives a sync message from a sleep coordinator which is in deployment mode, the sync will be rejected and a corrective sync will be sent to the sleep coordinator. Deployment mode can be disabled using the sleep options command (SO).

A sleep coordinator which is not in deployment mode or which has had deployment mode disabled will send a sync message at the beginning of the wake cycle The sleep coordinator will then listen for a neighboring node to relay the sync. If the relay is not heard, the sync coordinator will send the sync one additional time.

10.2. Becoming a Sleep Coordinator

A node can become a sleep coordinator in one of several ways:

10.2.1. Synchronization Messages

A node can be specified to always act as a sleep coordinator. This is done by setting the preferred sleep coordinator bit (bit 0) in the sleep operations parameter (SO) to 1. A node with the sleep coordinator bit set will always send a sync message at the beginning of a wake cycle. For this reason, it is imperative that no more than one node in the network has this bit set. Although it is not necessary to specify a preferred sleep coordinator, it is often useful to select a node for this purpose to improve network performance.

The preferred sleep coordinator bit should be used with caution. The advantages of using the option become weaknesses when used on a node that is not positioned or configured properly.

10.2.2. Nomination and Election

Nomination is the process where a node becomes a sleep coordinator at the start of a sleeping network or in the event a sleep coordinator fails as a replacement. This process is automatic with any sleeping node being eligible to become the sleep coordinator for the network. This process can be managed through 'Sleep Options' by allowing a node to alter the algorithm used for nomination giving the node a greater chance to become the sleep coordinator. This option is designed for maintenance purposes and is not necessary for cyclic sleep operation.

If the node has the preferred sleep coordinator option-enabled ('Sleep Options'=1), then it will poll during its first cycle for a synch message. If it becomes synched by receiving a synch message, it will cycle back to sleep and will not become the sleep coordinator. If it does not become synched during that first cycle, then it will nominate itself as the sleep coordinator and will start sending synch messages at the start of its second cycle.

Any sleeping node, if it does not receive a message for three cycles, may nominate itself to act as a replacement sleep coordinator.

Depending on the platform and other configured options, such a node will eventually nominate itself after a number of cycles without a sync. A nominated node will begin acting as the new network sleep coordinator. If multiple nodes nominate themselves at the same time, then an election will take place to resolve which node will function as network's sleep coordinator. A node will disable synching if it receives a synch message from a senior node. A node running in normal mode (with preferred sleep coordinator option enabled) is senior to any node operating in sleep mode. A node with the largest MAC address value is senior to any other node operating in the same mode.

10.2.3. Changing Sleep Parameters

Any sleep compatible node in the network which does not have the non-sleep coordinator sleep option set can be used to make changes to the network's sleep and wake times. If a node's SP and/or ST are changed to values different from those that the network is using, that node will become the sleep coordinator. That node will begin sending sync messages with the new sleep parameters at the beginning of the next wake cycle.

10.3. Configuration

10.3.1. Starting a Sleeping Network

By default, all new nodes operate in normal (non-sleep) mode. To start a sleeping network, follow these steps:

1. Enable the preferred sleep coordinator option on one of the nodes, and set its SM to a sleep compatible mode (7 or 8) with its SP and ST set to a quick cycle time.
2. Next, power on the new nodes within range of the sleep coordinator. The nodes will quickly receive a sync message and synchronize themselves to the short cycle SP and ST.
3. Configure the new nodes in their desired sleep mode as cyclic sleeping nodes (SM8) or sleep support nodes (SM7).
4. Set the SP and ST values on the sleep coordinator to the desired values for the deployed network.
5. Wait a cycle for the sleeping nodes to sync themselves to the new SP and ST values.
6. Disable the preferred sleep coordinator option bit on the sleep coordinator (unless a preferred sleep coordinator is desired).
7. Deploy the nodes to their positions.

