MICROCHIP

AN1371

Microchip MiWi™ PRO Wireless Networking Protocol

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INTRODUCTION

MiWi™ PRO wireless networking protocol is one of the key components of MiWi Development Environment (MiWi DE). MiWi DE integrates the support for all Microchip RF transceivers and proprietary wireless communication protocols into a single development environment to meet different needs from the customers.

MiWi DE system includes three layers from bottom to top:

- RF transceiver drivers
- Wireless communication protocols
- User application layers

Each of these layers has corresponding configuration files and are interconnected by two Microchip proprietary interfaces from bottom to top:

- Microchip Wireless Media Access Controller Interface (MiMAC): It is the interface between Microchip RF transceivers and Microchip wireless communication protocols.
- Microchip Wireless Application Programming Interface (MiApp): It is the interface between user application and Microchip wireless communication protocols.

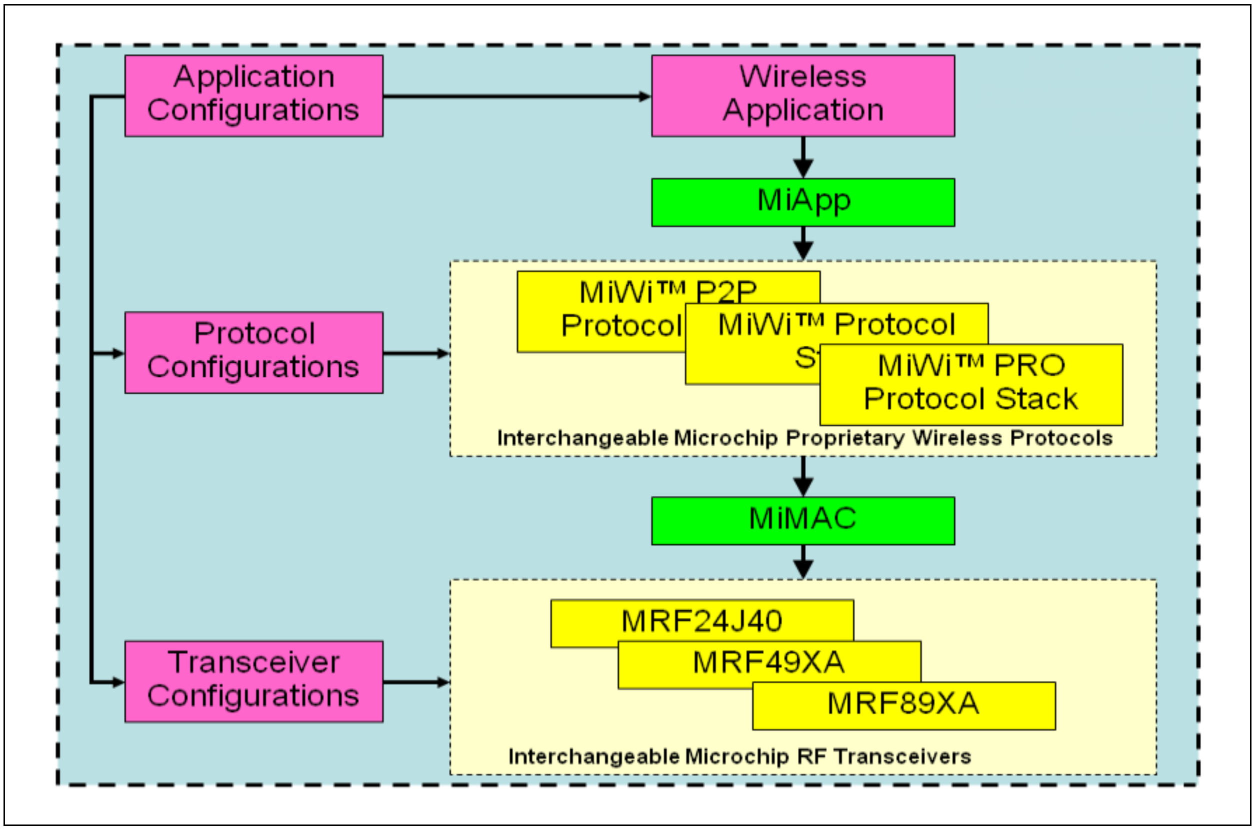
As a result of two well-defined universal interfaces below and above the communication protocol, all supported Microchip RF transceivers and wireless communication protocols can be interchanged easily with configuration change but little or no modification in the application layer source code.

For more information on the components of MiWi DE, refer to the Microchip application notes AN1066 "*MiWi Wireless Networking Protocol Stack*" (DS01066), AN1204 "*Microchip MiWi P2P Wireless Protocol*" (DS01204), AN1283 "*Microchip Wireless Media Access Controller – MiMAC*" (DS01283), AN1284 "*Microchip Wireless Application Programming Interface – MiApp*" (DS01284).

MiWi PRO wireless networking protocol targets applications that require support for larger networks. This protocol cover more areas and allow more nodes in the same network. As compared against MiWi P2P and MiWi networking protocols, MiWi PRO provides an enhanced routing capability in order to support up to 64 routing capable coordinators and delivers message up to 65 hops, with acceptable increase of system resources requirement. Each Coordinator is capable of accepting up to 127 end devices. Therefore, the total number of nodes that are supported within one MiWi PRO network has been increased to more than eight thousand. The network features are similar to MiWi P2P and MiWi protocols. As stated in the MiWi DE system, MiWi PRO uses MiMAC interface to communicate with Microchip RF transceivers driver, and so it can use any Microchip RF transceivers to exchange raw data. Also, MiWi PRO uses MiApp interface for user application layer, therefore, MiWi PRO protocol can be easily switched to MiWi P2P or MiWi protocols with little or no modification in the user application layer. Figure 1 illustrates the block diagram of MiWi DE.

For better understanding of this application note, it is highly recommended to start with IEEE 802.15.4 specification and Microchip application note AN1066 "*MiWi™ Wireless Networking Protocol Stack*" (DS01066).

FIGURE 1: MiWi™ DEVELOPMENT ENVIRONMENT DIAGRAM



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MiWi PRO PROTOCOL OVERVIEW

The MiWi PRO protocol is designed to be one of the protocol stacks that are supported in MiWi DE. MiWi PRO is configured to support wireless networks up to 64 Coordinators depending on system resources, including one PAN Coordinator that starts the network. Each Coordinator will be able to support up to 127 end device children. Coordinators are able to join another Coordinator. As a result, when linear topology is applied, MiWi PRO protocol supports up to 9, 17, 33 or 65 hops, respectively.

The MiWi PRO networking protocol is also designed to provide additional routing capability with reasonable system resource requirement. The full featured coordinator stack uses about 25 KB programming memory, while an end device fits into MCU with only 16 KB flash memory. There is a noticeable increase on RAM requirement for coordinator devices due to the enhanced routing requirement for MiWi PRO protocol. Due to the complexity of gaining routing information, the Network Freezer feature is mandatory for MiWi PRO protocol to recover from power loss. Network Freezer feature stores critical network information into nonvolatile memory (NVM) and restores the network topology from NVM after power cycles.

Another design goal for MiWi PRO networking protocol is backward compatibility. MiWi PRO is designed so that the end devices for MiWi protocol can join MiWi PRO networks and perform networking task similar to MiWi networks. On the other hand, end devices of MiWi PRO protocol can join MiWi networks and behave the same. This capability gives customer the option to only update the firmware of coordinators in the case that switching networking protocols is necessary. As in most of the applications, majority of nodes within the networks are end devices, the capability of end devices operating in each network may potentially lower the cost to upgrade the network with new MiWi or MiWi PRO protocols.

In summary, MiWi PRO networking protocol enables MiWi DE to provide a low-cost alternative solution for larger networks other than ZigBee™ protocol to the market where interoperability is not necessary.

FEATURES

The current implementation of the MiWi PRO protocol has the following features:

- Small footprint, less than 25 KB for coordinator and less than 13 KB for end devices
- MiMAC interface enables easy switch of Microchip RF transceivers
- MiApp interface enables easy migration between Microchip proprietary wireless protocols
- Support up to 64 Coordinators, up to 65 hops and up to eight thousand nodes for a large network
- End device is backward compatible with MiWi protocol
- Out-of-box support for PIC18/PIC24/dsPIC33/PIC32

WIRELESS PROTOCOLS

MiWi DE depends on wireless protocols to decide how to route the messages. The three wireless protocols supported by MiWi DE are:

