Low Power Mesh Protocol Stack User Guide

1vv0300944 Rev.2 – 2011-10-18

APPLICABILITY TABLE

PRODUCT
NE50-868

SW Version
GC.M0A.03.14

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Contents

1. Introduction

1.1. Scope

Scope of this document is to present the features and the application of the Low Power Mesh embedded firmware, available on the NE-50.

1.2. Audience

This document is intended for developers who are using the NE-50 modules and Low Power Mesh embedded firmware.

1.3. Contact Information, Support

For general contact, technical support, to report documentation errors and to order manuals, contact Telit Technical Support Center (TTSC) at:

TS-EMEA@telit.com
TS-NORTHAMERICA@telit.com
TS-LATINAMERICA@telit.com
TS-APAC@telit.com

Alternatively, use:

http://www.telit.com/en/products/technical-support-center/contact.php

For detailed information about where you can buy the Telit modules or for recommendations on accessories and components visit:

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To register for product news and announcements or for product questions contact Telit Technical Support Center (TTSC).

Our aim is to make this guide as helpful as possible. Keep us informed of your comments and suggestions for improvements.

Telit appreciates feedback from the users of our information.

1.4. Document Organization

This document contains the following chapters:

"Chapter 1: Introduction" provides a scope for this document, target audience, contact and support information, and text conventions.

"Chapter2: NE-50 architecture" gives an overview of the features of the product.

"Chapter 3: Functionalities" describes in details the characteristics of the product.

"Chapter 4: Configuring NE-50 Module" provides some fundamental hints about the module configuration.

"Chapter 5: Network building" provides some suggestion about the best configuration depending on the needs of the user.

"Chapter 6: Flashing" provides a little how to about the module flashing.

"Chapter 7: Low Power mode" provides some explanation about the low power mode and its features.

"Chapter 8: Appendix" Describes differences between "Low Power Mesh" and "M-One" protocols

"Chapter 9: Glossary" provides a complete list of acronyms and abbreviation used in this document.

"Chapter 10: Document History" provides a complete revision list

1.5. Text Conventions

Danger – This information MUST be followed or catastrophic equipment failure or bodily injury may occur.

Caution or Warning – Alerts the user to important points about integrating the module, if these points are not followed, the module and end user equipment may fail or malfunction.

Tip or Information – Provides advice and suggestions that may be useful when integrating the module.

All dates are in ISO 8601 format, i.e. YYYY-MM-DD.

1.6. Related Documents

- [1] EN 300 220-2 v2.3.1, ETSI Standards for SRD , February 2010
- [2] ERC Rec 70-03, ERC Recommendation for SRD, June 2010
- [3] NE50 868 RF Module User Guide, 1vv0300873
- [4] SR Tool User Guide, 1vv0300899

2. NE-50 architecture

A wireless mesh network topology stands for a multihop network where nodes can send and receive messages, and also function as a router to relay messages for its neighbors. Through the relaying process, a packet of wireless data will find its way to its destination, passing through intermediate nodes with reliable communication links.

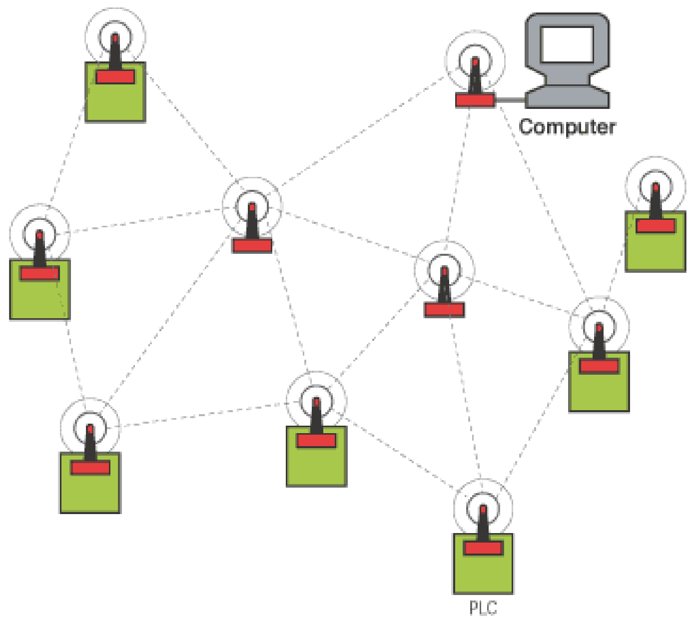

Figure 1 Example of mesh topology

Mesh networking is the ability to use a wireless device as logical repeater to transfer data between two end points without direct radio connection. It is a way to increase reliability and distance of a wireless link.

There are two types of mesh topology, full mesh and partial mesh:

- Full mesh topology occurs when every node has a connection to every other node in the network. Full mesh is very expensive to implement but yields the greatest amount of redundancy, so in the event that one of those nodes fails, network traffic can be directed to any of the other nodes. Full mesh is usually reserved for backbone networks.

Figure 2 Full mesh topology

- Partial mesh topology is less expensive to implement and yields less redundancy than full mesh topology. With partial mesh, some nodes are organized in a full mesh scheme but others are only connected to one or two in the network. Partial mesh topology is commonly found in peripheral networks connected to a full meshed backbone.

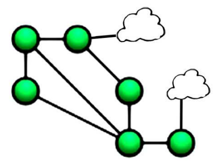

Figure 3 Partial mesh topology

2.1. Target of Telit Low Power Mesh

The target of Low Power Mesh is to fit the common customer applications, while keeping simplicity and cost efficiency.

Low Power Mesh protocol stack is the standard firmware on NE-50 Family [3].

Here are the key characteristics of Low Power Mesh :

- Most of the applications targeted is gathering in information from a central point or controlling devices from a central point. Therefore, a partial mesh is sufficient and cluster tree topology is a natural choice which matches most of the applications.

Low Power Mesh is a partial mesh network based on Cluster Tree topology

- A lot of applications targeted need efficient power management to be battery operated, so that all the network nodes must be low power. It implies a real management of stand-by mode for all the devices, even the router.

Low Power Mesh network is a true low power network

- Furthermore, according to ETSI standards, 868 MHz radio modules have limited baud rate: any dynamic routing protocol would take significant part of the global bandwidth, and would impact bandwidth available for user data. Routing by the natural hierarchical addressing keep the maximum bandwidth for the user application while ensure high reliability. The destination is directly read from the network address of the sending and receiving device.

Low Power Mesh network is based on hierarchical addressing

- To keep maximum efficiency and simplicity in the use of Low Power Mesh, it is important to implement an easy method for network building. It is done by auto acquisition capabilities, which means that each new device can automatically join the network if the ID parameters match.

Low Power Mesh network has auto acquisition capability

- Although Low Power Mesh is a STATIC network topology (i.e. nodes can’t move dynamically in the network), the Low Power Mesh has auto repair capabilities. If a link is lost for any reason, Low Power Mesh detects this trouble and tries others associations to reach normal data transmission.

Low Power Mesh network is static but with auto repair capability

2.2. Basic principles

2.2.1. Network Set Up

The network can be either set up manually according to user preferences or almost automatic for easier and faster configuration.

There are 3 different logical devices:

- The Coordinator is at the top of the tree (Layer 0), it is only able to exchange data with device placed under.
- Routers are present at each middle layers and can exchange data either with upper or lower devices. A Router can be the final recipient of a frame, or can route a frame to another layer.
- EndPoints are placed at each termination of the tree; they can only exchange data with the upper layer.

