WaveNet IP 2458

System Description

Abstract

This document contains the theory of operation information required for FCC Type Certification.

FCC ID: EV9WNIP2458C
FCC ID: EV9WNIP2458R

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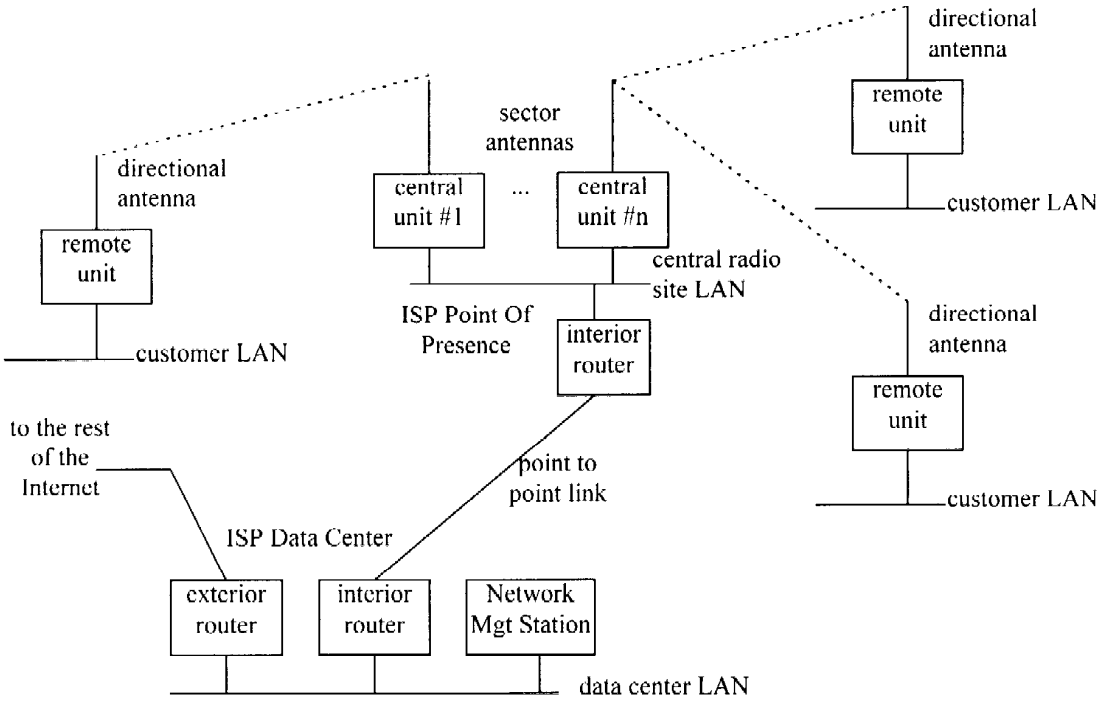
General System Overview

The *WaveNet IP 2458* system is a frequency hopping spread-spectrum wireless point-to-multipoint data communications system, operating simultaneously in both 2.4 and 5.8 GHz ISM bands. It is intended to provide reliable data transmission between remote location networks/devices and a central location. The system is tailored to provide internetworking communications, but could be extended for use with other transaction-oriented data traffic. The system will accept IP data packets of up to 1500 bytes from central and remote site networks/devices, and route these packets between central and remote site networks/devices in a manner consistent with typical industry internetwork access routers.

The number of remotes supported by the system is determined by the amount and type of traffic created by the end devices and the maximum delay permitted. The capacity can only be determined after the traffic characteristics of the attached devices/networks is known; however, the objective is to support at least 250 remotes sites per central site.

The *WaveNet IP 2458* system is expected to be managed with a network management system, NMS. This system provides the capability to monitor and control the network from any internetwork-connected location.

The system is illustrated in the figure below. The Remotes and Centrals are connected to local routers, or local computer systems via Ethernet/802.3. It is also possible for the Central to have no local connections, functioning only as a router for traffic between Remotes. The NMS can be connected via the Central or Remote sites.