- MiWi P2P
- MiWi
- MiWi PRO

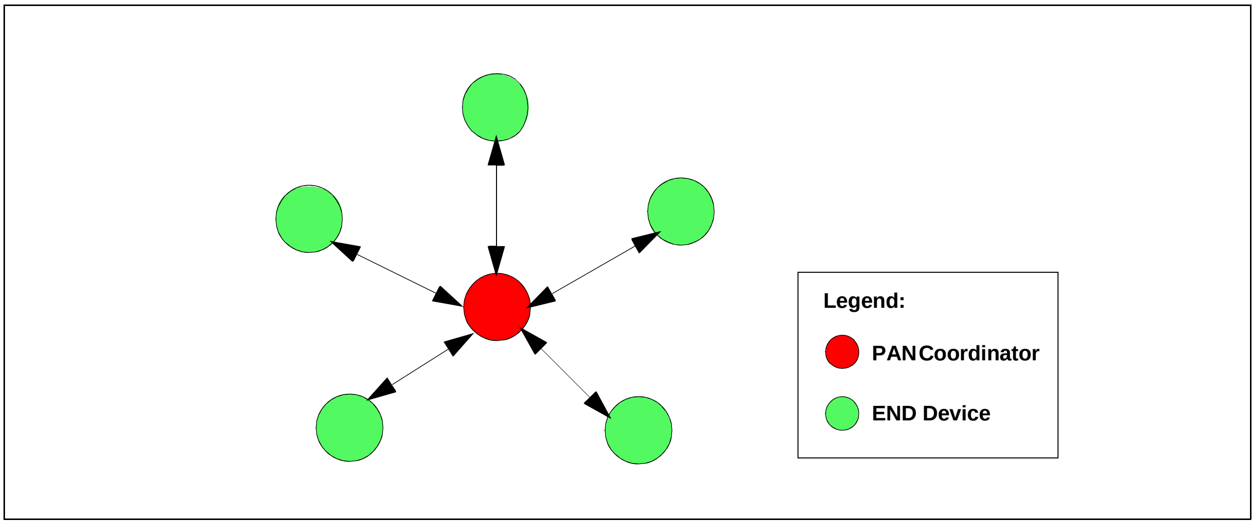
All these protocols have the capability to send a message from the source to the destination; the difference is how long the message can hop before reaching the destination.

MiWi P2P

MiWi P2P is the simplest protocol supported by MiWi DE. It supports only Star or Peer-to-Peer topology. There is no routing capability defined in this protocol. Therefore, the message can only be delivered within the source device's radio range. The most appealing feature for MiWi P2P is its simplicity, due to the fact that MiWi P2P device does not need to handle complex routing. The obvious limitation for MiWi P2P is that it only supports communication within the radio range. Sub-GHz transceivers or power amplifier can help to extend the radio range. However, when more communication range is required, a networking protocol to extend coverage by routing is necessary.

Figure 2 illustrates the network topology for MiWi P2P protocol.

FIGURE 2: NETWORK TOPOLOGY FOR MiWi™ P2P PROTOCOL



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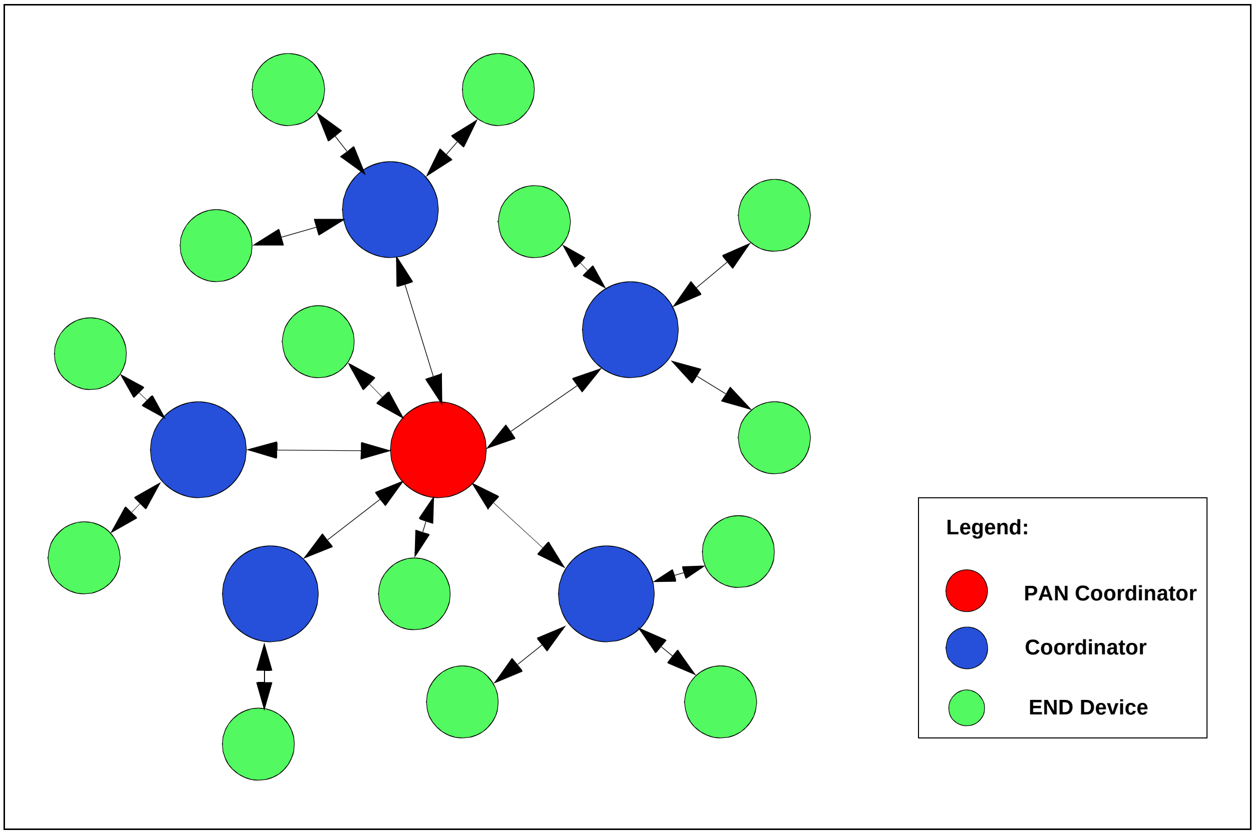
MiWi

MiWi wireless networking protocol is designed to extend the network coverage by providing routing capabilities for a small network. It supports up to 8 Coordinator capable nodes, including the PAN Coordinator that starts the network. It also supports routing up to 4 hops from end device to end device, or 2 hops from PAN Coordinator to any end device. To simplify the routing mechanism, a Coordinator can only join the PAN Coordinator. However, a Coordinator is unable to join another Coordinator. When a Coordinator capable device is unable to reach the PAN Coordinator, or there are already 8 Coordinators in the network, the Coordinator capable device can automatically demote itself and join the network as an end device. The obvious limitation for MiWi is that it only supports small networks, up to 4 hops from end device to end device.

Figure 3 illustrates the network topology for MiWi protocol.

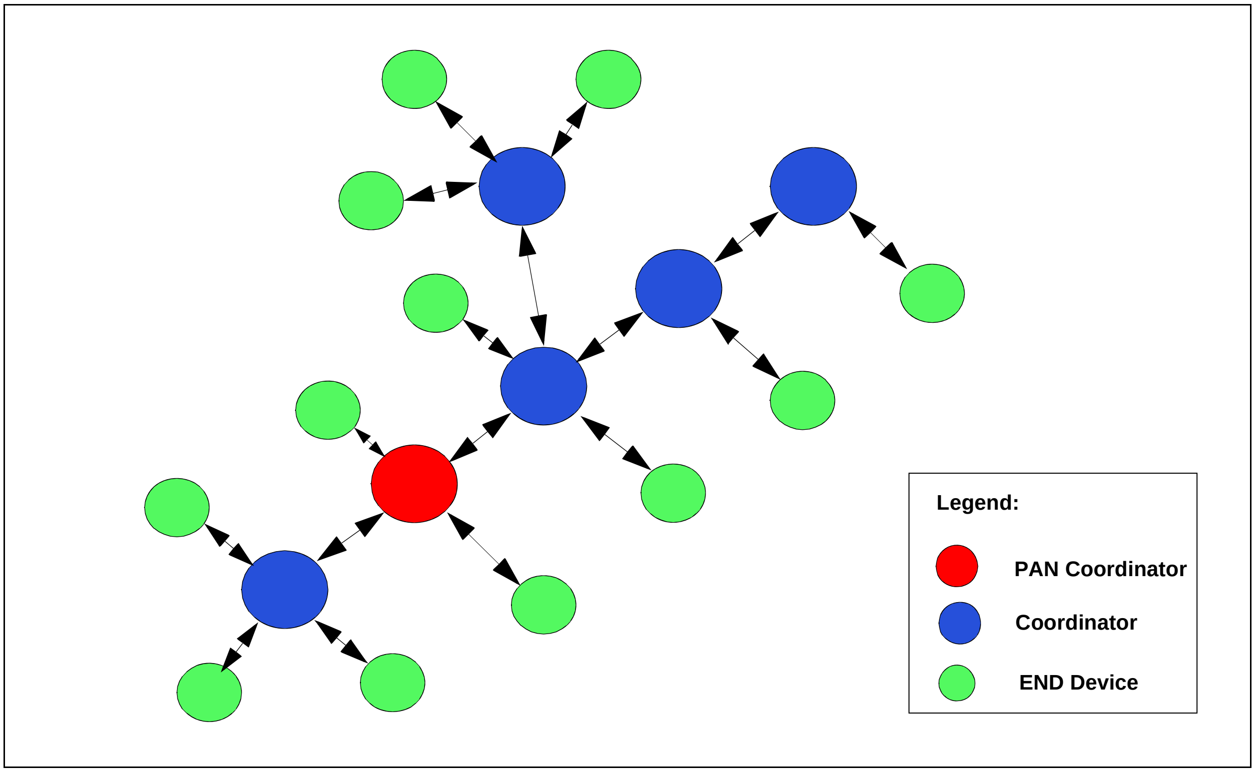
FIGURE 3: NETWORK TOPOLOGY FOR MiWi™ PROTOCOL



MiWi PRO

MiWi PRO wireless networking protocol has enhanced routing mechanism to support up to 64 Coordinators and a Coordinator can join another Coordinator. When the network is formed in a linear topology, a total of up to 65 hops can be achieved from end device to end device, or up to 64 hops from the PAN Coordinator to an end device. The behavior of MiWi PRO is same as MiWi, except that the details of implementation including packet exchanging, is different to work with a much larger networks. Figure 4 illustrates the network topology for MiWi PRO protocol.