The setting up of the network can be dynamic:

- Once the network master is up and running, any new device coming up in a reachable distance will attach itself to the root if the network ID and optional security parameters match.
- The same process applies for depth N node becoming root for depth N+1

2.2.2. Communication

Master – leaf communication:
This is the typical use of this functionality, devices are addressed by a unique identifier (serial number), and they dynamically acquire their network address. Since this address is based on a hierarchical structure, the data flow follows the tree structure (see Figure 4).

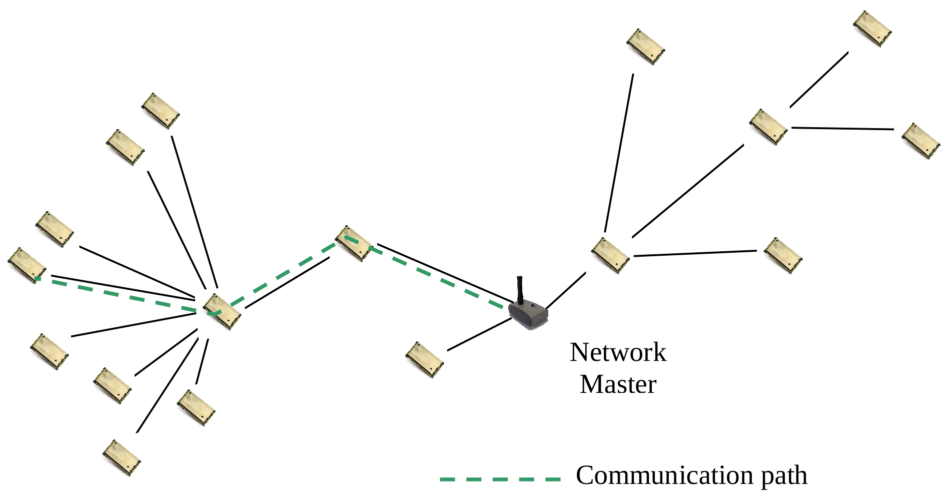

Figure 4 Master to Leaf Communication

Leaf- Leaf Communication:
This is also supported, but should keep in mind that whole traffic goes through the nearest common root node between the two leaves therefore, it is limited to low traffic type applications.

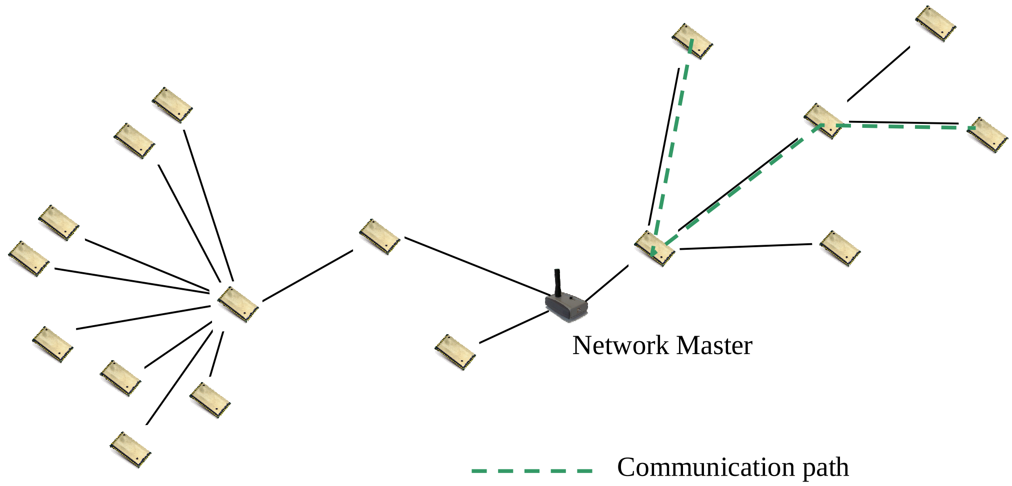

Figure 5 Leaf to Leaf Communication

2.2.3. Maintenance

The maintenance of the network is dynamic:

- Master node failure: it is a critical failure which requires this node to be replaced for the network to function again. Then the whole network sets back automatically.
- Router node failure: all the devices attached to this node reinitialize their network attachment procedure in a transparent way and find another attachment point inside the network.

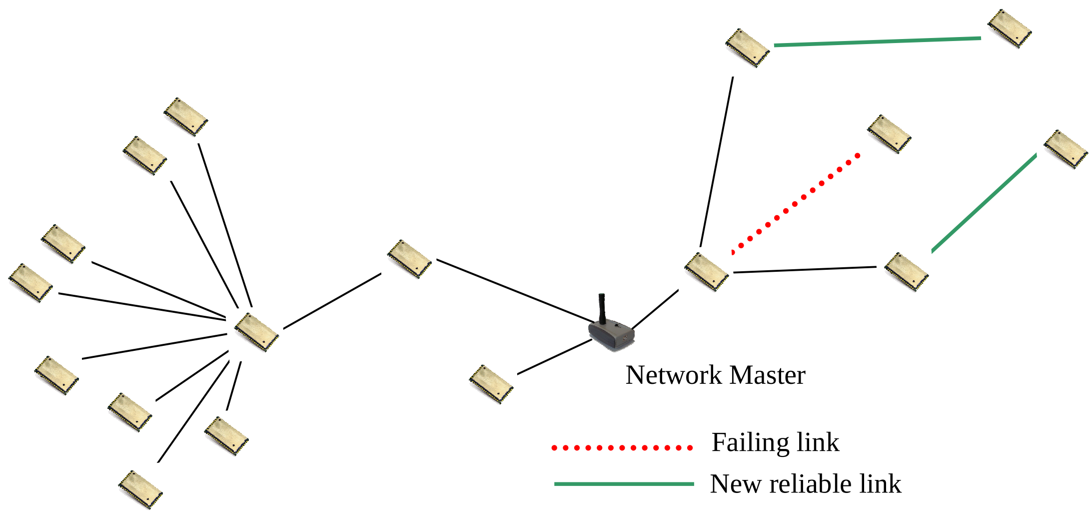

Figure 6 Auto-repaired Logical Configuration

3. Functionalities

3.1. Typical Network Architecture

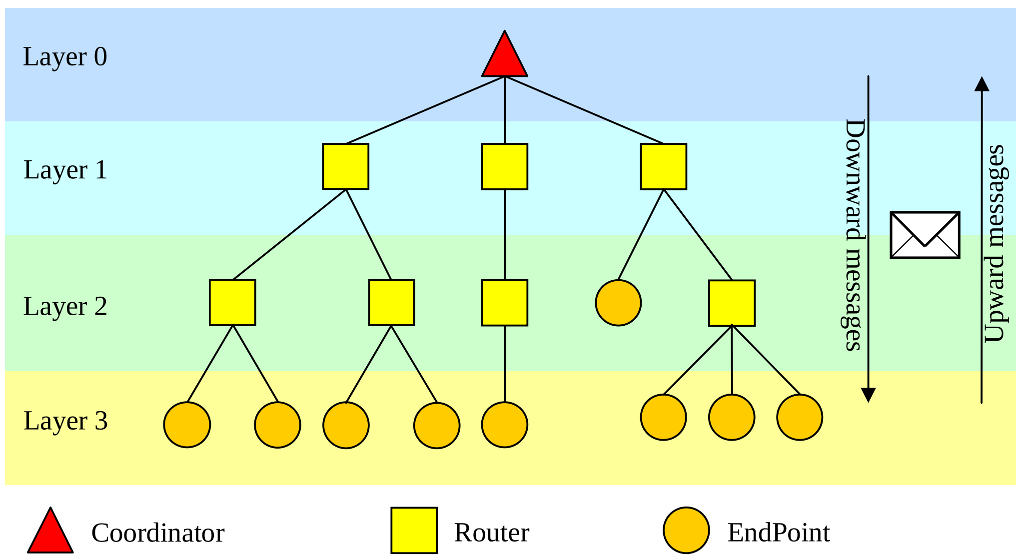

Figure 7 Symbolic tree Organization

3.2. Device Identification

Each device has a stable identifier, it is a 2 bytes device_ID, chosen and entered by the customer when setting its parameters.

