Development of Adaptive Gateway for LTE IP Conversion

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[Summary] Recently, social infrastructure communications systems are switching from aging analog leased lines to Internet Protocol (IP) based configurations offering higher functionality. However, switching analog communications infrastructure to digital IP infrastructure is very expensive. Moreover, the updates cycle for social legacy infrastructure systems is about 20 years, which creates issues with promoting IP system conversion. To solve this problem, instead of updating existing systems, we have developed the NN4000 Adaptive Gateway series for IP conversion of analog leased lines using Long Term Evolution (LTE) lines. This article introduces the technologies used by the Adaptive Gateway along with its key features.

1 Introduction

Analog leased lines and infrastructure, which have been the foundation of society's communications so far, have reached the time for renewal and there is increasing demand for a switch to Internet Protocol (IP) based configurations supporting higher functionality system.

However, due to severe financial situation, it is very difficult to make large investments in social infrastructure, such as information boards. As a result, rather than large-scale system updates, there is demand for a staged-IP-conversion update method in which use existing analog infrastructure and only analog leased lines are converted to IP lines. Although there is demand for low-cost IP lines to cut both maintenance and communications costs, a suitable solution has yet to be found.

IP lines using optical fiber have various advantages, such as wide bandwidth, high quality, and high reliability, but are expensive due to the costs for installation work and limited locations for optical cables.

On the other hand, Long Term Evolution (LTE) lines now serve more than 99.8% of the Japanese population, and provide almost 100% coverage for areas requiring communications for social infrastructure, so use of LTE line requires no new installation work or costs. In addition, the Ministry of Internal Affairs and Communications has been promoting operations by Mobile Virtual Network Operators (MVNOs) and carriers' LTE services are diversifying with the appearance of more low-cost data services[1].

However, in comparison to guaranteed bandwidth, priority controlled leased LTE lines, and optical fibers, low-cost LTE lines suffer from issues with degraded communications quality caused by packet loss and jitter, as well as reliability problems due to line faults.

In these circumstances, we have developed the NN4000 series of Adaptive Gateway models (Figure 1) based on our long experience in developing IP communications equipment.

Figure 1 Adaptive Gateway (NN4004A)

The Adaptive Gateway is for IP converter of analog leased lines to low-cost LTE lines. It solves issues with communications quality and reliability of low-cost LTE lines, and supports configuration of a mixed system combining continued use of existing analog communications infrastructure with IP infrastructure to support updating and development of aging social infrastructure.

The Adaptive Gateway converts analog lines to IP lines by digitizing analog signals to IP packets, and installing this device at both ends of a network facilitates stable IP conversion of a analog leased line (Figure 2).

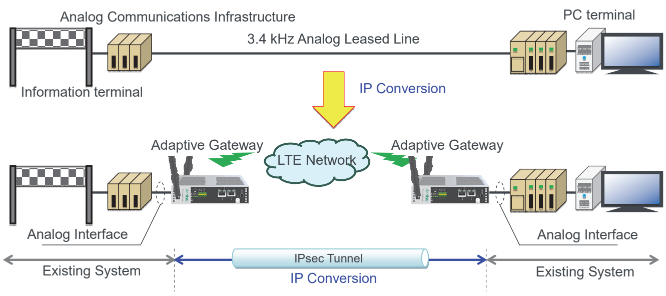

Figure 2 Analog Leased Line IP Conversion using LTE

2 Development Concept

IP conversion of social communications infrastructure requiring quality and reliability to low-cost LTE requires a product meeting the following conditions.

(1) Using Existing Analog Infrastructure

Updating existing analog communications infrastructure to IP infrastructure incurs high costs. Consequently, an IP conversion method using existing systems is required.

(2) Improving Communications Quality and Reliability

Systems using analog leased lines are presumed to operate with stability 24 hours, 365 days a year, and IP lines require the same level of communications quality and reliability. On the other hand, since low-cost LTE lines are shared by Mobile Network Operators (MNOs), the occurrence of packet loss and jitter degrades communications quality in comparison to an analog leased line. In addition, a LTE line communications fault can cause a system stoppage. Consequently, IP conversion using a low-cost LTE line requires to take measures to improve quality and reliability to realize communication that does not affect system operation.

