eNode Theory of Operation

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Revision History

Revision	Release Date	Change Description
01	February 1, 2010	Initial release for FCC submittal.
02	February 12, 2010	Addressed comments received from TCB: control of regulatory domain operations.
03	September 10, 2010	Updated for R8.
04	October 21, 2011	Updated for R11.

1 Introduction

1.1 Scope

This document provides a technical description of the Ultra-Link Processing™ (ULP) eNode characteristics and operational functions. It applies to the eNode represented by the following version numbers:

- eNode model ULPN120 (part #550-0004-02)
- eNode firmware version 4.5.25

1.2 References

- Node FCC/IC/ETSI EMC Compliance Test Procedures (009-0021-00)

2 System Overview

Ultra-Link Processing™ (ULP) is the first wireless system purpose-built to solve the challenges of metro scale and other challenging radio environments for sensor, metering and asset tracking data. The technology addresses problems limiting wide-scale deployments of wireless sensors and metering devices, such as signal range and robustness to interference. Operating in un-licensed spectrum, the ULP signal processing innovation finds weak signals even in high noise environments, yielding extreme coverage, high level of immunity to interference, and significantly lowers the cost to deploy and operate a network.

On-Ramp Wireless' field-demonstrated, receive sensitivity of -142 dBm, provides greater than 25x range advantage over existing technologies while maintaining extremely low power performance. ULP also uses a new high capacity multiple access scheme called Random Phase Multiple Access™ (RPMA). This technology offers a higher capacity system, which translates, to a higher number of users in the same area with lesser infrastructures. Ultra-Link Processing is based upon direct sequence spread spectrum (DSSS) communication.

2.1 ULP Network Architecture

The ULP system architecture bears many similarities to the familiar cellular wireless voice and data networks providing commercial services today, but with much higher performance and lower cost for many of the applications found within the Smart Grid, device monitoring, and location services. The Network Architecture (see Figure 1) shows the components of the ULP system. Wireless coverage is provided to endpoints via a network of one or more Access Points deployed over the intended coverage area. The On-Ramp Wireless Gateway provides management control functions for the Access Points and Nodes within the network and serves as a single point of entry into the On-Ramp Wireless ULP Packet Data Network.

On the network side, the On-Ramp Wireless Gateway interfaces to the application entities for user data and to a management entity or Network Management System (NMS)/Network Operating Center (NOC) for system management functions. On the Node side, the endpoint device interfaces to the On-Ramp Wireless eNode, providing a packet data communications facility.

Services provided by the On-Ramp Wireless Packet Network System include:

- Two-way packet data connections to up to 64,000 endpoints per Access Point
- Mobility management across coverage boundaries of the Access Points.
    - Aggregation of traffic in the Uplink direction
    - Routing of traffic in Downlink direction
- Dynamic Access Point selection for stationary Nodes, allows switching between Access Points which are configured on the same channel.
    - Ensures connectivity in spite of changing channel conditions for edge of coverage users
    - Provides seamless, ubiquitous coverage for Uplink and Downlink traffic without any disruption in data traffic flow

- Reliable and best effort packet delivery
- Authentication, Authorization of end devices
- Network Management (maybe separate from user services).
- DL broadcast data over broadcast channel. Supports system wide configuration updates, notifications, and firmware download
- DL multicast data. Supports group configuration and control.
- Security, Auditing, and Diagnostic Functions
- Access Point and Node channel agility between up to 5 preset channels ensuring deployment flexibility and on-the fly optimization
- Scheduled and on-demand traffic configurable by the NMS
- Battery operated device traffic management using schedule traffic function;
  - Scheduled traffic is particularly important for battery operated users which cannot afford to be always on and listening for communications due to battery life constraints
  - Scheduled traffic supports a wide range of sleep cycles for maximum battery life.
  - Supports paging function for optimal battery life
- Node endpoint synchronization services. Due to precisely synchronized Access Points (APs) nature of the DSSS communications link, end points are tightly synchronized – supporting a variety of advanced analysis and correlation functions.
  - Precise time stamping for events data
  - Calibration of time sensitive devices such as leak or fault sensors