3.3. Time Utilization

The timing used in our Low Power Mesh is inspired from ZigBeeTM : it uses beacon and super frame. Because of the slowness of our 868MHz devices (carrier duration, Rx to Tx switching time…), the CSMACA is not systematically used like in ZigBeeTM. This will be detailed in the 'Super frame schedule' paragraph.

Each device has to wake up and to listen to the beacon issued from the upper device; this beacon is waited at a known moment. At this time, start the super frame during which the most exchanges have to be done. At the end of the max super frame duration, the device must enter in sleeping mode. If there are uncompleted exchanges, they are planned for the next beacon. If no exchange is pending for the device at the start of the super frame, it can enter in sleeping mode without waiting the max super frame duration.

The super frame duration and the time between beacons are settings chosen at the installation and available for the entire network.

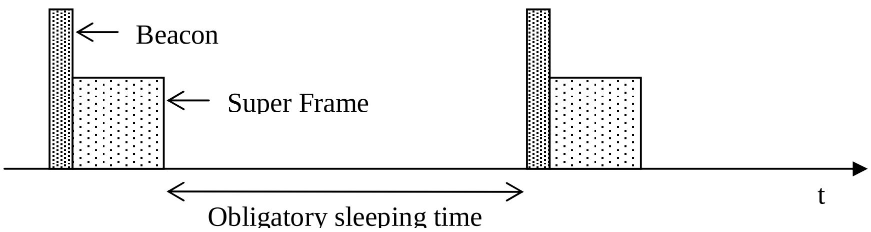

Figure 7 Time Repartition

3.4. Beacon information

The Beacon is sent periodically by an upper device to all lower devices directly associated to it.

The first information carried by the Beacon is the time synchronization. To not miss the beginning of the beacon, lower devices have to wake up a short time before. As the beacon begins, the lower devices synchronize their timers.

The beacon contains network information like Network ID, Super frame max duration, time between beacons etc. It also contains the upper device association capabilities and its deep from coordinator. The network capabilities is the number of new devices could still join the Router. More details will be done in the next parts.

Finally, the beacon gives the list of recipients for which a downward message is pending.

3.5. Super Frame schedule

Super frame time is divided in two parts: the first one is assigned for downward messages while the other one is for upward messages.

The duration of the first part could be null if no downward message is pending. By opposition, it can’t exceed half of the max super frame duration to allow upward message treatment. The downward messages are treated one by one following the list order given in the beacon; each lower device must wait its turn to download their messages.

During the second part, lower devices can upload their messages using CSMACA.

In order to save time, each transmission is always acknowledged immediately using neither CSMACA nor Device_ID. This would not decrease the reliability since the time between transmission and ACK is well known, and since the others devices are listening at least the Rx/Tx switching time before considering a channel is free.

3.6. Routing rules

A Router which has initiated a beacon is the master during the beginning Super Frame. Each Router has in its memory the list of all Device_ID present under it (children list).

When a router receives an upward message with valid CRC, it always acknowledges it and checks the recipient ID:

- If the recipient ID matches its own ID, it treats the frame for himself.
- Else, if the recipient ID matches one of the children list, the frame is buffered to be sent downstream later.
- Else, the frame is buffered to be sent upstream later.

When a router receives a downward message with valid CRC, it first checks the recipient ID:

- If the recipient ID matches its own ID, it acknowledges the message and treats the frame for himself.
- Else, if the recipient ID matches one of the children list, it acknowledges the message and the frame is buffered to be sent downstream later.
- Else, the frame is ignored and no acknowledge is performed.

3.7. Network capabilities

The coordinator doesn't need to have a children list because it is at the top layer. The only limit is fixed by the two byte ID assignation. It is possible to have a coordinator surrounded by 10.000 EndPoints.

For Routers, the limit of children list size is 200 bytes so each router can support 100 children (direct or not). A possible direct children number limitation is to be defined.

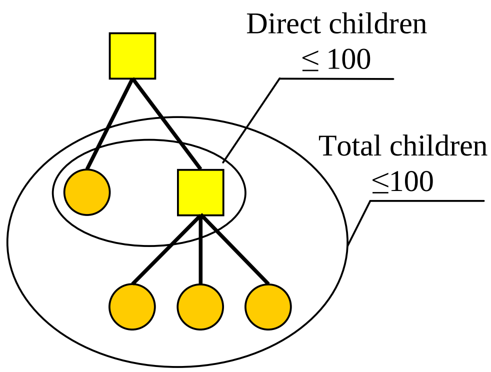

Figure 8 Children limitation

Due to timing precision necessity, there is also a limitation in the depth of the network. There can not be a link with more than 15 hops into the network.

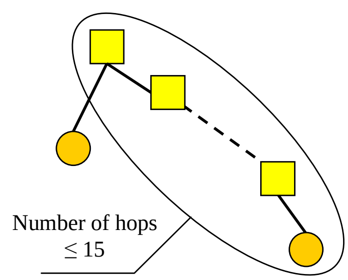

Figure 9 Depth limitation

To conclude on network capabilities, the limitations are:

- Not exceeding a total number of 10.000 devices into the network.
- Not exceeding a total number of 100 children per router.
- The depth limitation of the network is 15.

Those singles limitations allow imagining a lot of various networks from Rangy to Bushy type.

3.8. Auto Association and Auto Repair

As been said above, the Beacon contains the association capabilities and network depth of the Router. When a new device joins the network for the first time, it listens to all beacons and chooses the best Router. A 'good' Router is a device placed in a high layer, with a good RSSI level and which can still accept new children.

When the new device has selected its Router, it sends a frame to join it. Then, the router adds the new device to its children list.

In case of broken node, the top Router of the orphan sub network doesn't inform its children in a first time, it attempts to join a new Router which can accept the total number of devices. In case of success, the list of all sub network devices is given to the new Router reached. If it's impossible to find a Router with enough free space, the top Router of the orphan sub network informs its children to join another router by themselves.