FIGURE 4: NETWORK TOPOLOGY FOR MiWi™ PRO PROTOCOL



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MiWi PRO PROTOCOL MESSAGE FORMAT

MiWi PRO protocol defines a network layer on top of MAC layer similar to MiWi protocol to support multi-hop routing. Figure 5 illustrates the details of MiWi PRO frame format.

FIGURE 5: MiWi™ PRO FRAME FORMAT

Hops	Frame Control	Destination PANID	Destination Short Address	Source PANID	Source Short Address	Sequence Number	Report Type	Report ID
1	1	2	2	2	2	1	1	1

Legend: Numbers indicate packet component size in bytes.

The MiWi PRO frame format is comprised of the following components:

- **Hops**: The number of hops that the packet is allowed to be retransmitted (0x00 means do not retransmit this packet – 1 byte).
- **Frame Control**: The Frame Control field is a bitmap that defines the behavior of this packet. The individual bits are defined in Table 1 (1 byte).
- **Destination PANID**: The PANID of the final destination node (2 bytes).
- **Destination Short Address**: The final destination's short address (2 bytes).
- **Source PANID**: The PANID of the node that originally sent the packet (2 bytes).
- **Source Short Address**: The short address of the node that originally sent the packet (2 bytes).
- **Sequence Number**: A sequence number that can be used to track the status of packets as they travel through the network (1 byte).

The frame control byte in the MiWi Pro header defines how to interpolate the MiWi Pro packet. Table 1 shows the details of the frame control byte.

TABLE 1: FRAME CONTROL BIT FORMAT(1)

bit 7-3	bit 2	bit 1	bit 0
Reserved	ACKREQ	INTRCLST	Reserved

bit 7-3 **Reserved:** Maintain as '0' in this implementation

bit 2 **ACKREQ:** Acknowledge Request bit

When set, the source device requests an upper layer Acknowledgement of receipt from the destination device.

bit 1 **INTRCLST:** Intra Cluster bit

Reserved in this implementation, maintain as '1'.

bit 0 **Reserved**

Note 1: Abbreviated bit names are for convenience of display only; they are not an official part of IEEE 802.15.4™.

As shown in Figure 5, MiWi PRO uses 2 byte short address to specify nodes in the network when performing routing across the network. MiWi PRO follows a similar way to distribute the short address as MiWi. Similar to MiWi protocol, the lower byte is used to identify the end devices. Instead of 3 bit in MiWi protocol to identify the Coordinators, MiWi PRO expands the Coordinator Identifier to 6 bits, enough to address up to 64 Coordinators.

Table 2 shows the short address assignment in MiWi PRO and the details of MiWi PRO short address assignment.

TABLE 2: MiWi™ PRO SHORT ADDRESS FORMAT

bit 15:14	bit 13:8	bit 7	bit 6:0
Reserved	Coordinator Identifier	RxOnWhenIdle	End Device Identifier (0x00 to identify Coordinator)

MiWi PRO ENHANCEMENTS

MiWi DE is a complete system to help customers to develop wireless applications with different wireless protocols and RF transceivers easily and quickly. MiWi PRO inherited the same benefits of the MiWi DE system. Even though the implementation details varies widely between the protocols due to network size, they all have the same configurations and programming interfaces from the application layer. For more information on the features supported in MiWi P2P and MiWi, refer to the application note AN1066 "*MiWi Wireless Networking Protocol Stack*" (DS01066), and AN1204 "*Microchip MiWi P2P Wireless Protocol*" (DS01204).

The three major enhancements for MiWi PRO that are essential for a good performance in a much larger network are:

- Broadcast Enhancement
- Mesh Routing
- Frequency Agility

Broadcast Enhancement

Multicast is the communication method that targets a group of devices as destination. Usually, multicast destinations are distinguished by their role on the network. For instance, the multicast destination can be all Coordinators, or all Full Function Devices (FFD). To achieve this goal, a special short address will be assigned to represent the multicast. The multicast destination address will only be transmitted in the MiWi PRO header. In the MAC header, it is still a broadcast. It is MiWi PRO protocol stack role to filter out packets that target different types of nodes, therefore multicasts that do not target current node will not be forwarded to the application layer.

Table 3 represents the multicast destination address.

From the application layer, when a multicast address is assigned as the destination address in MiApp interface `MiApp_UnicastAddress`, the message will be sent out as multicast message that targets specific group of devices.

TABLE 3: MULTICAST/BROADCAST ADDRESSES

Multicast Short Address	Description
0xFFFF	Broadcast to every device
0xFFFE	Multicast to all FFD's
0xFFFD	Multicast to all Coordinators

Mesh Routing in Larger Network

Before describing the details of mesh routing in MiWi PRO protocol, it may be beneficial to look at industry's general approach to support mesh networking. To support mesh routing, ZigBee v1.0 and ZigBee 2006 use a special algorithm called CSkip to calculate node location based on short address. ZigBee PRO uses random short address assignment. As a result, there is no way for the ZigBee PRO node to track network topology and depends on mesh networking only to pass packets. All solutions in ZigBee require much more system resources and are complex to implement. As a result, all versions of ZigBee protocol stack footprints outpace MiWi PRO significantly. Furthermore, as the paths from source to destination are discovered during the message transfer by broadcasting route related protocol services, the latency of the first packet that routes to the destination is very high.

The family of MiWi DE Microchip proprietary protocols takes a different path to solve the mesh routing problem.

MiWi P2P protocol supports communication within the transceiver's radio range. MiWi P2P does not have any routing capability.

MiWi protocol chooses a simple way to bypass the routing problem. It only allows a PAN Coordinator to accept a Coordinator to join. As a result, the network topology will be a fixed extended star topology. This design in MiWi protocol provides mesh routing capability, at the same time greatly simplifies the routing mechanism. However, this design also introduces the limitation of up to 4 hops between end devices and up to 2 hops from PAN Coordinator to any end device.

MiWi PRO follows a similar path to distribute the short address as MiWi, except expanding the Coordinator Identifier to be 6 bits, enough to address up to 64 Coordinators. A message can always be distributed to the end device by its parent. The routing mechanism is focused on routing to the destination if the destination is a Coordinator, or the parent of the destination if the destination is an end device.

To route to the destination, there are two common ways:

- Tree routing
- Mesh routing

TREE ROUTING

Tree Routing is the routing mechanism where message is delivered through the parent and children relationship. To use tree routing, every routing node must know the network topology of the networks. MiWi PRO protocol keeps track of network topology by allowing only the PAN Coordinator to assign the short address for a Coordinator. As a result, PAN Coordinator acquires all the information about the network topology during the process of assigning short address for a Coordinator. Then PAN Coordinator will distribute the network topology information to all Coordinators, which have the capability of routing message within the network. By this way, the network topology is no longer fixed and any Coordinator can join another Coordinator. The maximum hops are no longer limited by the network topology, but by the number of Coordinators allowed in the network. The maximum hops for MiWi PRO can be calculated as:

(Number_of_Maximum_Coordinators + 1)

To save system resources and transmit the network topology easily, MiWi PRO uses family tree table to represent the network topology, as shown in Table 4.

TABLE 4: FAMILY TREE TABLE(1)

Higher Byte of Coordinator Address (Implied by table Index)	Higher Byte of Coordinator Parent's Address(2)	Description
0	0	PAN Coordinator 0x0000 has no parent, so it points its parent to itself
1	0	Coordinator 0x0100's parent is 0x0000
2	1	Coordinator 0x0200's parent is 0x0100
3	1	Coordinator 0x0300's parent is 0x0100
4	3	Coordinator 0x0400's parent is 0x0300
...	...	...
n-2	1	Coordinator 0x(n-2)00's parent is 0x0100
n-1	0xFF	Coordinator 0x(n-1)00 has not join the network yet, so it points to non-exist Coordinator 0xFF00

Note 1: 'n' is maximum number of Coordinators.

2: Represents the pointer to the parent of the current Coordinator.

In this table, higher byte of the short address is used to represent the Coordinator, as the lower byte of the short address of the Coordinators is always 0. The higher byte of Coordinator is implied by the index of the table. The data within the table is the higher byte of the short address of a parent node. The address of the parent node is implied by the index of the table, which minimizes the footprint of the network topology

Each time a Coordinator tries to join the network, it is the Coordinator's parent's responsibility to report to PAN Coordinator and get the short address of the joining Coordinator from the PAN Coordinator. It is PAN Coordinator's responsibility later to update the Family Tree table and then distribute the Family Tree table to all routing capable devices. As all Coordinator devices have a copy of the Family Tree table, they are able to route the messages along the parent or children relationship across the network.