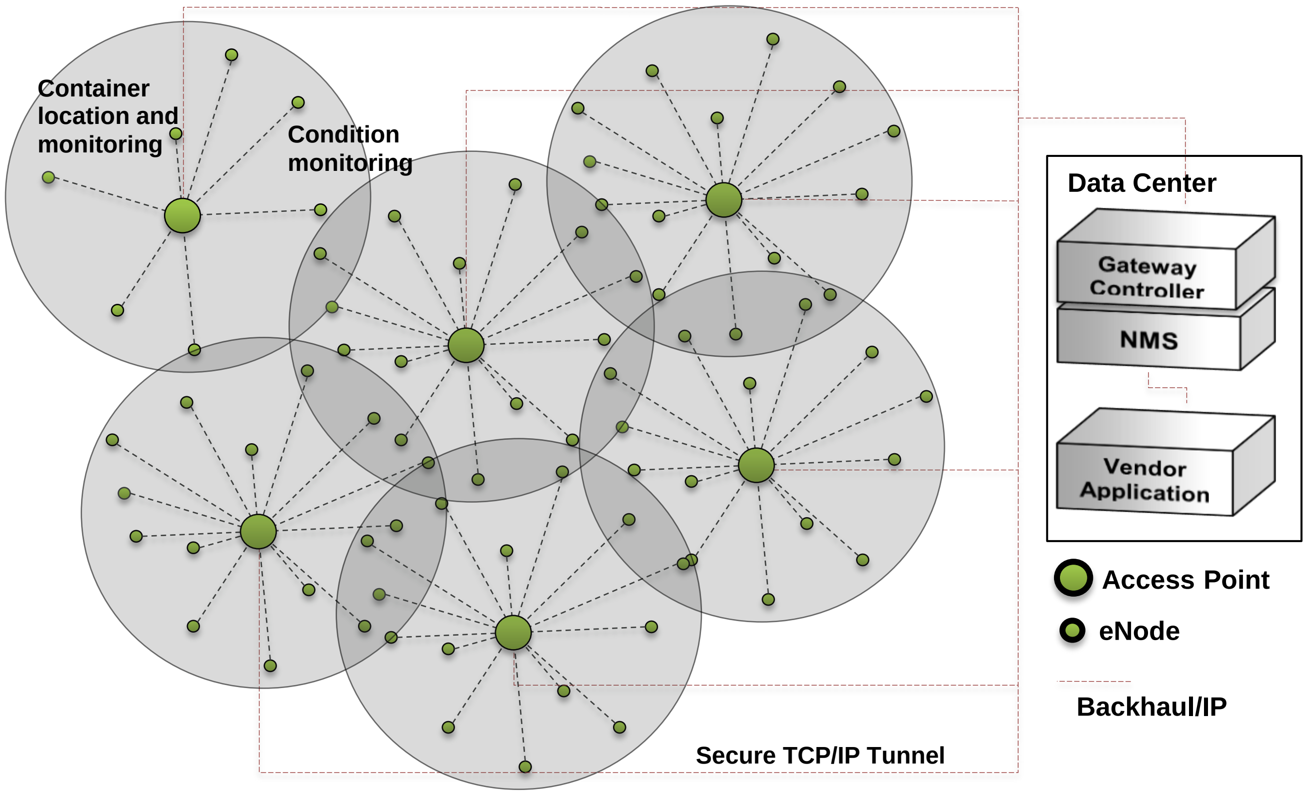

Figure 1. ULP Network Architecture

2.2 System Operation

2.2.1 Network Deployment

A ULP network consists of the On-Ramp Wireless Gateway (physically a redundant hardware platform, typically a Linux box, running load sharing network applications), which is securely connected to a collection of APs. The APs are identified by a specific channel/frequency (1 MHz bandwidth assignment), and a Gold Code, used for spreading the wireless signal. Each of the APs within radio proximity of each other can be distinguished by radio channel, by code, or both. Commonly a single channel is used across multiple APs. APs are time-synchronized via a GPS source embedded in the AP, keeping uplink and downlink frame time synchronization across the network. The APs, in turn, communicate with the Nodes within coverage.