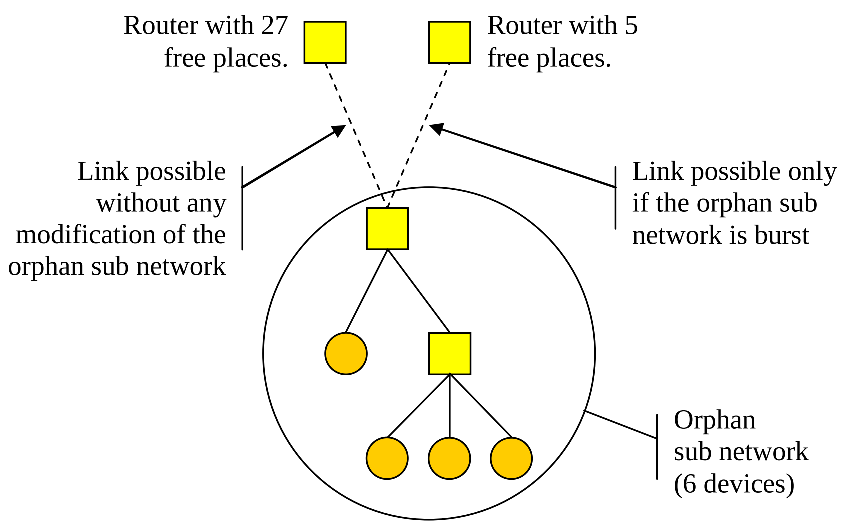

Figure 10 Auto repair

3.9. Low power

We have seen that at the end of the super frame, devices have to enter in sleeping mode. Power can be dramatically saved by setting a very long time between beacons but, of course, the final time to transmit a message through the entire network could take several minutes. By opposition, the speed can be enhanced by increasing the frequency of beacons.

Obviously, Routers are the devices which need the more amount of power because they should wake up twice, one time to receive the upper layer beacon and one to send a beacon to the downer level.

EndPoints can be very low power if the application can accept to wake up only once every n Beacons.

4. Configuring NE-50 Module

4.1. Register description

LEGEND: **R:** **read-only register**
R/W: **writable register**
Default value in bold

WARNING: Modifications in registers S31X, S306, S307 and S330 are taken into account only after an 'ATO' command

Register	Access	Register Name	Possible Values	Description
192	R	Serial Number		Serial Number of the radio module. The answer is only composed by the 11 characters of serial number followed by <CR> Ex: GCAJ4400018<CR>
202	R/W	Radio Output Power	0: -8dBm / 0.16mW 1: -5dBm / 0.32mW 2: -2dBm / 0.64mW 3: +1dBm / 1.25mW 4: +4dBm / 2.5mW 5: +7dBm / 5mW **6: +10dBm / 10mW** 7: +13dBm / 20mW	Indicate the output power of the RF module.
214	R/W	Serial Time Out	From 2 to 100 ms **Default: 5ms**	Serial time out on the Serial Link: Rx IDLE time before considering a frame is finished. It is possible to set this register with value 255 in order to enable the new

				serial protocol; see chapter 4.2.
300	R/W	Association Mode	**0: Auto** 1: Manual	Specifies the association method: ‘Auto’: indicates that the device will first try to associate to the historical parent or to the one specified in ‘Parent ID’. If impossible, the device will choose another parent among the bests available. ‘Manual’: module looks only for the parent specified manually in ‘Parent ID’ register. This register is valid only for Router and Endpoint.
301	R/W	Association Criteria	**0: Deep** 1: High level	If Auto Association is used, this register indicates how the device will choose its parent. Deep means that the device will try to join the network as deep as possible, at branch termination. If High level is chosen, the device will try to join the network in upper layer, as close as possible of the coordinator. This register is valid only for Router and Endpoint.
302	R	Association Status	Bit Position: 0: Configuration Mode 1: Association on going 2: Associated 3: Only reception 4: Parent side Tx 5: Child side Tx 6: Free transmission 7: Sleep or Wait	It is possible know the module association status querying the register 302. This register is read only. The value returned by the command is a bitmask

304	R/W	Number of failed beacon	From 0 to 255 **Default: 2**	Number of consecutive beacon failed (not received correctly) before run the Auto Repair procedure. This function is available only if Auto Repair is activated. This register is valid only for Router and Endpoint.
305	R/W	RSSI Association Level	From 0 to 3 **Default: 0**	Minimum RSSI level required to allow association. Set 0 to allow association even in bad conditions of reception. Set up to 3 to allow association only when beacon parent is strong received. This register is valid only for Router and Endpoint.
306	R/W	Module Type	**0: EndPoint** 1: Router 2: Cordinator	This register allows the user selecting the module behaviour.
307	R/W	Radio Band	0: 868.300 MHz 1: 869 MHz **2: 869.525 MHz**	This register allows the user selecting the radio band
310	R/W	Network ID	From 0 to 255 **Default: 48**	Network identifier. Mesh Lite is monochannel, this register is used when two different applications are running in the same place.
311 (LSB) **312 (MSB)**	R/W	Client ID	0 to 254 **Default: 48** 0 to 255 **Default: 48**	Client identifier. Each device in the network has a unique address specified here. Note that 0 is reserved for broadcast operations. For coordinator, this ID is fixed at 65535 and the registers are read only.
313 (LSB) **314 (MSB)**	R/W	Parent ID	0 to 254 **Default: 255** 0 to 255 **Default: 255**	Mesh Lite is cluster tree architecture, this register Indicate the ID of the parent. If auto association is chosen, this register is read only.

				This register is valid only for Router and Endpoint.
315 (LSB) **316 (MSB)**	R/W	Default Recipient ID	0 to 255 **Default: 48** 0 to 255 **Default: 48**	If no encapsulation is possible on the serial link (for example with a basic automate), all frames are sent to the Default Recipient ID. Reset this register to 48 to disable the functionality.
320 (LSB) **321** **322 (MSB)**	R/W	Network Period	From 0 to 65000ms **Default: 5000 ms**	The Network period is the time between two beacons sent by the coordinator. Each network period begins by synchronous exchanges and network updates. The network period must be greater than the sum of all routers super frame durations (see below). Be careful to be compliant with ETSI Rules, especially the duty cycle. Only entire number seconds are available. This register is accessible only on the coordinator. The value is broadcasted to all other devices. However the value read on other devices is not updated.
323	R/W	Base Time	3: 63 ms **4: 125 ms** 5: 250 ms 6: 500 ms 7: 1000 ms	Mesh Lite is a partial synchronous network. During the first part of the network period, time is organized in slots separated by beacons. This is the synchronous part where each router has a dedicated time slot to exchange data. The remaining part of the network period is asynchronous. During this time, devices can sleep, listen or exchange data at any moment without waiting a specific slot. Mesh protocol need to organize the time in slots.

				This register specifies the elementary bloc of time. Choosing a short Base Time allows to have very low power devices waked up during short time. Long Base Time is used for network where many data are exchanged without low power consideration. This register is accessible only on the coordinator. The value is broadcasted to all other devices. However the value read on other devices is not updated
324	R/W	Super Frame Duration	From **1** to 255	The Super Frame is the synchronous slot attributed to a router; it begins by sending a beacon followed by data exchanged with children. Each router can ask for a personal super frame duration depending of the amount of data planed to route. Choose a small Super Frame duration if the device has just a couple of children exchanging short and rare information. Choose a large duration if many exchanges have to be done during the super frame. Super Frame duration is given in number of Base Time: if super frame duration is set to 8 and Base Time set to 4, the duration will be 8x125ms. This register doesn't exist on EndPoints.
325	R/W	Position	From 0 to 255	The coordinator lists all routers of the network and the Super Frame duration asked by each one. To avoid collision, coordinator attributes a place to each router in the time. The position obtain by a router is readable in