Each Central Unit will typically cover no more than a 120 degrees arc, and up to 10 Central Units may be located at any single central site (testing limit only). The Central Units may cover overlapping arcs. It is possible to use an omni-directional antenna for a Central Unit, at a

reduced distance due to lower antenna gain. At first release, 60 Remotes will be supported by each Central Unit (e.g. a single central site with 10 Central Units could support 600 Remotes). Multiple Central Units would typically share a single point-to-point link to the central site, NMS, and server resources located at the central site. The central site may simply be a relay point into a backbone network, in which case an exterior router would connect to the Central and provide a WAN link perhaps using VSAT, point-to-point narrowband radio, or copper cable connection. Other point-to-point links may be used to connect several Central sites together, or to connect high traffic remotes (such as server locations) into the network.
To make efficient use of the radio channel, media access control (MAC) and link layer communications protocols are implemented. This protocol permits reliable data transport and multiplexing of multiple logical connections between the central and the remotes, insuring that the system will continue to function well even in periods of peak demand.

Theory of Operation

FCC ID: EV9WNIP2458C, Central Unit.
FCC ID: EV9WNIP2458R, Remote Unit.

Radio Boards (Central and Remote)

The *WaveNet IP 2458* radio operates in the 2400 MHz and 5800 MHz ISM bands using frequency hopping spread spectrum. The radio hops between 79 channels in the frequency ranges of 2403 to 2481 MHz and 5770 to 5848 MHz. A Central transmits in the 2403 to 2481 MHz band and receives in the 5770 to 5848 MHz band. A Remote transmits in the 5770 to 5848 MHz band and receives in the 2403 to 2481 MHz band. The channel step size is 1 MHz. There are a total of 26 unique pseudo-random hopping sequences that can be selected. GMSK modulation is used to obtain 850 kbps raw data rate in a 20 dB occupied bandwidth of 1 MHz.

The *WaveNet IP 2458* operates full duplex. Every 40 milliseconds it hops to another channel frequency, and once a Remote is synchronized with a Central, it too will hop every 40 milliseconds in synchronization with the central. While a Remote is attempting to synchronize with a Central (acquisition mode) it will hop from one frequency to another every 300 milliseconds. A Remote's transmitter remains off until it synchronizes with a Central.

A Central will transmit a minimum of 3, and a maximum of 40 data packets during each 40 millisecond frequency dwell. A Remote will transmit a minimum of 0, and a maximum of 27 data packets during each 40 millisecond frequency dwell. The *WaveNet IP 2458* radio link operates a proprietary protocol that is controlled by the Router board. The Router board controls transmit and receive functions, as well as the frequency hopping.

On the transmit side of a Central, digital data is fed to the modulator, where the incoming bit stream is translated into digital baseband 0.4 GMSK modulation. The digital modulation is then fed to a pair of digital to analog converters which convert the signals into the analog I/Q baseband channels. The baseband signals are low pass filtered and then fed to an I/Q modulator whose output is 478 MHz. After amplifying and filtering the 478 MHz intermediate frequency is

upconverted to the transmit frequency range of 2403 to 2481 MHz. The signal is then amplified and filtered to generate a +24 dBm maximum output level. To accommodate several different antenna gains, the transmit output power is settable from +15 to +24 dBm in 1 dB increments.

On the transmit side of a Remote, digital data is fed to the modulator, where the incoming bit stream is translated into digital baseband 0.4 GMSK modulation. The digital modulation is then fed to a pair of digital to analog converters which convert the signals into the analog I/Q baseband channels. The baseband signals are low pass filtered and then fed to an I/Q modulator whose output is 2160-2260 MHz. After amplifying and filtering the 2213 MHz intermediate frequency is upconverted to the frequency range of 5770 to 5848 MHz. The signal is then amplified and filtered to generate a +24 dBm maximum output level. To accommodate several different antenna gains, the transmit output power is settable from +15 to +24 dBm in 1 dB increments.