In this article the analog communications bit error rate (BER) due to packet loss and jitter is defined as an index of communications quality, and the system availability is defined as an index of reliability.

(3) Communications Band Width

LTE lines have different band width depending on the services provided by the telecommunications carrier. Since the communication band width for low-cost LTE lines is limited generally to 128 kbit/s, this device should operate under 128 kbit/s.

3 Adaptive Gateway Features

3.1 IP Conversion Method

The developed Adaptive Gateway encodes the analog signal input from the analog terminal using the μ-law method before data encapsulation in IP packets. At the same time, received IP packets with encapsulated data are decoded to recover the analog signals. This continuous parallel processing implements communications of analog signals in both directions over an IP line (Figure 3).

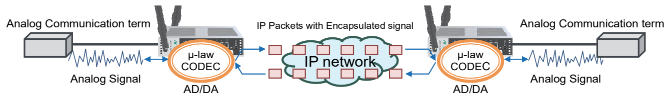

Figure 3 IP Conversion Method

Since this method is equivalent to transmit or receive an analog signal, IP line conversion is supported irrespective of the type of analog communications terminal.

3.2 Improve Communications Quality Functions

The following functions are implemented to improve the communications quality.

(1) Jitter Absorption Function

In general low-cost LTE lines have jitters caused by packet delay and packet burst in the IP network. If a large delay occurs, the analog signals will be disrupted. Consequently, this Adaptive Gateway design incorporates a buffer (Figure 4) for holding up to 990 ms of analog-signal data to absorb jitter.

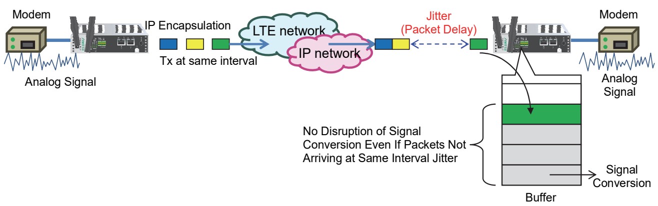

Figure 4 Jitter Absorption Buffer

(2) Packet Retransmission Function

Networks using low-cost LTE lines suffer packet loss, which is suppressed using a packet retransmission function.

Although the Transmission Control Protocol (TCP) retransmission time varies with the implementation, the TCP retransmission timer described in RFC6298 specifies a minimum time of 1 s and a maximum time of 60 s. Since there is no consideration of delay time specified in second units for analog terminal communications, this Adaptive Gateway uses the User Datagram Protocol (UDP) with high real-timeness. Although UDP does not have a retransmission function and must be implemented separately, it can be achieved according to the application. We implemented a small delay unique UDP retransmission function by assigning a management ID to UDP packets for immediately detecting and managing packet loss by performing retransmission processing. During retransmission processing, analog signal data stored in the buffer for absorbing jitter is converted to maintain analog-signal continuity (Figure 5).

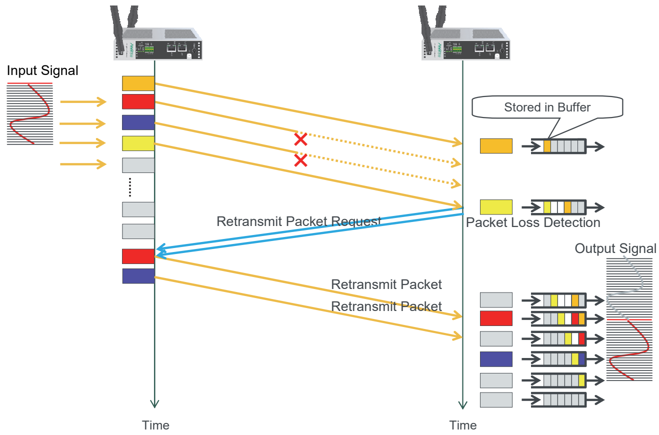

Figure 5 Packet Retransmission Function

(3) Packet Recovery Function

Adding a redundant packet to UDP packets enables a function for recovering lost packets by matching other UDP packets (Figure 6).

A redundant packet is added to a specified number of UDP packets using XOR processing. If a lost packet occurs, the lost packet can be recovered from the redundant packet without retransmitting. Although the recovery rate is highest when the redundancy (number of packets versus XOR packets) is smallest, since the ratio depends on the communications data rate, the redundancy is set so as to match the line bandwidth in use (Table 1).