				this register. Write to this register is allowed only on Router. This register doesn’t exist on EndPoints.
330	R/W	Payload	**0: 18 frames – 14 bytes** 1: 12 frames – 46 bytes 2: 6 frames – 110 bytes	Depending of the targeted application, memory buffers can be split either in a couple of large frames or a lot of small frames. The number of frames indicated is the maximum number of frames which can transit by the router at the same time. The default setting is 18 frames of 14 bytes each. This register needs a reboot (ATO) to be taken in account. This register is accessible only on the coordinator. The value is broadcasted to all other devices. However the value read on other devices is not updated.
332	R/W	Acknowledge	0: Disable **1: Enable**	When acknowledgement is enable, an ‘ACK’ frame is sent back to certify correct RF transmission. If the transmitter receives no ‘ACK’ back, it repeats the frame once more. Acknowledgement is made for each RF link into the network, not globally between initial sender and final receiver. This register is accessible only on the coordinator. The value is broadcasted to all other devices. However the value read on other devices is not updated.
333	R/W	Flow Control Threshold	**0: Half buffer** 1: Full buffer	0: the RTS serial flow control goes high when half the buffer is reached to let place for arriving radio frames. 1: the RTS serial flow control goes high only when the whole buffer is

				full. This increases the serial storage capacities but any arriving radio frame is lost if buffer is full.
340	R/W	Low Power Mode	**0: LP Disable** 1: LP Childres side 2: LP Total	Indicates if the device must sleep during asynchronous part of the network period. LP Children Side indicates that the device can exchange with upper level (parent side) but should be low power on children side. This case is very useful to set a network with dynamic (short response time) heart while keeping low consumption satellites (valid only on Coordinator and Routers). LP Total forces the module to sleep completely during the asynchronous part of the network period.
341	R/W	Periodic Wake up	From **1** to 255	In normal operation, devices are waked up at least each network period to receive their parent beacon. To save power, this register allows setting the waking up only once every N network period. This setting is only available on EndPoints. This case is very useful to set a network with very low consumption EndPoints. Nevertheless, it can only be used when no information has to be sent to the device. Only applications where data are sent from EndPoint to the upper level can use this function.

345	R/W	Direction of I/O	**Default: 0** MSB … LSB -, IO9, IO8_AD_DA, IO7_AD_DA, IO6_A, IO5_A, IO4_A, IO3_A 0, 0, 0, 0, 0, 0, 0, 0	Set each pin independently as input or output. 0: Output (it is impossible to set a pin as output if it is configured to rise interrupt on register S346) 1: Input Note: IO9 is not analog inputs capable and it is not able to generate interrupt.
346	R/W	Interrupt Input	**Default: 0** MSB … LSB -, -, IO8_AD_DA, IO7_AD_DA, IO6_A, IO5_A, IO4_A, IO3_A 0, 0, 0, 0, 0, 0, 0, 0	An edge occurring on an interrupt input causes the sending of an I/O status frame to the default recipient. In addition, an edge on these pin is capable to wake up the module if it is in standby mode. 0: Interrupt disable (general I/O) 1: Interrupt enable (pin must be set as input in S345 register). The I/Os 3 and 4 are able to rise an interrupt only in rising edge; the I/Os 5 and 6 are able to rise an interrupt only in falling edge; I/Os 7 and 8 rise an interrupt both in rise and in falling edge.
347	R/W	Automatic Telemetry frame sending	**0: Disable** 1: Digital only 2: Analog only 3: Digital and Analog	Program an automatic sent of inputs values every network period without needing to send telemetry read order before. The frame is sent to the default recipient specified trough S315, S316 registers. You can choose to send digital or analog values or both. If both are programmed (S347=3), the module sends values

				in two distinct frames. Very suitable for low power sensor endpoint: combined with periodical wake up (S341) the inputs values are sent only once each wake up of the endpoint.
350	R	Total number of children	From 0 to 100	In the routers indicates the total number of children directly or indirectly associated to the device. In the coordinator indicates only the total number of children directly associated and the router indirectly associated
351	R	Number of direct children	From 0 to 100	Indicates the number of children directly associated to the device.
400 to 499	R	Child address LSB	From 0 to 255	Here is the list of all children associated to the module. Direct children are listed from 400 to (400+ Number of Direct Children-1) Indirect child are listed from (400+ Number of Direct Children) to (400+ Total Number of Children-1)
500 to 599	R	Child address MSB	From 0 to 255	
600 to 699	R	Type of module	1: N/A 2: Router 3: Endpoint	For each child, the type of module is known by reading this register. Type of Child number (40X, 50X) is readable at the 60X register.
700 to 799	R	Position	From 0 to 255	If the child is a router, the position attributed to it by the coordinator is readable in this register.
800 to 899	R	Super Frame Duration	From 0 to 255	If the child is a router, the super frame duration of this router is readable in this register.

WARNING: Unlike the M-One firmware for Tiny modules, now the registers values are checked and also the accessibility of all register is verified with the exception of registers 320 and 321. Registers 320 and 321 contain the network period in milliseconds. Value accepted are only those whose value divided by 1000 returns an integer. These values are not checked when set.

WARNING: The registers 350, 351, 400-499, 500-599, 600-699, 700-799, 800-899 are available only for Coordinator and Router

The behaviour of registers from 400 to 899 is the following.
We suppose querying a router in order to know the number of direct children and it answers in the following way:
S351=2 → two direct children
S400=69, S500=49, 600=3→ the first children is an EndPoint with client id "E1" (69,49)
S401=82, S501=49, S601=2, S701=3, S801=1 → This is a router with client id "R1" (82,49) with an assigned router position 3 and with a super frame duration equals to 1.

4.2. New serial protocol

The new serial protocol is based on two very important bytes:

- START byte (hex value 0xAB)
- END byte (hex value 0xCD)

These two bytes define a serial frame; each serial frame has to begin with a START byte and finishes with an END byte. Into the serial frame these two bytes have not to be present. In order to avoid this possibility, a bit stuffing algorithm will be used, as explained in the following chapter. For this reason, the STUFF byte (hex value 0xEF) will be used.

Typical serial frame:

| START | byte | byte | byte | byte | byte | byte | byte | … | END |

Each kind of Mesh message (Hayes, Data, etc.) shall be encapsulated using these two bytes.

Example:

Hayes command: mE1ATS300?<CR>

Old serial frame: |0x6D|0x45|0x31|0x41|0x54|0x53|0x33|0x30|0x30|0x3F|0x0D|

New serial frame: |0xAB|0x6D|0x45|0x31|0x41|0x54|0x53|0x33|0x30|0x30|0x3F|0x0D|0xCD|

4.2.1. Bit Stuffing algorithm

The scope of this algorithm is to hide each possible repetition of START and END byte into the data frame.

The algorithm works in the following way:

If the START or END byte is present into the payload, the algorithm adds a special byte (STUFF byte) into the stream before the “critical” byte and then it changes the “critical” byte value adding 1 to the real value.

If the STUFF byte is present into the payload, the algorithm adds a STUFF byte before the “critical” byte but it does not change the value of the “critical” byte.

Example:

Original DATA frame to send: |0x65|0x45|0x31|0x12|0x15|0xAB|0x33|0xEF|0x6F|

After bit stuffing: |0x65|0x45|0x31|0x12|0x15|0xEF|0xAC|0x33|0xEF |0xEF|0x6F|

Serial frame: |0xAB|0x65|0x45|0x31|0x12|0x15|0xEF|0xAC|0x33|0xEF |0xEF|0x6F|0xCD|

This algorithm has to be applied to all the frame bytes; it means also the frame type and LSB/MSB recipient bytes shall be stuffed if it is necessary.

4.3. Behaviour after changing module type

Every time a change of 306 register happens, it can cause changes also to other registers; these changes are different depending on transition (from EndPoint to Router, from Router to Coordinator, etc.). In order to avoid the loss of register modification, when it is necessary to modify other registers together with the 306 register, it is suggested to perform first the modification of 306 register and then the other registers setting.