10.3.2. Adding a New Node to an Existing Network

To add a new node to the network, the node must receive a sync message from a node already in the network. On power-up, an unsynchronized sleep compatible node will periodically send a broadcast requesting a sync message and then sleep for its SP period. Any node in the network that receives this message will respond with a sync. Because the network can be asleep for extended periods of time, and as such cannot respond to requests for sync messages, there are methods that can be used to sync a new node while the network is asleep. e.g. Power the new node on within range of a sleep support node. Sleep support nodes are always awake and will be able to respond to sync requests promptly.

10.3.3. Changing Sleep Parameters

Changes to the sleep and wake cycle of the network can be made by changing the SP and/or ST of the sleep coordinator. If the sleep coordinator is not known, any node that does not have the non-sleep coordinator sleep option bit set, can be used. When changes are made to a node's sleep parameters, that node will become the network's sleep coordinator (unless it has the non-sleep coordinator option selected) and will send a sync message with the new sleep settings to the entire network at the beginning of the next wake cycle. The network will immediately begin using the new sleep parameters after this sync is sent.

Changing sleep parameters increases the chances that nodes will lose sync. If a node does not receive the sync message with the new sleep settings, it will continue to operate on its old settings. To minimize the risk of a node losing sync and to facilitate the resyncing of a node that does lose sync, the following precautions can be taken:

1. Whenever possible, avoid changing sleep parameters.
2. Enable the missed sync early wake up sleep option (SO). This command is used to tell a node to wake up progressively earlier based on the number of cycles it has gone without receiving a sync. This will increase the probability that the unsynced

node will be awake when the network wakes up and sends the sync message. Note: using this sleep option increases reliability but may decrease battery life.

3. When changing between two sets of sleep settings, choose settings so that the wake periods of the two sleep settings will happen at the same time. In other words, try to satisfy the following equation: (SP1 + ST1) = N * (SP2 + ST2), where SP1/ST1 and SP2/ST2 are the desired sleep settings and N is an integer.

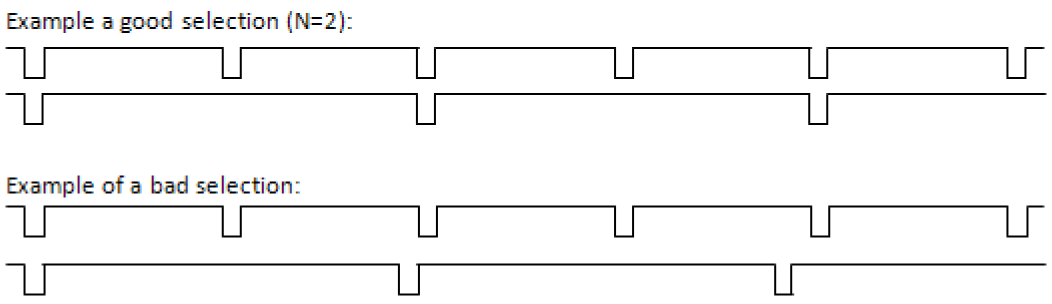

Figure 10.1: Sleep setting examples

10.3.4. Rejoining Nodes Which Have Lost Sync

It is recommended to build the network with redundant mesh nodes to increase robustness. If a scenario exists such that the only route connecting a subnet to the rest of the network depends on a single node and that node fails, then multiple subnets may arise while using the same wake/sleep intervals. When this occurs the first task is to repair, replace, and strengthen the weak link with new and/or redundant modules to fix the problem and prevent it from occurring in the future. Subnets can drift out of phase with each other if the network is configured in one of the following ways:

- If multiple modules in the network have had the non-sleep coordinator sleep option bit disabled and are thus eligible to be nominated as a sleep coordinator.
- If the modules in the network are not using the auto early wake-up sleep option.