MESH ROUTING

Typically, mesh routing is the preferred way to route the message. However, tree routing is the backup plan to route the message across the network. Tree routing is only used when mesh routing mechanism cannot find a better path. Unlike tree routing that depends on joining tree structure to perform routing, mesh routing tries to find the shortest path between the source and destination, without considering the parent or children relationship. Mesh routing capability enables MiWi PRO network to deliver a message through multiple paths to the same destination.If some of the nodes fail for any reason within the network, it is possible for mesh routing network to bypass those malfunctioning nodes and still deliver the message across the network through alternative paths. Mesh routing capability can avoid possible single point of failure. The network with mesh routing capability can dynamically adjust the routing path. Therefore, mesh routing is more robust and stable.

To use mesh routing, every routing node must know its neighbors and its neighbors' neighbors. To achieve this, every Coordinator needs to exchange its neighbor table with its neighbors after joining networks. The neighbor table for each Coordinator uses one bit to indicate if it can contact another Coordinator directly. The bit order represents higher byte of the short address of the neighbor Coordinator. For instance, if bit 9 of the neighbor table is set, it means that the Coordinator 0x0900 can be accessible directly. To enable the Coordinator to do mesh routing, they need to introduce each other by sending their own neighbor table and keep the neighbor's neighbor table that is acquired during the process. By this way, each Coordinator has its own neighbor table and its neighbor's neighbor table. It can at least look two hops ahead to do mesh routing. Optionally, the neighbor table can be maintained dynamically by exchange of neighbor table information with neighbors periodically during normal operation time.

The routing mechanism of MiWi PRO is a combination of mesh routing and tree routing. Basically, a Coordinator can look two steps ahead to see if a mesh routing is possible to the destination or destination's family tree. If such mesh routing is not available, it will send the message along the family tree to see if anybody in its family tree has the mesh routing available to reach the destination. MiWi PRO uses simple look up table to find the mesh route availability instead of using expensive route request/reply approach used by ZigBee to lower the total system resources requirement as well as high latency when the first packet is transmitted.

Figure 6 illustrates the complete MiWi PRO routing mechanism.

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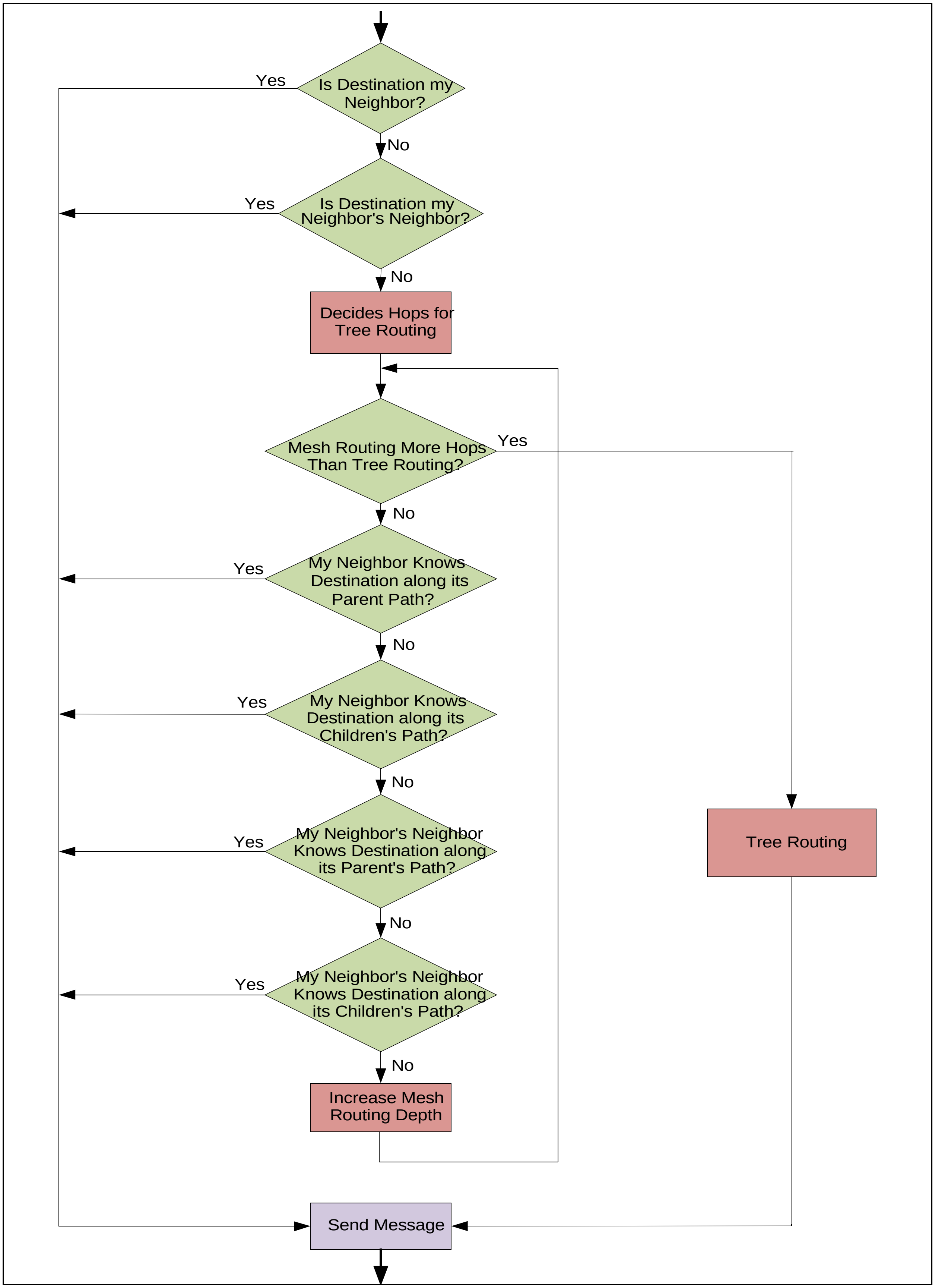
FIGURE 6: MiWi™ PRO ROUTING MECHANISM



To enable MiWi PRO to support more than four hops and do mesh routing, MiWi PRO has introduced a new set of protocol services. All protocol services follow the same MiWi protocol report format. The protocol services will use Report Type 0x00. For different protocol services, different report identifiers will be used as shown in Table 5.

TABLE 5: NEW MiWi™ PRO PROTOCOL SERVICES FOR NETWORKING

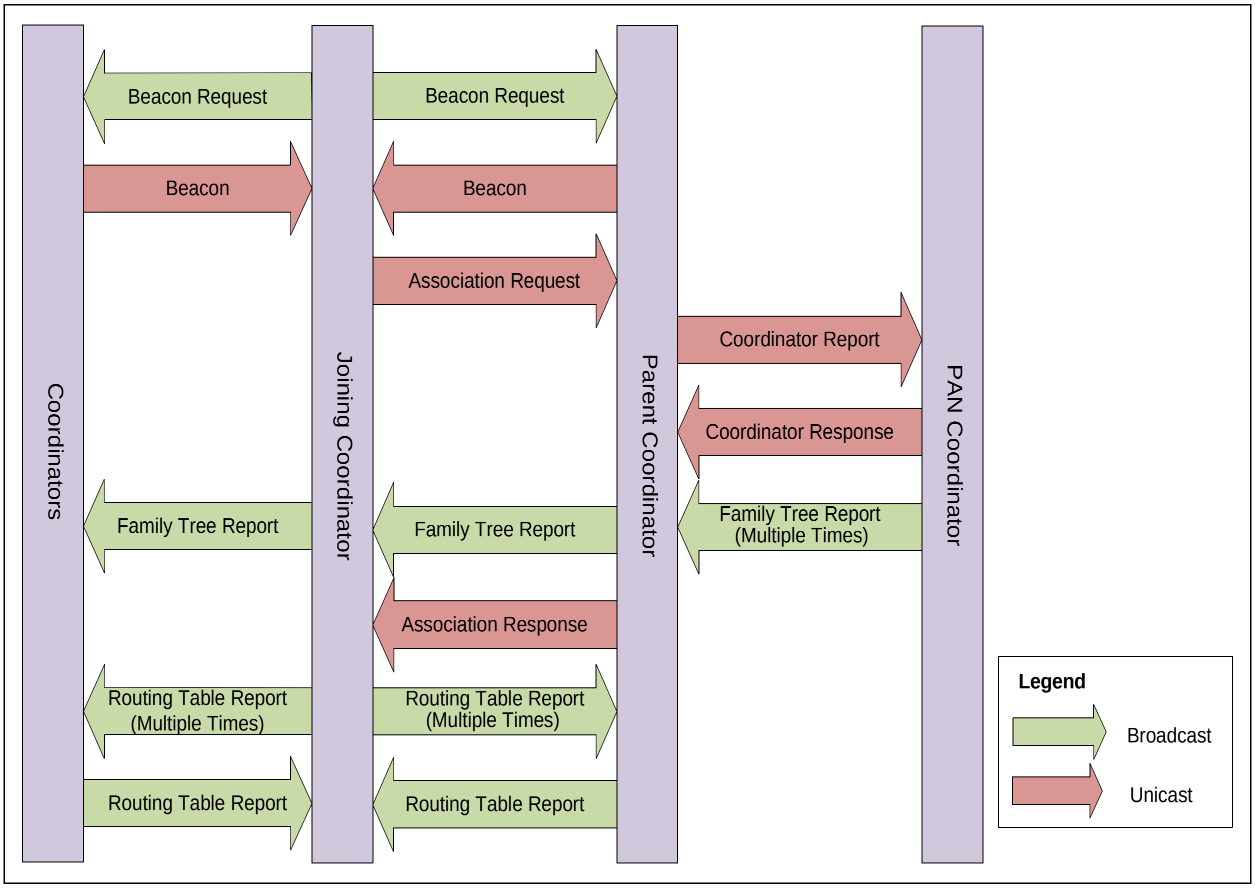
Report Identifier	Name	Description
0xA0	COORDINATOR REPORT	Whenever a Coordinator joins another Coordinator, the parent Coordinator will use COORDINATOR REPORT to notify the PAN Coordinator this event and wait for the joining Coordinator's short address from the PAN Coordinator.
0xA1	COORDINATOR RESPONSE	Once PAN Coordinator receives COORDINATOR REPORT, it will assign a short address to the joining Coordinator and send it to the parent of the joining Coordinator with COORDINATOR REPORT.
0xA2	FAMILY TREE REQUEST	FAMILY TREE REQUEST service is used to request the up-to-date network topology information.
0xA3	FAMILY TREE REPORT	FAMILY TREE REPORT service is used to transmit the network topology information.
0xA4	ROUTING TABLE REPORT	ROUTING TABLE REPORT service is used to exchange neighbor tables to ensure mesh routing capability for Coordinator.