The Network may also be deployed with multiple channels (separate frequencies) providing coverage to the same geographic area. This may be desired to increase the network capacity that can be served – either more endpoints or higher bandwidth applications – within the coverage area, or to provide a measure of redundancy, or both. The following figure depicts an example of such a deployment with two channels of coverage. Independent networks of APs provide each layer of coverage. APs are likely, but not necessarily, co-located. A single Gateway provides control and management functionality to both layers of coverage and a Node may access communication services on either channel.

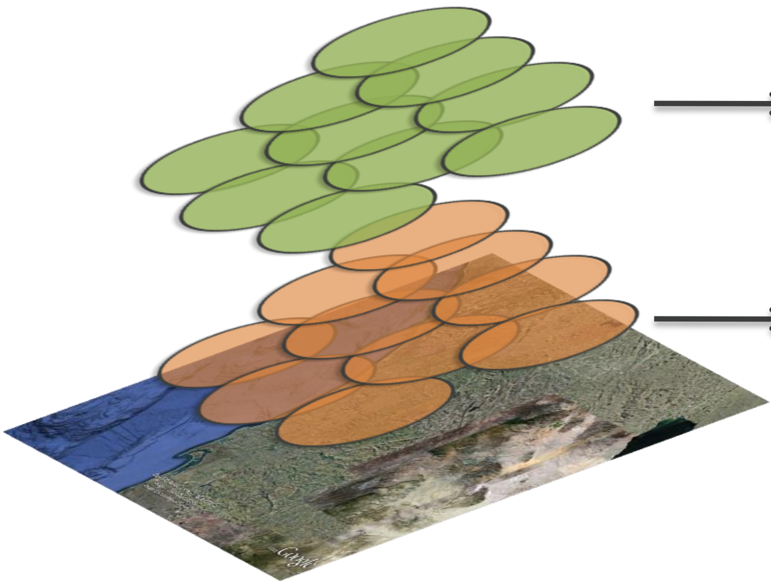

Figure 2. Network Deployment Showing APs Separated by Gold Code on 2 Distinct Channels

Deployed APs are always powered on and transmitting a Broadcast Channel, which provides a mechanism for Nodes to acquire the network and receive system information. After acquiring the Network, a Node will perform a Join Procedure to register itself with the network and begin making use of system services.

The essential operation of the system consists of Time Division Duplex (TDD) operation with a TDMA (Time Division Multiple Access) scheme in the Downlink and a proprietary multiple access scheme in the uplink. The general frame structure is shown in the following figure. The downlink and uplink transmit times are occupied by AP transmissions (downlink) and eNode transmissions (uplink) sent at a dynamically varying amount of processing gain (or spreading factor) per eNode based upon the eNode's current channel conditions.