A detailed description of the modified registers for each transition is reported in the following subparagraph.

From EndPoint to Router

Command ATS306=1.

1. The Router position (register 325) is forced to 0x00 but still editable by user;
2. The Parent Id (registers 313 and 314), the Network Id (register 310) and Client Id (registers 311 and 312) continue to have the old value and also all other registers keep the values;
3. The routing table will be reset at reboot;
4. The new behaviour will be available after the module reboot.

4.3.1. From EndPoint to Coordinator

Command ATS306=2.

1. The Client Id (registers 311 and 312) will be forced at 0xFF | 0xFF without any further possible change by user;
2. The Parent Id (registers 313 and 314) will be forced at 0xFF | 0xFF without any further possible change by user;
3. The Router position (register 325) is forced to 0x00 without any further possible change by user;
4. All the other registers are not modified;
5. The routing table will be reset at reboot;
6. The new behaviour will be available after the module reboot.

4.3.2. From Router to EndPoint

Command ATS306=0.

1. No change is done either on the Client Id or on Router Position;
2. The routing table will be reset at reboot;
3. The new behaviour will be available after the module reboot.

4.3.3. From Router to Coordinator

Command ATS306=2.

1. The Client Id (registers 311 and 312) will be forced at 0xFF | 0xFF without any further possible change by user;
2. The Parent Id (registers 313 and 314) will be forced at 0xFF | 0xFF without any further possible change by user;
3. The Router position (register 325) is forced to 0x00 without any further possible change by user;
4. All the other registers are not modified;
5. The routing table will be reset at reboot;
6. The new behaviour will be available after the module reboot.

4.3.4. From Coordinator to EndPoint

Command ATS306=0.

1. The Client Id (registers 311 and 312) will be forced at 0x30 | 0x30 but still editable by user;
2. All the other registers are not modified;

3. The routing table will be reset at reboot;
4. The new behaviour will be available after the module reboot.

4.3.5. From Coordinator to Router

Command ATS306=1.

1. The Client Id (registers 311 and 312) will be forced at 0x30 | 0x30 but still editable by user;
2. The Router Position is set to 0x00;
3. All the other registers are not modified;
4. The routing table will be reset at reboot;
5. The new behaviour will be available after the module reboot.

4.4. Advanced use

In this paragraph is described the different application profiles available within the Low Power Mesh firmware.

There is 1 functional application:

- <u>Data</u>: it allows serial data transmission through the network.
- <u>Telemetry</u>: it allows consulting digital & analog input (I) or modifying digital output (O) on a remote unit through the network.

Apart from these two functional applications, there are two other operating applications available:

- <u>Ping-pong</u>: it allows the verification of the radio link between 2 units within the network (one unit sends a ‘ping’ and receives back a ‘pong’).
- <u>Hayes</u>: it allows to send a Hayes command within the network, directly through the serial link (for local unit) or through the radio link (for remote unit).

It is the format of serial frames that defines the application.

WARNING: All the serial frames must be sent @19200 bauds with 8/N/1 format (8 data bits, no parity, and 1 stop bit).

If a Demoboard is used, it can happen that a 0x00 serial character is sent by the Demoboard directly after power up. This behavior is due to serial interface initialization.

Below is described the format of transmitted serial frames.

TYPE	RECIPIENT	CONTENT

Field	Length (Bytes)	Description
TYPE	1	Type of frame : • 0x65 ➝ data • 0x68 ➝ telemetry • 0x6A ➝ ping • 0x6D ➝ Hayes
RECIPIENT	2	Recipient ID (LSB first)
CONTENT	-	Message content : • data to be sent (for 0x65) • telemetry command (for 0x68) • blank (for 0x6A) • Hayes command (for 0x6D)

It is possible to send a serial frame without “type” and “recipient” fields. In that case, the frame will automatically be a data type, and will be sent to the default recipient defined by S315 & S316 registers. It is very useful when no encapsulation is possible from the host.

Below is described the format of received serial frames.

TYPE	SENDER	CONTENT

Field	Length (Bytes)	Description
TYPE	1	Type of frame : • 0x65 ➝ data • 0x69 ➝ telemetry • 0x6B ➝ ping • 0x6E ➝ Hayes
SENDER	2	Sender ID (LSB first)
CONTENT	-	Message content : • data received (for 0x65) • telemetry response (for 0x69) • blank (for 0x6A) • Hayes response (for 0x6E)

When a radio frame is received from the default recipient, (S315 & S316), no encapsulation is added, so the received serial frame has no “type” and “sender” fields.

The different contents are defined in the following paragraphs.

4.4.1. Content for data transmission

The data transmission will depend on the payload chosen (S330 register). The payload defines the maximum amount of data that can be sent in one radio frame.

For example, if payload is set to '1' (12 frames/46 bytes), data up to 46 bytes will be sent in once, data up to 92 bytes will be sent in 2 frames, and so on.

The transmission of higher amount of data is possible (multi-frames transmission): in that case, it is necessary to manage the serial flow control in order to avoid buffer saturation.

When multi-frames transmission is used, in order to secure the transmission, it is highly recommended to enable acknowledgement (S332 register) and to protect data integrity at application level (using for example CRC).

4.4.2. Content for Hayes commands and responses

Hayes or 'AT' commands complies with Hayes protocol used in PSTN modem standards. This 'AT' protocol or Hayes mode is used to configure the modem parameters, based on the following principles:

- A data frame always begins with the two ASCII 'AT' characters, standing for 'ATtention';
- Commands are coded over one or several characters and may include additional data;
- A given command always ends up with a <CR> Carriage Return.

'AT'	Command	Additional data	<CR>

A Hayes command must be sent in once

Below is the complete list of the 'AT' commands available.

Command	Description
ATF	***Factory parameters*** The Hayes command ATF allows user restoring the "Factory" settings. It means that **module type becomes 0x00, Network ID is 0x30, Client ID is 0x30, 0x30**, and so on. In order to know the factory settings, please refer to the V.1. After this command the user shall reboot the module sending ATO command or using the hardware switch. Answer : OK<CR>
ATR	***Parameters reset*** 'ATR' command resets a great part of register default values; the difference with ATF command is that the **module type will be not changed** and the default values depend on the module type. If a module used as Coordinator receives the command ATR, restore all the default values but module type continues to have the value equals to 2 and the Client ID will be not changed (0xFF, 0xFF). For the other module types the module type (register 306) does not change but the Client ID becomes 0x30, 0x30. After sending this command it is not mandatory to perform a module reboot.