If a network has multiple subnets that have drifted out of phase with each other, get the subnets back in phase with the following steps:

1. Place a sleep support node in range of both subnets.
2. Select a node in the subnet that you want the other subnet to sync up with. Use this node to slightly change the sleep cycle settings of the network (increment ST, for example).
3. Wait for the subnet's next wake cycle. During this cycle, the node selected to change the sleep cycle parameters will send the new settings to the entire subnet it is in range of, including the sleep support node which is in range of the other subnet.
4. Wait for the out-of-sync subnet to wake up and send a sync. When the sleep support node receives this sync, it will reject it and send a sync to the subnet with the new sleep settings.
5. The subnets will now be in sync. The sleep support node can be removed. If desired, the sleep cycle settings can be changed back to what they were.

In the case that only a few nodes need to be replaced, this method can also be used:

1. Reset the out-of-sync node and set its sleep mode to cyclic sleep. Set it up to have a short sleep cycle.
2. Place the node in range of a sleep support node or wake a sleeping node with the commissioning button.
3. The out-of-sync node will receive a sync from the node which is synchronized to the network and sync to the network sleep settings.

11. Security and Data Encryption

11.1. DigiMesh Security and Data encryption Overview

The encryption algorithm used in DigiMesh is AES (Advanced Encryption Standard) with a 128b key length (16 Bytes). The AES algorithm is not only used to encrypt the information but to validate the data which is sent. This concept is called **Data Integrity** and it is achieved using a Message Integrity Code (MIC) also named as Message Authentication Code (MAC) which is appended to the message. This code ensures integrity of the MAC header and payload data attached.

It is created encrypting parts of the IEEE MAC frame using the Key of the network, so if we receive a message from a non trusted node we will see that the MAC generated for the sent message does not correspond to the one what would be generated using the message with the current secret Key, so we can discard this message. The MAC can have different sizes: 32, 64, 128 bits, however it is always created using the 128b AES algorithm. Its size is just the bits length which is attached to each frame. The more large the more secure (although less payload the message can take). **Data Security** is performed encrypting the data payload field with the 128b Key.

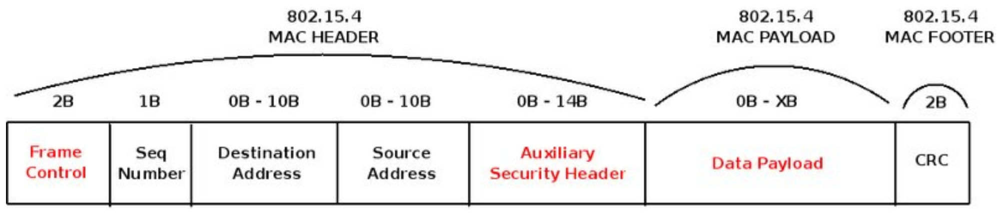

Figure 11.1: IEEE 802.15.4 Frame

11.2. Security in API libraries

As explained previously, DigiMesh provides secure communications inside a network using 128-bit AES encryption. The API functions enable using security and data encryption.

11.2.1. Encryption Enable

Enables the 128-bit AES encryption in the modules.

Example of use:

```
{
  xbeeDM.encryptionMode(1); //  Enable encryption mode
}
```

Related Variables

xbeeDM.encryptMode → stores if security is enabled or not

The mode used to encrypt the information is AES-CTR. In this mode all the data is encrypted using the defined 128b key and the AES algorithm. The Frame Counter sets the unique message ID ,and the Key Counter (Key Control subfield) is used by the application layer if the Frame Counter max value is reached.