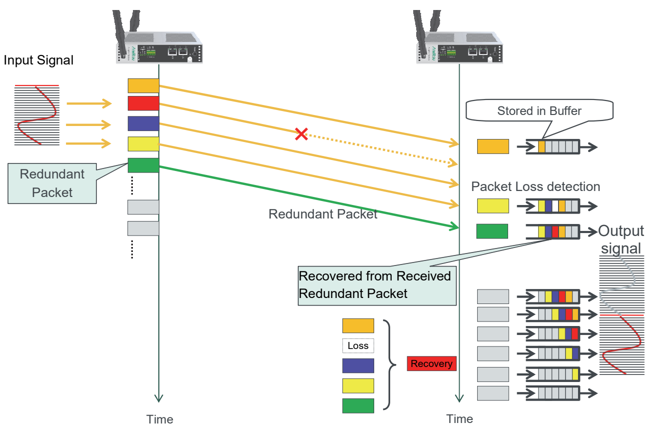

Figure 6 Packet Recovery Function (Redundancy 4)

Table 1 Communications Data Rate

Recovered Packet Redundancy[1]	Communications Data Rate [kbit/s]	
	IPsec Disabled	IPsec Enabled
0 (Disable)	78	88
2	117	133
3	104	118
4	98	110
5	94	106
6	91	103
7	89	101
8	88	99
9	87	98
10	86	97
11	85	96
:	:	:
20	82	92
:	:	:
30	80	91

Note 1: Low value = high redundancy

3.3 Redundant Line Function

We implemented a redundant line function to improve communications reliability with support both NTT Docomo and KDDI LTE lines. Using this function, if communications fail over one LTE line due to engineering works or faults, communications can continue over the other LTE line (Figure 7).

Based on the settings, the two lines are specified as the Primary line and Secondary line; the Primary line is used under normal conditions but if a fault is detected, communications switch to the Secondary line. Subsequently, when the communications fault is recovered and detected, the communications path switches back to the Primary line.

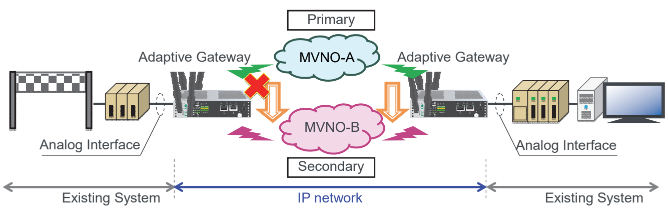

Figure 7 Line Redundancy Function

3.4 Security Function

To assure secure IP communications, a Virtual Private Network (VPN) function is implemented using the IP Security Architecture (IPsec) with data snooping and wiretapping prevented by packet encoding. The IPsec-based VPN attaches a tunnel header to packets and encoding increases the packet size. To deal with this, even with 128 bit/s low-cost LTE lines, it is necessary to consider the packet size and packet transmitting interval for the supported IP-conversion communications data rate (section 3.5).

This Adaptive Gateway uses the Advanced Encryption Standard (AES) encoding with a 128-bit key. Additionally, the encoding mode is the Counter Mode (CTR) with a little added data.

3.5 Communications Data Rate

The μ-law analog signal encoding method generates 1 byte of digital data every 125 μs. Since, it is possible to transmit an encapsulated UDP packet at every 125 μs in a wideband IP line, the delay is minimal. But the required communications bandwidth is 4,096 kbit/s because the UDP packets minimum packet size is 64 bytes (Figure 8).

Because the assuming the maximum communications data rate is 128 kbit/s, transmitting data en masse creates delays. Consequently, considering the balance between the amount of delay and data size, the value must be optimized to achieve a communications data rate of about 100 kbit/s.