	Answer : OK<CR>
ATC	***Clear Children Table*** ‘ATC’ command performs an erase of all children tables. Available on Coordinator and Routers. Answer : OK<CR>
ATO	***Modem Reboot*** ‘ATO’ command to reboot the modem that can be useful to trig a new association or take into account a new configuration. Answer : OK<CR>
AT/V	***Modem’s firmware version*** ‘AT/V’ command displays the modem’s firmware version number as follows: Answer : GC.M0A.xx.yyb<CR> Where: GC: means NE50 hardware platform M: Low Power Mesh firmware 0: firmware built for demoboard A: All In One firmware xx: Major number of version yy: minor number of version b: build version
AT/B	***Bootloader version*** ‘AT/B’ command displays the bootloader version number as follows: Answer : GC.B00.xx.yy<CR> Where: GC: means NE50 hardware platform B00: bootloader xx: Major number of version yy: minor number of version
ATSn?	***Register interrogation*** ‘ATSn?’ command displays the content of Hayes register number n (refer to the register description table). Some registers are standard for every Telit modems while others are specific to some products. Answer : Sn=x<CR> except when n=192
ATSn=m	***Register modification*** ‘ATSn=m’ command configures Hayes register number n with the value m, e.g. ATS300=1<CR> enters the value ‘1’ in the register S300. The value is automatically stored in the EEPROM memory. Answer : OK<CR> or ERROR<CR>
ATBL	***Switch to Bootloader*** ‘ATBL’ command escape from the main program and run the bootloader. This command is useful to update the firmware by serial or radio link. See the dedicated part for details. Answer : OK<CR>

WARNING: Modifications in registers S31X, S306, S307 and S330 are taken into account only after an ‘ATO’ command

4.4.3. Content for Telemetry commands and responses

Telemetry commands allow reading or writing I/Os remotely through the serial link.

The I/Os status (input or output) is defined through the S345 register. By default, all I/Os are set in output, so that it is very important to apply the correct value to S345 register before “playing” with them. Furthermore, it is recommended to put a serial resistance on I/O signals to avoid level conflict when S345 is not correctly set.

Below is the format of a telemetry command:

COMMAND	MASK	VALUE

<table>
<tr><th>Field</th><th>Length (Bytes)</th><th>Description</th></tr>
<tr><td>COMMAND</td><td>1</td><td>3 possibilities:
0x01: read digital inputs
0x02: read analog inputs
0x03: write digital outputs</td></tr>
<tr><td>MASK</td><td>1</td><td>It corresponds to the mask desired for write command. Only I/Os defined as output by S345 register are considered.
<table>
<tr><td>-</td><td>IO9</td><td>IO8</td><td>IO7</td><td>IO6</td><td>IO5</td><td>IO4</td><td>IO3</td></tr>
<tr><td>X</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td></tr>
</table>
0 : do not apply (output keeps its previous value)
1 : apply the new value (defined by the next field)
<u>Note</u>: this field is not used in case of read command (0x01 and 0x02)</td></tr>
<tr><td>VALUE</td><td>1</td><td>It corresponds to the value to apply for write command. Only outputs defined by the mask are considered.
<table>
<tr><td>-</td><td>IO9</td><td>IO8</td><td>IO7</td><td>IO6</td><td>IO5</td><td>IO4</td><td>IO3</td></tr>
<tr><td>X</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td></tr>
</table>
<u>Note</u>: this field is not used in case of read command (0x01 and 0x02)</td></tr>
</table>

Below is the content of the telemetry <u>response</u>:

<table>
<tr><th>COMMAND</th><th>RESPONSE</th></tr>
<tr><td>Read digital inputs</td><td>1Byte defined as follow
<table>
<tr><td>-</td><td>IO9</td><td>IO8</td><td>IO7</td><td>IO6</td><td>IO5</td><td>IO4</td><td>IO3</td></tr>
<tr><td>0</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td><td>0 or 1</td></tr>
</table>
The response contains the value of all I/Os, whatever their status (input or output)</td></tr>
<tr><td>Read analog inputs</td><td>12 bytes defined as follow:
MSB LSB
<table>
<tr><td>IO8</td><td>IO7</td><td>IO6</td><td>IO5</td><td>IO4</td><td>IO3</td></tr>
<tr><td>Value (2 Bytes)</td><td>Value (2 Bytes)</td><td>Value (2 Bytes)</td><td>Value (2 Bytes)</td><td>Value (2 Bytes)</td><td>Value (2 Bytes)</td></tr>
</table>
Each value is expressed in mV</td></tr>
<tr><td>Write digital outputs</td><td>Blank</td></tr>
</table>

The typical answer is:
0x69 | ClientId LSB | ClientId MSB | IO3 LSB | IO3 MSB | IO4 LSB | IO4 MSB | IO5 LSB | IO5 MSB | IO6 LSB | IO6 MSB | IO7 LSB | IO7 MSB | IO8 LSB | IO8 MSB | <Cr>

Six digital inputs have an additional functionality (interrupt capable) that can be enabled through the S346 register. When an input is set as interrupt, an edge occurring on it triggers the sending of an I/O frame to the default recipient (the frame is equivalent to the response to a 'read digital inputs' command). The I/Os 3 and 4 are able to rise an interrupt only in rising edge; the I/Os 5 and 6 are able to rise an interrupt only in falling edge; I/Os 7 and 8 rise an interrupt both in rise and in falling edge.

This interrupt functionality is also available for module in low power mode: the edge wakes up the module which then sends its I/O frame. It allows a real power consumption efficiency for battery operated application. If several I/Os raise simultaneously an interrupt (or the time gap is less than 1 second), just the first interrupt wakes up the module. The module sends the telemetry frame to the default recipient when is possible (it waits for a next parent beacon time) and then it returns to sleep.

WARNIG: In the analog IO, the value of maximum analog input voltage is Vcc/1.6. The IOs are able only to read positive voltage values.

5. Network building

In this paragraph, we will detail how to build a network. The main steps are:

- Network dimensioning
- Device setting
- Network start-up

5.1. Network dimensioning

Before implementing the network, it is necessary to first identify device allocation: Coordinator (unique), Routers and EndPoints.

Then, it is important to correctly dimension the network in order to adjust timing parameters. Criteria to take into account are:

- Characteristics of the network (deep or wide, low power elements, time response)
- Size of the data exchanged
- Weight of the routers (number of children)

They will impact in the Base Time, Network Period, SuperFrame Duration and Payload (refer to the next chapter to get an example that illustrates the method of calculation).

5.2. Device setting

WARNING: First check all the modules of the network are correctly flashed.

There are 2 key points to parameter the radio module:

1. you must have an access to the serial link of the module
2. you must have an access to the setting signal (ProgS)

In that case, the setting procedure is described below:

1. Power ON the device,
2. Apply a logical '1' to 'ProgS' input, between 150mS and 500mS after Power ON,
3. Send all Hayes commands needed for module setting, using serial format described in 4.4. For that, you can also use "SR Tool Manager" software [4] and its Mesh configuration Wizard.

4. Finish the setting with an ‘ATO’ command.
5. Power OFF the device and lower the ‘ProgS’ signal (logical ‘0’ or open).

Below is given the minimum list of parameters to set for each type of device, considering a network with auto-association and auto-repair modes, and basic data transmission application. The others registers keep their default value.

DEVICE	***PARAMETER***	***REGISTER***
Coordinator	The Network ID	ATS310
	The Network Period	ATS320
	The Base Time	ATS323
	The SuperFrame Duration	ATS324
	The Payload	ATS330
Router	The Network ID	ATS310
	The Client ID	ATS311
	The SuperFrame Duration	ATS324
	The LowPower Mode *(if low power)*	ATS340
EndPoint	The Network ID	ATS310
	The Client ID	ATS311
	The LowPower Mode *(if low power)*	ATS340
	The Periodic Wake up *(if low power)*	ATS341

5.3. Network start-up

After setting all the devices, it is possible to install the network. Below is the description of a typical network installation.

1. Power ON the Coordinator: its LED (connected on ‘ASSO’ signal) lights ON continuously, and the coordinator sends periodically its beacon.
2. One by one, power ON the other devices (it is interesting to start with routers to optimize the auto-association mode): each device will automatically enter the network, choosing the best parent. The status of the association procedure can be monitored by the LED:
   - Fast blink (2 per second) indicates that no network has been found at this time.
   - Slow blink (1 per second) indicates that a valid network has been found and the device is looking for the best parent into this network.
   - LED ON (continuously) indicates that association is successful and that the device is ready into the network.