The procedure for an end device to join the network is the same as MiWi protocol. On the other hand, as a result of all the changes mentioned above, the procedure for a Coordinator to join the network has been changed. Similar in MiWi joining procedure, the potential child Coordinator performs an active scan with MAC command Beacon Request. Potential parent Coordinators will respond with a Beacon. The potential child Coordinator may choose one of the potential parent Coordinators and request to join the network by unicast MAC command Association Request to the potential parent Coordinator. Up to this step, the procedure is identical to MiWi protocol. The following steps in the joining procedure for MiWi PRO are different from MiWi to ensure delivering topology and routing information to support larger network. Once a Coordinator capable node tries to join another Coordinator, the parent Coordinator uses Coordinator Report protocol service to report this event to the PAN Coordinator. Upon receiving the Coordinator Report protocol service, if a Coordinator is available for network, the PAN Coordinator assigns a new Coordinator short address and notify the parent Coordinator using the Coordinator Response protocol service. Otherwise, a dummy short address will be assigned and forwarded to the potential parent Coordinator by Coordinator Response protocol service. After the potential parent Coordinator receives the Coordinator Response protocol service, depending on the assigned short address from the PAN Coordinator, the potential parent Coordinator will assign either Coordinator or end device address to the joining Coordinator.

Once a new Coordinator joins the network, after assigning a new Coordinator address by the PAN Coordinator, it is PAN Coordinator's responsibility to forward the new network topology, i.e. family tree information, to all the Coordinators. By using Family Tree Report protocol service to multicast to all Coordinators multiple times, the PAN Coordinator delivers the network topology change. On the other hand, it is joining Coordinator's responsibility that routing information should be updated for nearby Coordinators. This goal is achieved by multicasting a few times to all Coordinators in radio range Routing Table Report protocol service and responding to Routing Table Report with the same protocol service. Neighbor table information is in the payload of Routing Table Report protocol services and stored by the Coordinators that receive them.

The changed procedure guarantees that any Coordinator that joins the network will be able to get the family tree information as well as the neighbor's neighbor table information. This information are the foundations of tree and mesh routing, respectively. Figure 7 shows the details of the changed procedure.

FIGURE 7: MiWi™ PRO NETWORKS JOIN PROCEDURE



Frequency Agility Enhancement

Similar to MiWi P2P and MiWi protocols, MiWi PRO protocol also supports the frequency agility feature. MiWi P2P and MiWi protocols handle a relative small network. As a result, we can assume that the noise distribution in such a small geographic area is consistent. Under such assumption, the PAN Coordinator itself can make decision about which channel to hop based on its own energy scan results. However, MiWi PRO protocol faces a much complex problem to implement the frequency agility due to its bigger network size. The noise distribution between PAN Coordinator and other Coordinators up to 64 hops away can no longer be considered the same, therefore the energy scan for PAN Coordinator should not be the only factor in the process of making decision for the channel to hop. Instead, energy scan results for every Coordinator may count.

With all energy scan results from every Coordinator, it is still a complicated problem to choose an optimal channel for operation. Due to the much larger size of the network that covers a large area, noise distribution at different locations of the network may differ widely. One channel may be very quiet at one point within the network, but may be very noisy at another point in the same network. Consensus to the best channels for the entire network may be hard to reach. MiWi PRO protocol chooses a voting mechanism to enable every Coordinator to be involved in the process of choosing the optimal channel, while still keeping the decision process relatively simple.

In this voting mechanism for the MiWi PRO protocol to choose the optimal channel, the PAN Coordinator acts as the frequency agility initiator. Any Coordinator which encounters unreliable communication may send a Frequency Agility Request protocol service to PAN Coordinator to request the start of Frequency Agility. The PAN Coordinator will then multicast to all Coordinators a Frequency Agility Energy Scan Request protocol service request. Upon receiving the Frequency Agility Energy Scan Request protocol service, all Coordinators, including PAN Coordinator, will start the energy scan and store the scan results. After all energy scans are finished, the PAN Coordinator will multicast to all Coordinators the Frequency Agility Suggest Channel protocol service to ask if a particular channel is OK for all Coordinators. All Coordinator will compare the energy scan result of the proposed channel to a predefined noise level. Only if the energy scan noise in proposed channel is higher than the predefined noise level, then Coordinator will send back Frequency Agility Against Channel protocol service to against the suggested channel from the PAN Coordinator. After receiving the Frequency Agility Against Channel protocol service from at least one Coordinator, then PAN Coordinator will propose another channel until no Coordinator against the suggested channel. The order of suggested channel will start with the channel with least noise first at PAN Coordinator location. When a suggested channel is turned down by at least one of the Coordinators, the noise level of that channel will be set as maximum, thus no longer be suggested again in the future. If all channels lower than the predefined noise level at PAN Coordinator have been tried but voted against by at least one Coordinator, the Frequency Agility operation fails and stops.

After a suggested channel has been accepted by all Coordinators, that is, Frequency Agility Against Channel protocol service packet is not received within the predefined time by the PAN Coordinator, the PAN Coordinator will send out Frequency Agility Change Channel protocol service to all devices on the network. After a predefined time period after receiving the Frequency Agility Change Channel protocol service, the devices will change channel according to the Frequency Agility Change Channel payload.

For those devices that sleep or fail to receive the Frequency Agility Change Channel protocol service packet, they should use resynchronization to find the channel that the MiWi PRO network jumps to. Usually, continuous packet delivery failure to a Coordinator will trigger the resynchronization process. Resynchronization will use new protocol services such as, Resynchronization Request and Resynchronization Response to find the lost connection.

In order to support the frequency agility, following new protocol services have been introduced as shown in Table 6.