On the receive side of a Central, the low level signal is amplified, filtered, then down converted to an intermediate frequency range of 2160-2260 MHz. The 2160-2260 MHz IF is then down converted to the intermediate frequency of 240.25 MHz, which is further amplified and filtered. The 240.25 MHz IF signal is then fed to a quadrature detector. A clock recovery and data timing circuit follows the quadrature detector to synchronize the data before sending it to the Router board.

On the receive side of a Remote, the low level signal is amplified, filtered, then down converted to an intermediate frequency range of 240.25 MHz. The 240.25 MHz IF signal is then fed to a quadrature detector. A clock recovery and data timing circuit follows the quadrature detector to synchronize the data before sending it to the Router board

Frequency hopping is achieved hopping by the frequency synthesizer that is used as the local oscillator for both the upconverter and downconverter stages. By hopping this synthesizer in 1 MHz steps the corresponding transmit and receive frequencies will also change. One of 26 pseudo-random hopping sequences is set at the time of installation.

Radio Protocol Operation

The radio protocol controls the time when data is transmitted and received over the radio channel, and when it hops to the next frequency in the hopping sequence.

WaveNet IP 2458 operates in a full duplex mode, meaning that the transmitter is always on, except for a short period when the frequency hopping occurs. Every 40 milliseconds (dwell time) the system hops in synchronism to the next frequency in the hop sequence. Within each 40 millisecond dwell time the central will transmit at least three frames and a remote can transmit up to four frames.

The central site radio controls the hopping for all of the radios in the network. During each dwell (hop) the central always transmits outbound data frames, a beacon, and two other protocol

frames. The outbound data frames are bit stuffed when there is not enough live data traffic to fill them.

The central site is continuously cycling through all of the 79 channels in the hop sequence, hopping to a new channel every 40 milliseconds, and transmitting data frames, a beacon, and two other protocol frames.

As all of the remotes hear the central, the fixed timing of the beacon and other protocol frames are used to synchronize the dwell timing of the remotes. Once synchronized, the remotes use the timing of the beacon and protocol frames to determine position within the dwell, and then hop to the new channel at the appropriate time. Hop sequences are programmed into the Central radio only. When a Remote hears a transmission from a Central with the correct network ID (rfNetId), the Remote will derive the hop sequence number from the Central beacon data. The Remote will then use this hop sequence to track the Central. The hopping at the remotes takes place regardless of whether a remote has data to transmit.

Remotes must synchronize with the central before they are allowed to transmit. The initial turn on synchronization for a remote consists of a very slow hop, around 300 msec, where the remote is not transmitting, but sitting on a frequency, waiting to hear from its central, identified by the information sent in the beacon. Once the remote sees the correct beacon information, it will hop in sequence with its central. It should be noted that the remote must see a valid beacon before it can transmit thus assuring that the remote is on the same channel as the central.

A single hopping synthesizer is used for both the transmitter and receiver, so that when the receiver hops, the transmitter hops, and vice a versa. When a remote has a data frame to transmit, it will be transmitted on the frequency channel of the current dwell time. If another remote or the same remote has another data frame to transmit, it will be sent on the channel current at the time the second data frame is sent. As the channel is hopping every 40 milliseconds, each data frame transmission will begin at a different place in a dwell, or hop sequence, based on the length of (and the time since) the previous transmission.

Hopping Patterns:

There are 26 hopping sequences according to the following formula:

$$\text{Hopping channel}_m[i] = (b[i] + 3*m) \bmod 79$$

where m = 0, 1, 2, ...,25, i= 0, 1, 2, ..., 78

i	b[i]	i	b[i]	i	b[i]	i	b[i]	i	b[i]	i	b[i]	i	b[i]	i	b[i]
0	0	10	76	20	18	30	34	40	14	50	20	60	48	70	55
1	23	11	29	21	11	31	66	41	57	51	73	61	15	71	35
2	62	12	59	22	36	32	7	42	41	52	64	62	5	72	53
3	8	13	22	23	72	33	68	43	74	53	39	63	17	73	24
4	43	14	52	24	54	34	75	44	32	54	13	64	6	74	44
5	16	15	63	25	69	35	4	45	70	55	33	65	67	75	51
6	71	16	26	26	21	36	60	46	9	56	65	66	49	76	38
7	47	17	77	27	3	37	27	47	58	57	50	67	40	77	30
8	19	18	31	28	37	38	12	48	78	58	56	68	1	78	46
9	61	19	2	29	10	39	25	49	45	59	42	69	28	-	-