3. You can monitor the network by connecting the Coordinator to a PC and use the “SR Tool Manager” software.
4. The network is now ready to work. You can either use “SR Tool Manager” software from a PC.

5.4. Timing calculation for NE50 modules

Below is given the timing formula for data transmission with mesh protocol in case of TinyOne PRO/PLUS modules.

Transmit time = LBT + TX_switching + Preamble + Header + Payload + CRC + Rx_switching

With:

- LBT = N x Random Waiting time
  - Random waiting time: from 4 to 80ms during Synchronous period and from 4 to 135ms during Asynchronous period
  - N is the number of retries if channel isn’t free
  - LBT = 0 for beacons and downward frames sent during the Synchronous part
- TX_switching = RX_switching = 1.65 ms
- Preamble = 4.0ms (19 bytes @ 38085b/s for receiver synchronization)
- Header = 2.73ms (13 bytes @ 38085b/s including mesh protocol)
- Payload = P x 0.21ms (1 byte @ 38085b/s)
  - P is the number of user bytes to be transferred
  - P = 22 for beacons
- CRC = 0.42ms (2 bytes @ 38085b/s for consistency checking)

Examples:

- Beacon
  - Beacon duration= 0 + 1.65 + 4.0 + 2.73 + 22 x 0.21 + 0.42 + 1.65 = 15.07ms

- 3 Bytes synchronous downward data frame
  - Frame duration= 0 + 1.65 + 4.0 + 2.73 + 3 x 0.21 + 0.42 + 1.65 = 11.08ms

6. Flashing

It is important to be able to flash or re-flash the modules in order to update the firmware at the last version released; every release will be available into the download zone of Telit web site.

6.1. Serial flashing

To flash the radio module through the serial link, the same key points are necessary as for setting

- You must have an access to the serial link of the module,
- You must have an access to the setting signal (ProgS).

In that case, the flashing procedure is described below:

1. Apply a logical ‘1’ to ‘ProgS’ input before Power ON (or < 50mS after Power ON).
2. Power ON the device.
3. Flash the module with the PC software “Sr Manager Tool”.
4. Power OFF the device and lower the ‘ProgS’ signal (logical ‘0’ or open).

7. Low Power mode

A key functionality available into the Mesh firmware is the ability to have all nodes of the network in low power mode. The setting of this mode is made through S340 and 341 registers.

7.1. Serial access in low power

In case of serial link with a module in low power mode, it is important to wait for the module to be wake-up before sending it some serial data.

For that, 2 solutions are possible:

1. *Use hardware flow control (RTS):* when the module is in stand-by, the ‘RTS’ signal goes high (logical ‘1’), so no serial transmission is possible. When the module wakes up, if buffers are not full, the ‘RTS’ signal goes to low (‘logical ‘0’), so that serial transmission is possible. If no serial data is received up to *SerialTimeOut* (in ms) after the falling edge of RTS, the module returns to stand-by, else the module operates the complete transmission.
2. *Use the wake-up signal (WAKEUP):* if serial transmission can not wait for the next wake-up or if no hardware control is managed, it is possible to force the module to wake-up by applying a logical ‘1’ to the ‘WAKEUP’ signal. When serial transmission is finished, ‘WAKEUP’ signal must be put back to a logical ‘0’ to allow the module returning in stand-by.

Below is the timing diagram to respect :

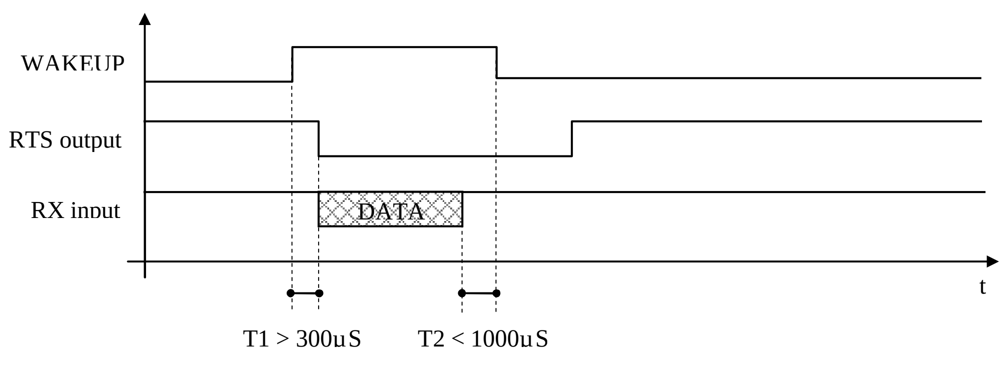

Figure 11 Wakeup/RTS behaviour

7.2. Standby Status signal

The ‘STAND BY STATUS’ output signal is set to logical ‘1’ while the module is operating and return to ‘0’ during stand by periods. This signal is useful to synchronize the wake up of external equipment according to Low Power Mesh wakeup slots. It can also be use to power a small sensor like a thermistor only during operating phase; in this case, current must be less than 10mA.

8. Appendix

8.1. Differences between M-One on TinyPro and Low Power Mesh on NE-50

With the new Low Power Mesh stack implementation some change has been made:

- Some register has been removed.
- Added some register.
- All registers access is now checked by the firmware in order to avoid unexpected behaviours.
- The telemetry feature is temporary unavailable; it will be available in the next firmware release.

8.1.1. Removed registers

The register 202 has been removed because it is not present a power amplifier. At the moment the new NE-50 can transmit only with a power of 25 mW.

The register 210 has been removed because the serial baud rate is fixed at 19200 bit per second.

8.1.2. Added registers

The register 302 has been added in order to allow the user knowing the association status of the module.

The register 307 has been added in order to choose the working center frequency.

9. Glossary

ACP	Adjacent Channel Power
BER	Bit Error Rate
Bits/s	Bits per second (1000 bits/s = 1Kbps)
CER	Character Error Rate
dBm	Power level in decibel milliwatt (10 log (P/1mW))
DOTA	Download Over The Air
EMC	Electro Magnetic Compatibility
EPROM	Electrical Programmable Read Only Memory
ETR	ETSI Technical Report
ETSI	European Telecommunication Standard Institute
FM	Frequency Modulation
FSK	Audio Frequency Shift Keying
GFSK	Gaussian Frequency Shift Keying
GMSK	Gaussian Minimum Shift Keying
IF	Intermediary Frequency
ISM	Industrial, Scientific and Medical
kbps	kilobits/s
LNA	Low Noise Amplifier
LSB	Least Significant Byte
MHz	Mega Hertz (1 MHz = 1000 kHz)
µC	Micro Controller
ms	Millisecond
MSB	Most Significant Byte
PLL	Phase Lock Loop
PROM	Programmable Read Only Memory
NRZ	Non return to Zero
RF	Radio Frequency
RoHS	Restriction of Hazardous Substances
RSSI	Receive Strength Signal Indicator
Rx	Reception
SRD	Short Range Device
Tx	Transmission
SMD	Surface Mounted Device
VCO	Voltage Controlled Oscillator
VCTCXO	Voltage Controlled and Temperature Compensated Crystal Oscillator

10. Document History

Revision	Date	Changes
0	2011-07-07	First issue
1	2011-07-25	Added telemetry management
2	2011-10-18	Modified description of register 311-314-345