TABLE 6: NEW MiWi™ PRO PROTOCOL SERVICES FOR FREQUENCY AGILITY

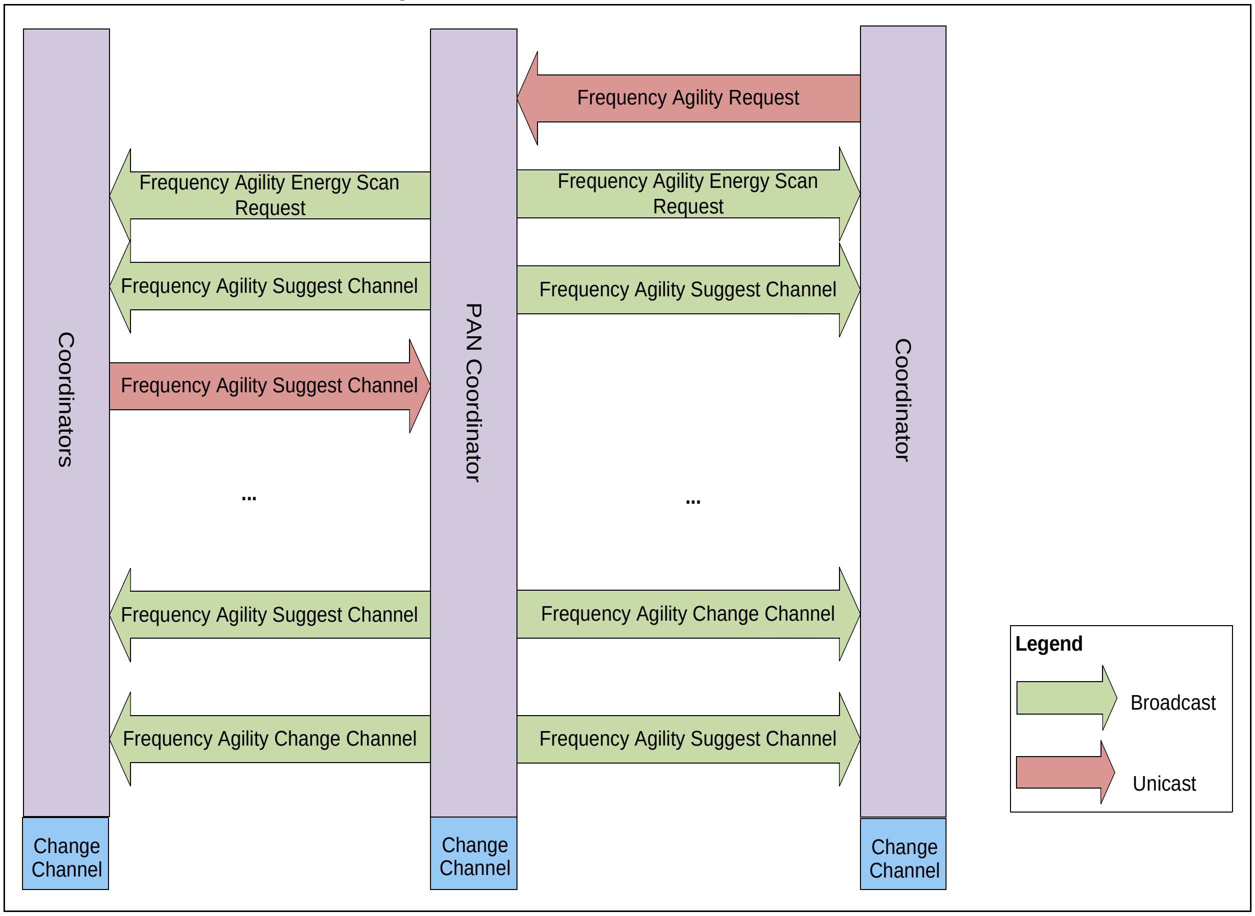
Report Identifier	Name	Description
0xB0	Frequency Agility Request	Request the PAN Coordinator to start a frequency agility procedure. The potential channels to jump to is embedded in the request
0xB1	Frequency Agility Energy Scan Request	Sent by PAN Coordinator to request all Coordinators to perform energy scan. This step is usually used to prepare for the steps follows to accept or deny channel(s) proposed by the PAN Coordinator.
0xB2	Frequency Agility Suggest Channel	Sent by PAN Coordinator to propose a channel to jump to. If no objection received in the predefined time period, PAN Coordinator will make the decision to jump to this channel.

TABLE 6: NEW MiWi™ PRO PROTOCOL SERVICES FOR FREQUENCY AGILITY (CONTINUED)

Report Identifier	Name	Description
0xB3	Frequency Agility Against Channel	Sent by Coordinator to oppose the channel selection proposed by the PAN Coordinator. The decision by Coordinator is usually based on the energy scan results achieved by Frequency Agility Energy Scan Request.
0xB4	Frequency Agility Change Channel	Sent by PAN Coordinator to request devices on the network to jump to a new channel.

Figure 8 illustrates the procedure to perform Frequency Agility.

FIGURE 8: TYPICAL FREQUENCY AGILITY PROCEDURE



NEW MiWi PRO PROTOCOL SERVICES

MiWi PRO protocol supports all protocol services in MiWi protocol. When protocol services are used, they are provided in the form of Report ID under the condition that Report Type is set to MiWi Report Type (0x00). In order to perform the additional functionalities beyond MiWi protocol, namely the more complicated routing and frequency agility services, additional protocol services are defined in the form of MiWi Report ID. Following sections list the details, definitions and format of each protocol services.

Coordinator Report

Coordinator Report is a protocol service used by the Coordinator to report to the PAN Coordinator that a new Coordinator is trying to join. As described before, a Coordinator has no capability of assigning a short address to another joining Coordinator. The PAN Coordinator is only node in the network that is able to assign the short address of a Coordinator, therefore, keeps track of the network topology. In case where the parent Coordinator is not a PAN Coordinator, the parent Coordinator uses Coordinator Report protocol service to report to PAN Coordinator that a new Coordinator is waiting to join the network. PAN Coordinator will respond to the parent Coordinator with Coordinator Response protocol service with assigned short address for the joining Coordinator. In case no Coordinator is allowed in the network, the higher byte of the short address for joining Coordinator will be assigned to 0xFF, be able to demote the joining Coordinator as an end device in the network. After receiving Coordinator Response protocol service, the parent Coordinator will be able to respond to the joining Coordinator with IEEE 802.15.4 MAC command Association Response. If the parent Coordinator is PAN Coordinator, the PAN Coordinator will assign the short address of the joining Coordinator directly, therefore, Coordinator Report procedure is no longer necessary.

Coordinator Report protocol service can also be used by a parent Coordinator to report to the PAN Coordinator that a child Coordinator is leaving the network. The PAN Coordinator will update the family tree structure and notify all Coordinators the modification. When Coordinator Report protocol service is used to report leaving of a Coordinator to the PAN Coordinator, the Coordinator Response protocol service is not expected from the PAN Coordinator.

Only the PAN Coordinator is expected to receive Coordinator Report protocol service. The format of Coordinator Report service is described in Table 7.

TABLE 7: COORDINATOR REPORT SERVICE FORMAT

	Report Type	Report ID	Status	Report Payload
Size	1	1	1	8
Value	0x00	0xA0	0x00/0x01	Long Address
Note	Protocol Report Type is MiWi Report Type	Report ID for Coordinator Report is 0xA0	Status of the report Join: 0x00 Leave: 0x01	The extended long address of the joining/ leaving Coordinator

Coordinator Response

Coordinator Response is a protocol service that the PAN Coordinator use to respond to the Coordinator Report. PAN Coordinator uses this protocol service to notify the parent of the joining Coordinator the higher byte of the short address of the joining Coordinator. In case the PAN Coordinator has run out of available Coordinator spot, it will respond with invalid short address, 0xFF in this case, so that the joining Coordinator will join the network as a FFD end device.

After receiving Coordinator Response protocol service by the parent of the joining Coordinator, the parent Coordinator will check the higher byte of the short address of joining Coordinator. If the value is 0xFF, the parent Coordinator will choose an address for its child FFD end device and send it to the joining Coordinator by MAC command Association Response, actually demote the joining Coordinator to be an end device. Otherwise, it will set the lower byte of the short address for the joining Coordinator as 0x00 and send the short address to the joining Coordinator.

The format of Coordinator Response service is described in Table 8.

TABLE 8: COORDINATOR RESPONSE SERVICE FORMAT

	Report Type	Report ID	Report Payload	
Size	1	1	8	1
Value	0x00	0xA1	Long Address	Higher Byte of Short Address
Note	Protocol Report Type is 0x00	Report ID for Coordinator Response is 0xA1	The long address of the joining Coordinator	The higher byte of the short address of the joining Coordinator. 0xFF means out of Coordinator spot and the joining Coordinator must be demoted to be an FFD end device.

Family Tree Report

Family Tree Report is a protocol service that updates Coordinators with the latest network topology information. This protocol service will be multicast to all Coordinators from the PAN Coordinator once a new Coordinator joins the network. It is also used to report the up-to-date network topology information in response to a Family Tree Request protocol service. After receiving Family Tree Report protocol service, the Coordinators will update its network topology according to the new topology embedded in the service packet. The updated network topology will be saved into the NVM and used for the message routing.

The format of Family Tree Report protocol service is described in Table 9.

TABLE 9: FAMILY TREE REPORT SERVICE FORMAT

	Report Type	Report ID	Report Payload
Size	1	1	Number of Coordinators
Value	0x00	0xA3	Family Tree Info
Note	Protocol Report Type is 0x00	Report ID for Family Tree Report is 0xA3	The Family Tree Table that is formatted in Table 4.

Family Tree Request

Family Tree Request is a protocol service that requests the up-to-date network topology.

In many instances, network topology will be multicast to all Coordinators when PAN Coordinator accepts another Coordinator to join the network. However, there are a few situations that the network topology information needs to be retransmitted. If the Coordinator rejoins the same parent again for any reason, the parent of the Coordinator will not notify the PAN Coordinator, instead the parent will reassign the old short address to the joining Coordinator again. In this case, the network topology information will not be multicasted by the PAN Coordinator. The joining Coordinator will use Family Tree Request protocol service to request network topology information from its parent. If a Coordinator suspects that its network topology information is no longer up-to-date for any reason, the Coordinator may use Family Tree Request protocol service to request the latest network topology information from the PAN Coordinator.

The format of Family Tree Request protocol service is described in Table 10.