For the 2.4 GHz ISM band we have:

$$f_{channel} = 2403 + \text{hopping channel [MHz]}$$

For the 5.8 GHz ISM band we have:

$$f_{channel} = 5770 + \text{hopping channel [MHz]}$$

Example 1: for m = 0, we obtain the following hopping sequence expressed in MHz,

- 2.4 GHz band:
2403,2426,2465,2411,2446,2419,2474,2450,2422,2464,2479,2432,2462,2425,2455,2466,2429,2480,2434,2405,2421,2414,2439,2475,2457,2472,2424,2406,2440,2413,2437,2469,2410,2471,2478,2407,2463,2430,2415,2428,2417,2460,2444,2477,2435,2473,2412,2461,2481,2448,2423,2476,2467,2442,2416,2436,2468,2453,2459,2445,2451,2418,2408,2420,2409,2470,2452,2443,2404,2431,2458,2438,2456,2427,2447,2454,2441,2433,2449

- 5.8 GHz band:
5770,5793,5832,5778,5813,5786,5841,5817,5789,5831,5846,5799,5829,5792,5822,5833,5796,5847,5801,5772,5788,5781,5806,5842,5824,5839,5791,5773,5807,5780,5804,5836,5777,5838,5845,5774,5830,5797,5782,5795,5784,5827,5811,5844,5802,5840,5779,5828,5848,5815,5790,5843,5834,5809,5783,5803,5835,5820,5826,5812,5818,5785,5775,5787,5776,5837,5819,5810,5771,5798,5825,5805,5823,5794,5814,5821,5808,5800,5816

It is important to understand that the system cycles through all 79 frequencies in the hopping pattern independent of data transmission. See the protocol description above.

This explanation of the radio protocol is quite general, as issues such as retransmission, addressing, and congestion control are not discussed. This general discussion is meant to convey how the hop synchronizing works.

Router Board

Router board functions include radio control functions (radio protocol and associated functions), the user interface, network management system, and IP router functions. The router board is responsible for converting IP data packets into a data stream that is fed to and from the radio board. As the router board is not involved in generating the radio emissions, it will not be described in detail here.

Antenna Requirements

The *WaveNet IP 2458* system is intended to be installed by professional installers only. Since the system is to be professionally installed it is exempt from the non-standard antenna connector requirements of section 15.203. There are several factors in the design, marketing, sales channels, and applications to which this system will be applied that will necessitate professional installation. See justification for professional installation in a subsequent paragraph.

The central radio transmitter in the *WaveNet IP 2458* system operates in a point-to-multipoint configuration. The central radio will transmit to as many as 60 remote radios. Depending on the configuration the central site antenna may be an omni-directional, a sectored antenna, or a directional antenna. The transmit power on the central radio must be programmed at installation to comply with the +36 dBm EIRP limit using an omni-directional or sectored antenna in a point-to-multipoint configuration, and with the "maximum peak output power reduced by 1 dB for every 3dB that the directional gain of the antenna exceeds 6 dBi" rule using a directional antenna in a fixed, point-to-point configuration.

In the *WaveNet IP 2458* system, each remote transmits only to the central site. In the remote to central direction, the link is operating fixed site point to point, using higher gain directional antennas. Depending on the configuration, a remote site will use a directional 1' or 2' dish antenna. . The transmit power on the remote radio must be programmed at installation to comply with the "may employ transmitting antennas with directional gain greater than 6 dBi without any corresponding reduction in transmitter peak output power" rule in a fixed, point-to-point configuration.