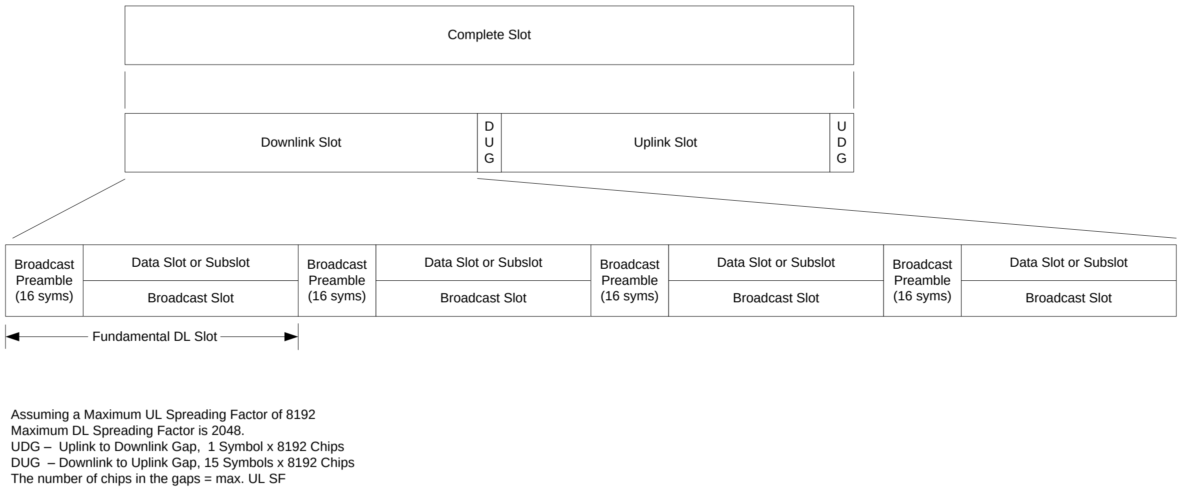

Figure 3. ULP System Frame Structure

2.2.2 ULP eNode Functions

The ULP eNode provides the communication capability for the endpoint, managing all aspects of the wireless communications with the network. The following figure shows a simplified model of the eNode function, including its basic acquisition, tracking, searching, receive, and transmit functions. When the Node acquires and joins the network, it essentially performs receive and transmit functions as required, along with the track and search procedure to manage mobility and changing wireless link conditions. Whenever there is no action to perform, the Node sleeps, conserving power.

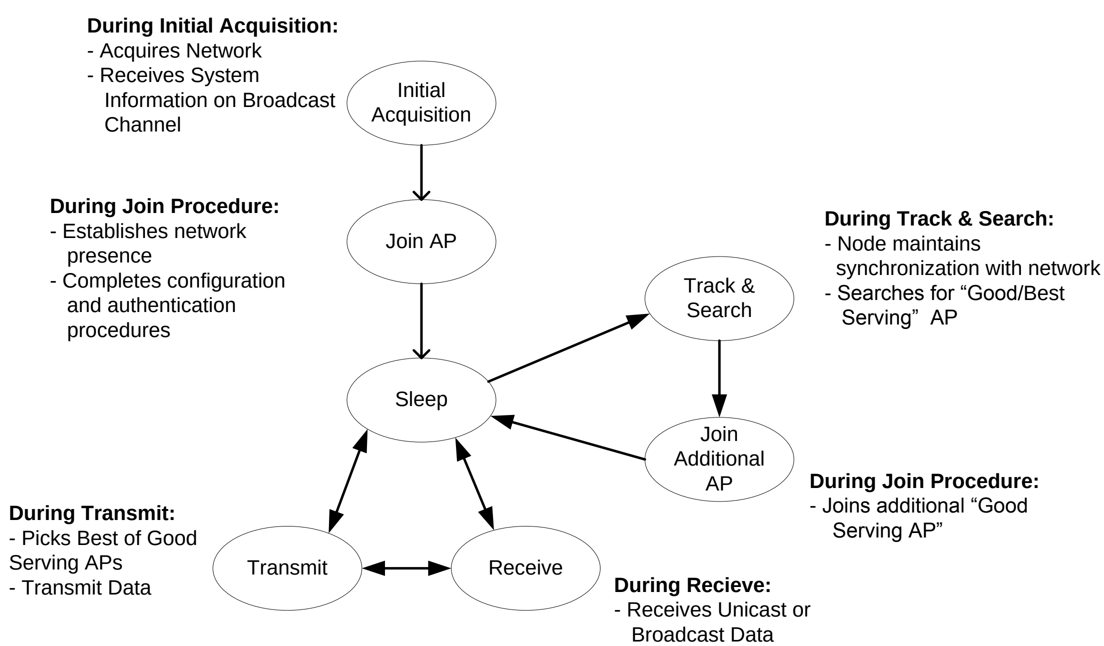

Figure 4. Simplified Node State Machine

3 eNode Technical Description

3.1 eNode Overview

3.1.1 Overview

The ULP eNode is a completely self-contained, FCC and ETSI certified communications module exposing an MMCX antenna port and digital signal pins for a low-power Serial Peripheral Interface (SPI) bus for interfacing with endpoint devices. On-Ramp Wireless provides an open software Application Programming Interface (API) and sample eNode device driver code, enabling easy integration for a variety of applications. The ULP wireless eNode can communicate with existing and planned systems, while allowing these systems to preserve upper layer protocol and application functionality.