TABLE 10: FAMILY TREE REQUEST SERVICE FORMAT

	Report Type	Report ID
Size	1	1
Value	0x00	0xA2
Note	Protocol Report Type is 0x00	Report ID for Family Tree Report is 0xA2

Routing Table Report

Routing Table Report is a protocol service that reports the known neighboring Coordinators. It is usually used to establish the routing table between neighboring Coordinators by multicasting to all Coordinators in the radio range. To limit the range of the message coverage, the radius setting of Neighbor Table Report in MiWi PRO header is set to be 1, and there is no rebroadcast. Upon receiving the Routing Table Report from the original source, a Coordinator will respond with a Neighbor Table Report with its own neighbor table and update its routing table to mark the sender's Neighbor Table Report as directly accessible. In addition, the Coordinator that receives the Routing Table Report will update its Neighbor Routing Table with the information from within the Neighbor Table Report payload. Using Routing Table Report, a Coordinator not only is able to know its neighbors, it can also know its neighbors' neighbors. The neighbor tables are the foundation of mesh networking.

The format of Routing Table Report protocol service is described in Table 11.

TABLE 11: ROUTING TABLE REPORT SERVICE FORMAT

	Report Type	Report ID	Report Payload	
Size	1	1	1	(Number of Coordinators) / 8
Value	0x00	0xA4	Higher Byte of Short Address for Original Source Coordinator	Routing Table
Note	Protocol Report Type is 0x00	Report ID for Coordinator Response is 0xA4	The higher byte of the original source Coordinator. Used to identify if the Neighbor Table Report needs to be rebroadcast	The routing table of the source device. Since one bit to indicate if one Coordinator is accessible, the neighbor table size in BYTE is 1/8 of Coordinator Number

Frequency Agility Request

Frequency Agility Request is the protocol service that starts the frequency agility process. Usually, once a device detects a high percentage of packet delivery errors, or a Coordinator detects high noise level through periodic energy scans, it may send a Frequency Agility Request to the PAN Coordinator to start the Frequency Agility process. When to send Frequency Agility Request is totally up to the application, and MiWi PRO protocol stack does not define the timing of sending Frequency Agility Request protocol service.

After the PAN Coordinator receives Frequency Agility Request protocol request, it may start the frequency agility process by issuing Frequency Agility Energy Scan Request protocol service.

The format of Frequency Agility Request protocol service is described in Table 12.

TABLE 12: FREQUENCY AGILITY REQUEST SERVICE FORMAT

	Report Type	Report ID	Report Payload
Size	1	1	4
Value	0x00	0xB0	Bit Map of Potential Channel
Note	Protocol Report Type is 0x00	Report ID for Frequency Agility Request is 0xB0	Four bytes of bit map of channels that may be available to hop to during frequency agility. All channels that the sending device thinks not suitable for operating will have their representative bit reset in the report payload.

Frequency Agility Energy Scan Request

Frequency Agility Energy Scan Request is the protocol service that requests the destination Coordinators to perform an energy scan to check noise level on different channel at their locations. The channels to be scanned are embedded in the packet payload. Once the Frequency Agility Energy Scan Request is received by the Coordinators, the destination Coordinators will perform energy scan on the channels defined. All energy scan results will be stored in the RAM and be checked against the noise level threshold when Frequency Agility Suggest Channel protocol service is received.

The format of Frequency Agility Energy Scan Request protocol service is described in Table 13.

TABLE 13: FREQUENCY AGILITY ENERGY SCAN REQUEST SERVICE FORMAT

	Report Type	Report ID	Report Payload
Size	1	1	4
Value	0x00	0xB1	Bit Map of Potential Channel
Note	Protocol report type is set to be 0x00	Report ID for Frequency Agility Energy Scan Request is 0xB1	Four bytes of bit map of channels that needs to perform energy scan. Usually, those channels are potential candidate of channels that MiWi PRO networks can hop to.

Frequency Agility Suggest Channel

Frequency Agility Suggest Channel is the protocol service that the PAN Coordinator uses to suggest the channel the whole network should change to. After this protocol service is received, all Coordinators will check if the noise level at the suggested channel exceeds the predefined maximum noise level. In case the noise level at the suggested channel does exceed the predefined maximum noise level, the Coordinator will send out Frequency Agility Against Channel protocol service to the PAN Coordinator to disapprove the choice. If no Frequency Agility Against Channel protocol service is received by the PAN Coordinator within predefined time period, the PAN Coordinator will issue Frequency Agility Change Channel protocol service to direct the whole network to jump to the channel suggested in the latest Frequency Agility Suggest Channel protocol service.

The format of Frequency Agility Suggest Channel protocol service is described in Table 14.

TABLE 14: FREQUENCY AGILITY SUGGEST CHANNEL SERVICE FORMAT

	Report Type	Report ID	Report Payload
Size	1	1	1
Value	0x00	0xB0	Channel Number
Note	Protocol report type is set to be 0x00	Report ID for Frequency Agility Suggest Channel is 0xB2	The suggested channel number that the whole MiWi PRO network jumps to.

Frequency Agility Against Channel

Frequency Agility Against Channel is the protocol service that a Coordinator uses to against the suggested channel sent by Frequency Agility Suggest Channel protocol service. The Coordinators that receive Frequency Agility Suggest Channel service packet will compare the noise level at the suggested channel to the predefined maximum noise level allowed for operation. The noise level reading is acquired during energy scan that was started by Frequency Agility Energy Scan Request protocol service beforehand. If the noise level at the suggested channel exceeds the maximum noise level allowed for operation, the Frequency Agility Against Channel will be sent out to the PAN Coordinator to reject the suggested channel.

Upon receiving Frequency Agility Against Channel protocol service by the PAN Coordinator, it will remove the current suggest channel from the potential channels candidate list. It then selects the next channel in the candidate list with least noise and multicast to all Coordinators with Frequency Agility Suggest Channel protocol service. The format of Frequency Agility Against Channel protocol service is described in Table 15.

TABLE 15: FREQUENCY AGILITY AGAINST CHANNEL SERVICE FORMAT

	Report Type	Report ID	Report Payload
Size	1	1	1
Value	0x00	0xB0	Channel Number
Note	Protocol report type is set to be 0x00	Report ID for Frequency Agility Suggest Channel is 0xB3	The channel number that the Coordinator against the whole MiWi PRO network jump to, usually due to noise level exceeds predefined maximum noise level.

Frequency Agility Change Channel

Frequency Agility Change Channel is the protocol service that PAN Coordinator sends out to notify the whole network which channel to jump to. The channel to be jumped to has been universally accepted by all Coordinators on the network. After Frequency Agility Change Channel protocol service is received, the Coordinators will rebroadcast it and jump to the new channel embedded in the packet after a predefined time period.

The format of Frequency Agility Change Channel protocol service is described in Table 16.

TABLE 16: FREQUENCY AGILITY CHANGE CHANNEL SERVICE FORMAT

	Report Type	Report ID	Report Payload
Size	1	1	1
Value	0x00	0xB0	Channel Number
Note	Protocol report type is set to be 0x00	Report ID for Frequency Agility Change Channel is 0xB4	The Channel that the MiWi PRO network to jump to.

Programming Interfaces

The application programming interface from application layer to MiWi PRO protocol has been documented in detail in Microchip application note AN1284 "*Microchip Wireless Application Programming Interface – MiApp"* (DS01284). Refer this application note for configurations and prototype of function calls.

Configuration of MiWi PRO Networking Protocol

As compared against MiWi P2P and MiWi protocols that support a small network and cover a small area, MiWi PRO supports a large network with up to 64 Coordinators. The complexity of supporting a network protocol increases exponentially with the size of the network. To support increased number of Coordinators as well as more complex network topology and routing mechanism, there are extensive message exchanges when a new Coordinator joins the network. To ensure that the power cycle does not intervene the network operation, it is mandatory for MiWi PRO to enable Network Freezer feature, which stores critical network information into NVM and restore those settings after power on to the state before the power cycle without any message exchange. Due to such requirement, NVM resources are required to support MiWi PRO wireless networking protocol. In addition, to enable MiWi PRO network protocol, at application layer configuration file `ConfigApp.h`, `PROTOCOL_MIWI_PRO` should be defined, with both `PROTOCOL_P2P` and `PROTOCOL_MIWI` being commented out.

Additional configurations in protocol layer are also introduced in MiWi PRO protocol to provide the user flexibility and capability to fine-tune the behavior of MiWi PRO. Table 17 list all new configurations available to MiWi PRO protocol. All configurations in the table can be defined in protocol layer configure file `ConfigMiWiPRO.h`.