Maximum FCC Tx Power Settings

The following tables show the maximum transmit power allowed within the FCC 4-watt EIRP limits when using the antennas that are currently offered by Wireless, Inc.

Central Units

This table applies to central site units that transmit to more than one remote unit in a point-to-multipoint configuration (the typical case). Transmit power setting in table assumes zero dB cable loss between transmit port and the antenna.

Antenna	Max. Power Setting	EIRP
Decibel DB906S, 8dBi Omni	+24 dBm	+36 dBm
Decibel DB977H90, 16dBi Panel	+20 dBm	+36 dBm

In the case of a central unit transmitting to only one remote, higher gain directional antennas can be used.

RadioWaves SP1-2/5, 14 dBi / 23 dBi	Dual Band 1' Parabolic	+24 dBm	+38 dBm
RadioWaves SP2-2/5, 21 dBi / 28 dBi	Dual Band 2' Parabolic	+24 dBm	+45 dBm

Remote Units

This table applies to remote sites. Transmit power setting in table assumes zero dB cable loss between transmit port and the antenna.

Antenna		Max. Power Setting	EIRP
RadioWaves SP1-2/5, 14 dBi / 23 dBi	Dual Band 1' Parabolic	+24 dBm	+47 dBm
RadioWaves SP2-2/5, 21 dBi / 28 dBi	Dual Band 2' Parabolic	+24 dBm	+52 dBm

Meeting any regulatory transmitter output power and/or EIRP requirements is the installer's responsibility. The formula for EIRP is given below:

$$EIRP_{dBm} = Tx\ Power_{dBm} + Tx\ Antenna\ Gain_{dBi} - Tx\ Antenna\ Cable\ Loss_{dB}$$

For example, to meet the FCC EIRP limit of +36 dBm (4W) using a 16 dBi sector antenna with a 1 dB loss antenna cable, the transmit power must be set to +21 dBm or lower.

RF exposure limits

As of October 15, 1997 all products must address the issue of Human Exposure to RF electromagnetic fields. Referring to OET bulletin 65, the limits for Occupational exposure, and General Population exposure are 5 mW/cm ^{2}, and 1 mW/cm ^{2} respectively above 1.5 GHz.

The WaveNet IP 2458 Central transmits a maximum output power of +24 dBm (250 mW), at 2.4 GHz, into a maximum antenna gain of +21 dBi (126). The duty cycle of the transmitter is 100%. The maximum EIRP of +45 dBm would occur at the site operating in a fixed, point to point configuration.

Using the equation $S = P * G / 4\pi R^2$ the Power density can be calculated. By rearranging this equation, the relationship between distance R and Power Density S can be found.

Rearranging $R = \sqrt{(PG / 4\pi S)}$, and solving for the maximum limits of 5 mW/ cm ^{2}, and 1 mW/ cm ^{2} we have:

$R(5\ mW/cm^2) = \sqrt{250\ mW * 126 / 4\pi * 5} = 23$ cm. or 9 inches.

$R(1\ mW/cm^2) = \sqrt{250\ mW * 126 / 4\pi * 1} = 50$ cm. or 20 inches.

These results show that the RF limits are met as long as the distance from the antenna is greater than 20 inches.

The WaveNet IP 2458 Remote transmits a maximum output power of +24 dBm (250 mW), at 5.8 GHz, into a maximum antenna gain of +28 dBi (631). The duty cycle of the transmitter is 100%. The maximum EIRP of +52 dBm would occur at the site operating in a fixed, point to point configuration (remote to central direction).

Using the equation $S = P * G / 4\pi R^2$ the Power density can be calculated. By rearranging this equation, the relationship between distance R and Power Density S can be found.

Rearranging $R = \sqrt{(PG / 4\pi S)}$, and solving for the maximum limits of 5 mW/ cm ^{2}, and 1 mW/ cm ^{2} we have:

$R(5\ mW/cm^2) = \sqrt{250\ mW * 631 / 4\pi * 5} = 50$ cm, or 20 inches.

$R(1\ mW/cm^2) = \sqrt{250\ mW * 631 / 4\pi * 1} = 112$ cm, or 44 inches.