Figure 5. ULP eNode

3.1.2 Interface

Physical interface to the eNode consists of a SPI bus with hardware signals for bi-directional wake-up and power management. An open interface description and code example provides an interface to configure and control the Node, and to send and receive Service Data Unit (SDU) packets.

The air interface supports operation on channels in the 2402 MHz – 2476 MHz range for FCC/IC regulatory domains and 2402-2481 for the ETSI regulatory domain.

Before the ULP eNode becomes operational, it must undergo a commissioning procedure, during which critical information required for operation is entered into the device and stored in non-volatile storage. It is during the initial commissioning procedure that the regulatory domain under which the device will operate is set. Subsequent configuration of the device during operation is checked against the commissioned regulatory domain and non-permitted channels or transmit power levels are rejected and the device will not transmit until a permissible configuration per the commissioned regulatory domain is set.

3.1.3 Physical Characteristics

The ULP eNode has a unified Radio Frequency (RF) and digital ground. The antenna connector makes use of the unified ground.

Table 1. Physical Characteristics

Physical Dimensions	26 mm (W) × 57 mm (H) × 9 mm (D)
Operating Temperature	-40 °C to 85 °C
Security	AES 128/256-bit encryption
Interfaces	SPI, UART

3.1.4 Performance

The ULP eNode specifications include:

- Industry leading range and capacity for wireless sensor network
- Low power with up several years of battery life
- 2.4 GHz free ISM-band using direct-sequence spread spectrum (DSSS) for increased robustness
- Down to -136 dBm receive sensitivity (balances -142 dBm uplink receive sensitivity)
- 100mW transmit power
- Dynamic receive sensitivity maximizes data rate and power savings
- AES 128/256-bit encryption
- Small form factor
- Completely engineered module ready for easy integration by Original Equipment Manufacturers (OEMs) into existing or planned products
- Supports open industry standard sensor interfaces
- Open software API for easy and quick integration

3.2 eNode Architecture

The key components of the eNode architecture and their functions are as follows:

- ARM7 MCU Flash 256k – AT91SAM7X256, provides the following eNode functions:
  - SPI slave interface
  - eNode power management
  - eNode ULP MAC system functions
  - Radio control functions via SPI
  - Test mode controller
- eASIC – Modem Processor
  - Low-level transceiver and AFE control
  - Digital Rx filtering
  - Rx AGC control of transceiver

- System acquisition processing
- Receive demodulation processing
- Rx RSSI estimation
- Viterbi decoding
- Rx MAC PDU delivery to ARM7
- Rx Test Mode processing
- Low-level Tx PDU scheduling
- Tx digital gain control
- Tx AGC control of transceiver

- AFE MAX19707 – Analog Front End
  - I/Q channel receive ADC – 26 MHz, 10-bit
  - I/Q channel transmit DAC – 26 MHz, 10-bit
- RF XCVR – MAX2830 Transceiver
  - Direct down-conversion of received signals
  - Direct up-conversion of transmit signals
  - Filtering, variable gain
  - The local oscillator (LO) generated by the MAX2830 Transceiver is the same as the frequency operation since it is a direct conversion receiver. The LO is programmed to be the desired channel of operation and is between 2402 MHz and 2476 MHz for FCC/IC regulatory domains, and between 2402 MHz and 2481 MHz for ETSI regulatory domains.

The ULP eNode high level architecture is shown in the following figure.