TABLE 17: NETWORK CONFIGURATIONS FOR MiWi™ PRO WIRELESS NETWORKING PROTOCOL

Example of Definition	Functionality	Restriction
`#define NUM_COORDINATOR 32`	Define the maximum number of Coordinators supported in the network. This definition has direct impact to RAM and NVM resources to be used by the stack.	Possible values are: 8, 16, 32 and 64. For PAN Coordinators, definition of `CONNECTION_SIZE` must be higher than `NUM_COORDINATOR`
`#define FAMILY_TREE_BROADCAST 3`	Define the number of broadcasts for Family Tree Report protocol service after a Coordinator joins the network.	To ensure delivery of the Family Tree table, it is recommended to set this value higher than 1.
`#define ROUTING_TABLE_BROADCAST 3`	Define the number of broadcasts for Routing Table Report	To ensure routing table accuracy on all coordinators, it is recommended to set this value higher than 1.
`#define COMM_RSSI_THRESHOLD 0x03`	Define the minimum signal strength that is acceptable for a Coordinator to route messages. A neighbor Coordinator that has signal strength that is higher than this threshold can be list as neighbor to be able to route message.	This setting usually is related to the signal strength interpretation for the specific RF transceiver. This value is represented by BYTE with 8-bit data width, thus should be less than 256.
`#define RANDOM_DELAY_RANGE 100`	Random delay range in milliseconds. When rebroadcast a message, it is recommended that a Coordinator should introduce a random delay to avoid multiple Coordinators rebroadcast and collide the messages at the same time. The actual random delay will be randomly selected between 0 and `RANDOM_DELAY_RANGE`.	This setting is recommended to be set higher than 20. The value is represented by BYTE with 8-bit data width, thus should be less than 256.
`#define PACKET_RECORD_SIZE 5`	`PACKET_RECORD_SIZE` define the parameter that specifies the maximum number of packet record available. Packet record is used to track the broadcast messages so that the wireless node knows if the same packet has been received before.	To ensure filtering out duplicate packet, thus value must be set higher than 1, but less than 256. Each packet record structure consumes 8 byte RAM.
`#define PACKET_RECORD_TIMEOUT (ONE_SECOND/2)`	`PACKET_RECORD_TIMEOUT` defines the timeout in symbols for a node to expire its packet record. The packet record is used to track the received packets and to prevent receiving duplicate broadcast message. This definition is only valid for a non-sleeping device.	This definition should be the time in symbols that ensures no duplicate message will be received beyond this time. One symbol is 16 us. To ensure remove duplicate message for unicast, this value must be higher than 4 ms. To ensure remove duplicate broadcast, it is transceiver dependent, but generally must be higher than 100 ms.
`#define FA_MAX_NOISE_THRESHOLD 0x30`	`FA_MAX_NOISE_THRESHOLD` defines the maximum noise level that a Coordinator accepts for a channel to avoid sending out Frequency Agility Against Channel protocol service when a new channel is proposed by PAN Coordinator to hop to during frequency agility operation.	This setting usually is related to the signal strength interpretation for the specific RF transceiver. This value is represented by BYTE with 8-bit data width, thus should be less than 256.

TABLE 17: NETWORK CONFIGURATIONS FOR MiWi™ PRO WIRELESS NETWORKING PROTOCOL (CONTINUED)

Example of Definition	Functionality	Restriction
`#define FA_WAIT_TIMEOUT ((ONE_SECOND) * 2)`	`FA_WAIT_TIMEOUT` defines the timeouts in symbols during the frequency agility process. Those timeouts include timeout for all Coordinators to start energy scan; timeout for the PAN Coordinator to receive Frequency Agility Against Channel protocol service after a channel is suggested and timeout for all devices to jump to the new channel after receiving Frequency Agility Change Channel protocol service.	To leave granularity for the protocol to run smoothly, it is recommended to set this timeout higher than 1 second.
`#define FA_BROADCAST_TIME 0x03`	`FA_BROADCAST_TIME` defines the total number of times to broadcast frequency agility related messages: the energy scan requests and the channel change requests, to the rest of PAN.	To ensure delivery of the broadcast message for the frequency agility operation, it is recommended to set this value higher than 1.
`#define FA_COMM_INTERVAL (ONE_SECOND)`	`FA_COMM_INTERVAL` defines the time interval between broadcasting the frequency agility related message for `FA_BROADCAST_TIME` times.	To leave granularity for the protocol runs smoothly, it is recommended to set this timeout higher than a half second.
`#define ENABLE_ROUTING UPDATE`	Enable the routing update feature to update routing table dynamically	
`#define ROUTING_UPDATE_INTERVAL (ONE_HOUR)`	Defines the routing update interval in symbols	This definition is within 4 bytes
`#define ROUTING_UPDATE_EXPIRATION 3`	Defines the total number of `ROUTING_UPDATE_INTERVAL` has passed before a valid routing path is expired without a valid Route Table Report update	Must be higher than 1, typically less than 10

SYSTEM RESOURCES REQUIREMENTS

MiWi PRO requires more system resources to support a much larger network. Even though the MCU hardware peripheral requirements are the same as MiWi P2P and MiWi, the ROM and RAM resources requirements for MiWi PRO are higher. Table 18 and Table 19 lists the basic ROM and RAM resources requirement for MiWi PRO when MRF24J40 transceiver for the original release on PIC18. There will be slight difference when a different family of MCU serves as host, a different transceiver is used and for subsequent releases.

TABLE 18: ROM AND RAM REQUIREMENTS FOR MiWi™ PRO COORDINATORS

Features	ROM Requirement (Byte)	RAM Requirement (Byte)
Basic	16291	Stack Size + (TX_BUFFER_SIZE * 2) + (RX_BUFFER_SIZE * BANK_SIZE) + (CONNECTION_SIZE * 16) + (PACKET_RECORD_SIZE * 8) + (NUM_COORDINATOR * (2 + NUM_COORDINATOR/8)) + (ACTIVE_SCAN_RESULT_SIZE * 14) + 100 bytes
Smallest Footprint with no inter PAN capability	-1260	0
Energy Scan	+420	0
Security	+1122	+56
Indirect Message	+1496	+(INDIRECT_MESSAGE_SIZE * 128)
Frequency Agility	+1890	+41
Enhanced Data Request	+1509	+(INDIRECT_MESSAGE_SIZE * 128)
Time Synchronization	+2416	+(INDIRECT_MESSAGE_SIZE * 128) +40
Routing Update	+332	+(4 + NUM_COORDINATOR)

TABLE 19: ROM AND RAM REQUIREMENT FOR MIWI™ PRO END DEVICES

Features	ROM Requirement (Byte)	RAM Requirement (Byte)
Basic	10734	Stack Size + TX_BUFFER_SIZE + (RX_BUFFER_SIZE * BANK_SIZE) + (CONNECTION_SIZE * 16) + (PACKET_RECORD_SIZE * 8) + (ACTIVE_SCAN_RESULT_SIZE * 14) + 100 bytes
Smallest Footprint with no inter PAN capability	-870	0
Sleep	+638	+4
Security	+1124	+74
Frequency Agility	+412	+9
Enhanced Data Request	+520	+4
Time Synchronization	+542	+8

ADDITIONAL CONSIDERATION

To support a much bigger network, MiWi™ PRO user needs to pay additional attention to operations of MiWi PRO network and its configurations.

Following are the list of additional considerations:

1. Due to the extensive message exchanges when a new Coordinator node joins the network, it is recommended that following precaution should be made:
    a) In order to receive multiple packets before processing the previous one, the received buffer bank size is recommended to be configured higher than `1` in transceiver configuration file `Config<Transceiver Model>.h.`
    b) MiWi PRO protocol stack has been programmed to take care of timing of message exchange during the joining process, but two or more Coordinators joining the network at the same time still introduces higher percentage of packet loss due to packet traffic control. It is highly recommended that user introduce at least 30 seconds interval between two Coordinators to join the network.
2. Due to different network role for PAN Coordinator and Coordinator, the PAN Coordinator needs to store all Coordinators that have joined the network. As the result, the CONNECTION_SIZE parameter for PAN Coordinator in file `ConfigApp.h` needs to be larger than the maximum number of Coordinators within the network. On the other hand, Coordinator may not need to store all other Coordinators in its connection table, thus CONNECTION_SIZE can be set much smaller. Since CONNECTION_SIZE is associated with RAM and NVM usage, the system resources requirements are higher for PAN Coordinator than Coordinators.
3. Due to differences of addressing mechanism in MAC layer, when Microchip sub-GHz transceivers are used as Coordinator, all known Coordinators within the routing table must have a record in the connection table. On the other hand, IEEE 802.15.4 transceiver does not have such requirement. As the consequence, the Coordinators for subGHz transceivers usually define a larger CONNECTION_SIZE parameter in file `ConfigApp.h`, compared to IEEE 802.15.4 transceiver, thus requiring more system resources in RAM and NVM.
4. Network Freezer feature is mandatory for MiWi PRO. It is highly recommended that in the real application, by default, Network Freezer is turned on when powering up. The installer of the wireless system could temporarily turn off Network Freezer and have the device joining the network by pushing a button, short a jumper or any other means. A magic number can be written to a specific address in NVM to indicate if network information is already stored, but physical mechanism to notify the MCU may be a more reliable and flexible approach to use Network Freezer feature.

CONCLUSION

MiWi Development Environment has provided stable and flexible solution for most of wireless applications. As one of the wireless protocols in MiWi DE, MiWi PRO provides much better support for large networks up to 64 Coordinators, up to 65 hops communication distance and up to 8 thousand devices on the same network. The larger network support in MiWi PRO protocol only causes a moderate increase in system resources. In addition MiWi PRO, inherited the MiMAC and MiApp interfaces from MiWi DE, users of MiWi PRO are able to switch any RF transceiver and port from any other families of MiWi proprietary wireless protocols. Such flexibility and scalability in MiWi PRO, as well as MiWi DE system as a whole, provide a solid foundation for the success of user application development for a larger network.

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REVISION HISTORY

Revision A (February 2011)

This is the initial release of the document.

NOTES:

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