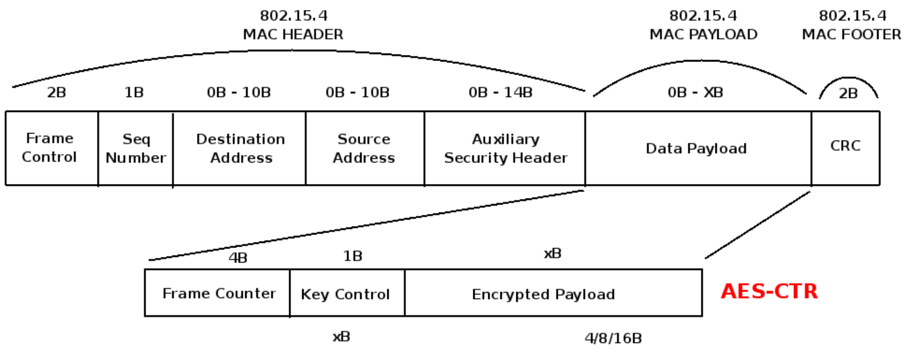

Figure 11.2: AES-CTR Encryption Frame

11.2.2. Encryption Key

128-bit AES encryption key used to encrypt/decrypt data.

The entire payload of the packet is encrypted using the key and the CRC is computed across the ciphertext. When encryption is enabled, each packet carries an additional 16 Bytes to convey the random CBC Initialization Vector (IV) to the receivers.

A module with the wrong key (or no key) will receive encrypted data, but the data driven out the serial port will be meaningless. A module with a key and encryption enabled will receive data sent from a module without a key and the correct unencrypted data output will be sent out the serial port.

Example of use

```
{
  char* KEY="WaspmoteLinkKey!"
  xbeeDM.setLinkKey(KEY); // Set Encryption Key
}
```

Related Variables

xbeeDM.linkKey → stores the key that has been set in the network

11.2.3. Maximum Data Payloads

As explained in chapter 3, maximum data payloads are not changed when using cyphering.

	Unicast	**Broadcast**
Encrypted	73Bytes	73Bytes
Un-Encrypted	73Bytes	73Bytes

Figure 11.3: Maximum Payloads

11.3. Security in a network

When creating or joining a network, using security is highly recommended to prevent the network from attacks or intruder nodes.

As explained previously, security prevents a network from being attacked by an stranger node. The node Discovery process will not work without knowing security key.

11.3.1. Creating a network enabling security

When creating a network, as explained in chapter 7, security measures can be set. After choosing PAN ID and channel, to enable security a key should be chosen. This key is a 128-bit AES encryption key that has to be the same in all the nodes of the same network.

Example of use:

```
{
 panid={0x33,0x31};
 xbeeDM.setChannel(0x0C); // Set Channel
 xbeeDM.setPAN(panid); // Set PAN ID
 char* KEY=”WaspmoteLinkKey!”
 xbeeDM.encryptionMode(1); //  Enable encryption mode
 xbeeDM.setLinkKey(KEY); // Set Link Key
}
```

Available Information

```
 xbeeDM.channel → it will store the channel selected
 xbeeDM.PAN_ID → it will store the PAN ID selected
 xbeeDM.encryptMode → it will store if security is enabled
 xbeeDM.linkKey → it will store the selected key
```

11.3.2. Joining a security enabled network

When joining a network with security enabled, PAN ID and channel has to be set in the node, as explained in chapter 8, but security parameters have to be enabled for a full communication. The joining node should know the 128-bit AES encryption key and enable security setting this key.

Example of use:

```
{
 panid={0x33,0x31};
 xbeeDM.setChannel(0x0C); // Set Channel
 xbeeDM.setPAN(panid); // Set PAN ID
 char* KEY=”WaspmoteLinkKey!”;
 xbeeDM.encryptionMode(1); //  Enable encryption mode
 xbeeDM.setLinkKey(KEY); // Set Link Key
}
```

Available Information

```
 xbeeDM.channel → it will store the channel selected
 xbeeDM.PAN_ID → it will store the PAN ID selected
 xbeeDM.encryptMode → it will store if security is enabled
 xbeeDM.linkKey → it will store the selected key
```

12. Code examples and extended information

For more information about the Waspmote hardware platform go to:

http://www.libelium.com/waspmote
http://www.libelium.com/support/waspmote
http://www.libelium.com/development/waspmote