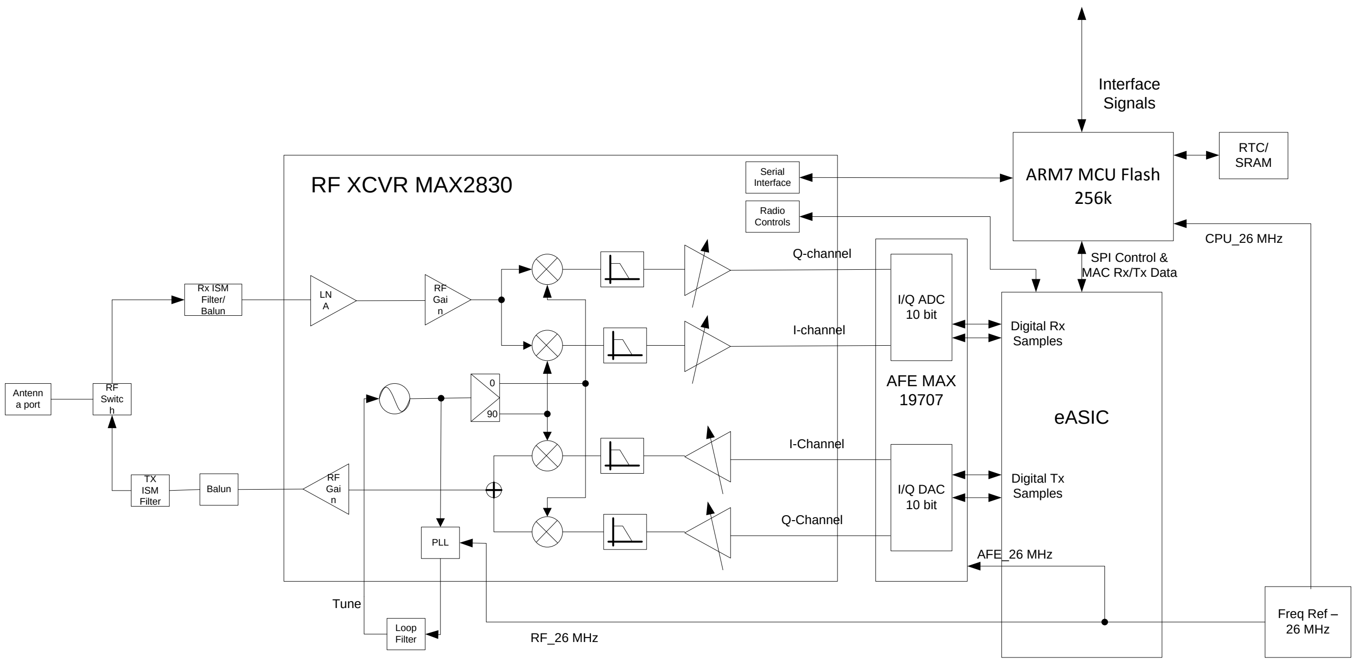

Figure 6. eNode High Level Architecture

Operationally, the eNode is intended to be used with a host system, providing control and configuration of the eNode as well as be the source and destination of transmitted and received data respectively.

1. When the eNode is powered on and configured, it attempts to acquire the Broadcast Channel of an AP for which the eNode has been configured.
2. Upon successful acquisition, the eNode will perform a Join procedure to register with the ULP Network.
3. Upon joining the network, the eNode will enter a steady state cycle of transmission attempts, reception attempts, and system tracking either upon a preset schedule, or asynchronously as commanded by the SPI master. For each Transmission/reception cycle the eNode will:
    a. Estimate the RSSI of the downlink signal from the AP.
    b. Use the RSSI estimate to select a spreading factor/processing gain for the attempted uplink transmission and perform the transmission at the selected processing gain. Note that this may occur over multiple frames.
    c. Attempt to receive the downlink transmissions at a particular processing gain that is a function of the processing gain used in the uplink transmission.

3.3 eNode Interfaces

3.3.1 SPI Slave Interface

The SPI Slave eNode Interface provides communication with an external host via a serial peripheral interface (SPI). The host is the SPI master and the eNode is the SPI slave. In addition to the standard SPI signals, a host-to-node wakeup request, a node-to-host status and a node-to-host transmit request are included to support eNode state transitions and bi-directional message traffic. The signals used between the SPI Master and SPI slave are described in the following table.