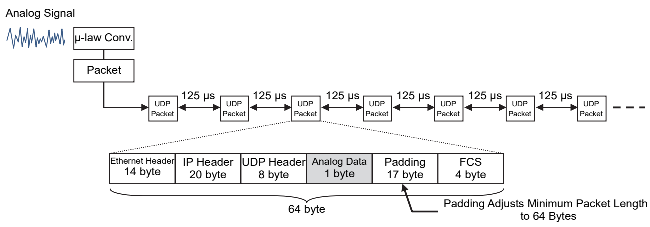

Figure 8 Transmitting at Every 1 Byte

This Adaptive Gateway transmits every 30 ms or in other words encapsulates 240 bytes in each packet for transumitting. When IPsec is disabled, the required bandwidth is 78 kbit/s and occupies 61% of the 128-kbit/s line. When IPsec is enabled and packet recovery function redundancy is 10, the required bandwidth is 97 kbit/s (almost 100 kbit/s), which is the standard setting (Table 1). The above value (240 bytes/30 ms) is found from the balance between the generated delay and the bandwidth required by the security function, retransmission request packets used by the above-described retransmission function and the redundancy packets used by the packet recovery function.

Figure 9 shows the UDP packet format.

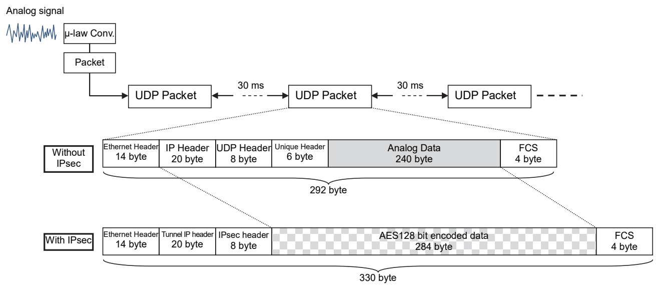

Figure 9 Transmit at Every 240 bytes

4 Design Considerations

4.1 Device Architecture

Figure 10 shows the Adaptive Gateway block diagram. We used a dual-core System on a Chip (SoC) for analog signal processing in realtime and IP packet processing while also improving the communications quality at the same time. For stability, one core of the SoC is assigned to analog signal input/output processing in realtime with a precision clock cycle. The other core runs the application software executing IP packet processing and communications quality improve functions.

4.2 Interfaces

(1) LAN (Local Area Network) Interface

The gateway has one analog interface for connecting existing analog communications equipment and one LAN port for future upgrades to IP communications terminals.

(2) WAN (Wide Area Network) Interface

The gateway has a wired WAN port and two wireless ports (LTE lines). IP conversion is supported for the LTE lines and the wired lines; Either the two LTE lines can be set as the redundant line, or the wired and LTE lines can be set as the redundant line. A different carrier can be set for the redundant line using two LTE lines.

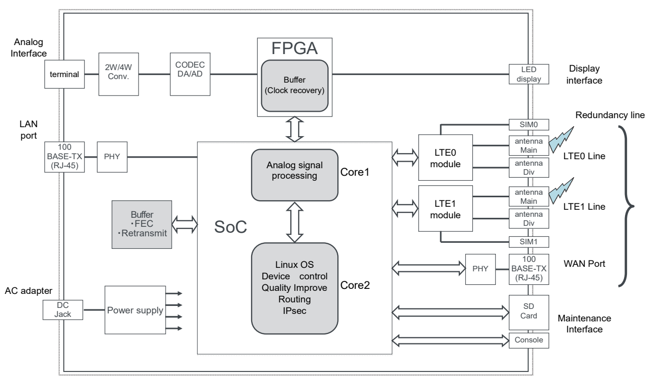

Figure 10 System Block Diagram

4.3 Clock Correction Function

As described above, this Adaptive Gateway is installed at both sides of a network to implement IP conversion of a analog leased line. At IP conversion, the analog signal is A/D (or D/A) converted using the μ-law method, but the conversion rate (8-kHz sampling frequency, 8-bit quantification) suffers ppm-order clock error at the other gateway. For example, at 8-kHz A/D conversion at one gateway, if the D/A conversion at the other gateway is 8 kHz – 50 ppm, the buffer increases by 8-bits every 2.5 s. As a result, the jitter absorption buffer overflows and the analog signal continuity is not maintained (Figure 11).

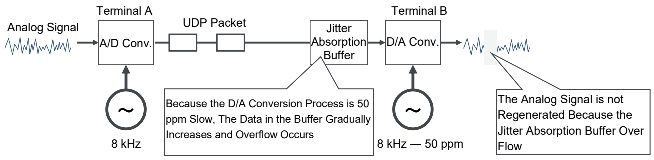

Figure 11 Impact of Clock Error

Moreover, we designed the Adaptive Gateway on the assumption that the modems use analog leased line with no consideration for echo cancelling due to large variations in delay, and for jitter (short-term signal variations in the time domain) or wander (long-term signal variations in the time domain) occuring from IP conversion. One issue with IP conversion equipment is reproduction of signals identical to analog signal characteristics on a leased line with connected modems.