These results show that the RF limits are met as long as the distance from the antenna is greater than 44 inches.

The WaveNet IP 2458 system is an outdoor system that is intended to be pole mounted such that the antenna will have a clear path to the opposite end of the link. As a result the WaveNet IP 2458 system will require that the antenna be mounted at least 10 to 20 feet above ground level.

The mounting elevation of the antenna will prevent the general population from getting within the 44-inch distance that could cause excessive exposure.

As for the occupational exposures, the antenna would normally be installed with the power disconnected from the WaveNet IP 2458 system.

Warnings concerning RF radiation exposure are located on pages 5-3 & 5-4 of the WaveNet IP 2458 Operations Manual.

Justification for professional installation

Marketing and Application

This system has been designed and is intended for use as an alternative to traditional wireline methods of providing Internet and intranet connectivity. As such the end user of this system will be small to medium sized businesses. The actual customer for, and operator of the WaveNet IP networks will be Service Providers such as ISP's, Competitive Access Providers (CAP's) or the local telco's themselves. This places the use of the system decidedly in the industrial/commercial application arena.

Furthermore, many of the aforementioned target customers are already involved in wireless communications technologies and have on staff professional RF installation crews. For those Service Providers who do not to date have in-house talent for the RF installation of the WaveNet IP systems, e.g. ISP's, they will be directed to a network of third party providers (largely from the cellular/PCS arena) who specialize in microwave equipment installations. Examples of some of these support shops are Valcom in the mid-west, and Netcom International based in Atlanta.

Technical Requirements

There are several steps involved in the setup and installation of the system that require tools and skills not found in the average technically inclined person's skill set. Some of these are:

- Routing Tables and Networking Configuration - in order to operate the WaveNet IP system, IP routing tables must be entered in each unit properly or they will not function. Configuration of route tables and subnet masks are decidedly specialized skills. Additional fields concerning SNMP configuration, MAC level authentication etc. add to the complexity of configuring the system.

- Physical Installation - these units are designed and intended for outdoor installation. The central units will be located on towers on tall buildings typical for microwave equipment sites. Access to these locations is typically restricted to those with authorization, which restricts access from the average lay person. The remote units as well will be mounted on the rooftops of the end users to be serviced, and again roof top access is typically restricted in some way. Furthermore, when installing the systems weather sealing of connectors is required, an additional somewhat specialized task.

- Antenna Alignment – in order to align the antenna of the remote units with the central radios, it is necessary for the installer to adjust the antenna based upon an RSSI (Received Signal Strength Indicator) voltage measured at a test point on the circuit boards.

List of antennas for FCC Type Certification

List of antennas to be certified for used with the *WaveNet IP 2458* system on Central radios (transmitting at 2.4 GHz and receiving at 5.8 GHz):

Model	Gain	
Decibel DB906S RadioWaves OMN-H-5-8	2.4 GHz, 8 dBi Omni 5.8 GHz, 8 dBi Omni	(tested as a pair)
Decibel DB977H90 RadioWaves SEC-H-5-16-90	2.4 GHz, 16 dBi 90° Panel 5.8 GHz, 16 dBi 90° Sector	(tested as a pair)

RadioWaves SP1-2/5 14 dBi @ 2.4 GHz / 23 dBi @ 5.8 GHz Dual Band 1' Parabolic Antenna

RadioWaves SP2-2/5 21 dBi @ 2.4 GHz / 28 dBi @ 5.8 GHz Dual Band 2' Parabolic Antenna

List of antennas to be certified for used with the *WaveNet IP 2458* system on Remote radios (transmitting at 5.8 GHz and receiving at 2.4 GHz):

Model	Gain	
RadioWaves SP1-2/5	14 dBi / 23 dBi	Dual Band 1' Parabolic Antenna
RadioWaves SP2-2/5	21 dBi / 28 dBi	Dual Band 2' Parabolic Antenna

Additional antennas may be added in the future, any additional antennas will be tested prior to adding them to the list.