Table 2. SPI Interface Signal Description

Pin Name	Pin #	Pin Description	Master	Slave	Remark
SPI-MISO	J701, 8	Master In Slave Out	In	Out	SPI Bus data line in the direction of slave to master.
SPI-MOSI	J701, 7	Master Out Slave In	Out	In	SPI Bus data line in the direction of master to slave.
SPI-SCLK	J701, 6	Serial Clock	Out	In	SPI Bus clock driven by master. Depending on how polarity and phase are configured, this clock's edges indicate when the data on MISO and MOSI are valid.
SPI-MRQ	J703, 6	Master Request	Out	In	Driven by the master to indicate to slave that SPI activity needs to take place. If the slave is sleeping, this signal will wake it up. When the slave detects this signal high, it must respond by driving Slave Ready high.
SPI-SRDY	J703, 7	Slave Ready	In	Out	Driven by the slave to indicate to the master that it is awake and ready to perform SPI Bus transactions.
SPI-SRQ	J703, 8	Slave Request	In	Out	Driven by the slave to indicate that it wishes to send a message over SPI Bus to the master. This is necessary since master drives the clock and this gives the slave a way to inform the master that the slave wishes the clock to be driven.
SPI-CS0	J701, 5	SPI Chip Select	Out	In	Used by Master to select which slave it is communicating with over SPI Bus
RXD0	J701, 1	Serial 0 Receive	Out	In	Reserved for future use.
TXD0	J701, 2	Serial 0 Transmit	In	Out	Reserved for future use.

Pin Name	Pin #	Pin Description	Master	Slave	Remark
T_OUT	J701, 3	Time Synchronization Signal	In	Out	Low-level signal for Slave to indicate timing of frame boundary events
RESET	J701, 4	eNode Reset	Out	In	Provides Host with ability to reset the eNode.
RXD1	J703, 3	Serial 1 Receive			Reserved for future use
TXD1	J703, 4	Serial 1 Transmit			Reserved for future use
VBATT1	J703, 1				
VBATT2	J703, 2				
GND	J701, 9				
GND	J701, 10				
GND	J703, 5				
GND	J703, 9				
GND	J703, 10				

3.3.2 Antenna Interface

The eNode is intended to operate with the following antennas:

- 2.4 GHz Fixed Mount Swivel Antenna – 181 Model. 2 dBi gain, Part # S181FL-L-RMM-2450S from NEARSON: ftp://ftp2.nearson.com/Drawings/Antenna/S181FL-L-RMM-2450S.pdf
- 2.4 GHz Fixed Mount Swivel Antenna – 151 Model. 5 dBi gain. Part # S151FL-L-RMM-2450S from NEARSON: ftp://ftp2.nearson.com/Drawings/Antenna/S151FL-L-RMM-2450S.pdf
- 2.4 GHz 1 dBi Rubber Duck Antenna – MMCX Plug Connector 1 dBi gain. Part # HG2401RD-MMCX from Hyperlink Technologies: http://www.l-com.com/item.aspx?id=22050

Appendix A Abbreviations and Terms

Abbreviation/Term	Definition
ADC	Analog-to-Digital Converter
AGC	Automatic Gain Control
AP	Access Point. The ULP network component geographically deployed over a territory.
API	Application Programming Interface
DAC	Digital-to-Analog Converter
DSSS	Direct Sequence Spread Spectrum
eNode	A small form factor wireless network module that works in combination with various devices and sensors. Also referred to as Node.
ETSI	European Telecommunications Standards Institute
FCC	Federal Communications Commission
IANA	Internet Assigned Numbers Authority
IC	Industry Canada
I/Q	In-Phase/Quadrature
LO	Local Oscillator
MISO	Master In Slave Out
MOSI	Master Out Slave In
NMS	Network Management System
NOC	Network Operating Center
Node	Also known as eNode. The generic term often used interchangeably with eNode.
OEM	Original Equipment Manufacturer
PDU	Protocol Data Unit
RF	Radio Frequency
RPMA	Random Phase Multiple Access
RSSI	Receive Signal Strength Indicator
RX	Receive / Receiver
SDU	Service Data Unit
SPI	Serial Peripheral Interface
TX	Transmit / Transmitter
TDD	Time Division Duplex
TDMA	Time Division Multiple Access
UART	Universal Asynchronous Receiver/Transmitter
ULP	Ultra-Link Processing™. The On-Ramp Wireless proprietary wireless communication technology.