This gateway implements a jitter absorption buffer for each byte (125 μs) using an FPGA and performs clock adjustments by monitor increases/decreases in buffered data. Fine-adjusting the clock in 125-μs units reduces jitter, wander, and delay fluctuations to stabilize long-term analog communications (Figure 12).

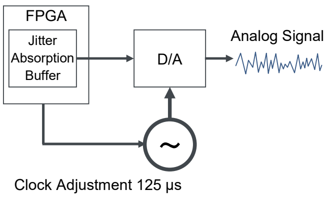

Figure 12 Clock Adjustment Function using FPGA

4.4 Installation Environment

This gateway is not only for indoors installations but can also be installed in spaces within existing outdoor cabinets used by analog communications infrastructure. Consequently, it is designed to meet the following requirements.

(1) Size Reduction

Due to space restrictions in existing outdoor cabinets, the gateway is designed to be as compact as possible. Based on our engineering tests we implemented the design in a small enclosure of just 35 (H) × 160 (W) × 130 (D) mm (excluding projections and AC adapter).

(2) Environmental Durability

Temperatures in outdoor cabinets can often exceed 50°C during sunny summer conditions but may fall below 0°C in winter. Consequently, this Adaptive Gateway is designed to operate in severe environments with an operating temperature range of −20° to 60°C. The case heat-radiating construction eliminates the need for cooling fans.

5 Effect of Communication Quality Improve Functions

We performed IP conversion tests using actual low-cost LTE lines. Measurements were made over 24-hour periods using low-cost LTE lines from the same MVNO carrier. We examined the jitter absorption buffer effect and the results when the communications quality functions (retransmitting and recovery) were enabled. The jitter absorption buffer was 510 ms. Figure 13 shows the test configuration.

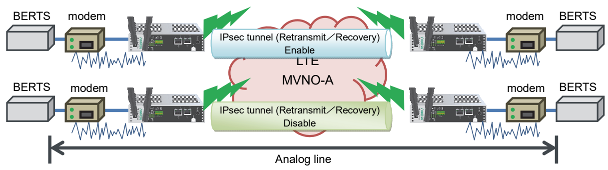

Figure 13 Test Configuration

5.1 Jitter Absorption Function

Figure 14 shows the distribution of packet jitter occurring on a low-cost LTE line. The distribution shows the statistically processed received packet intervals for the Adaptive Gateway.

Based on the measurement results, although there is some jitter above 500 ms, more than 99.999% of packet fluctuations were absorbed by the jitter absorption buffer (510 ms).

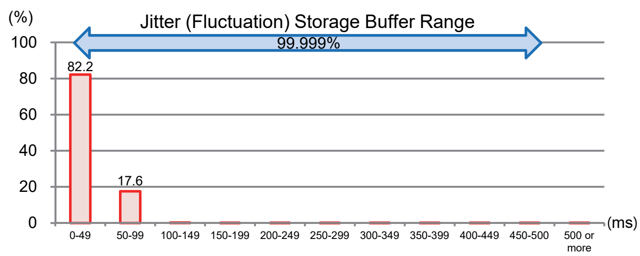

Figure 14 Jitter Distribution

5.2 Effect of Packet Retransmitting and Recovery Functions

Figures 15 and 16 show the packet loss counts versus time at the gateway. In Figure 16 with the retransmit and recovery functions enabled, there is clear reduction of lost packets. In this test, the packet recovery function redundancy was 10.

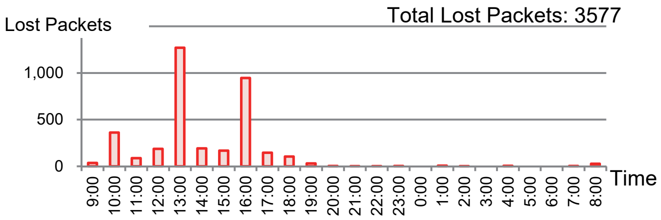

Figure 15 Packet Loss (with Retransmit/Recovery Disabled)

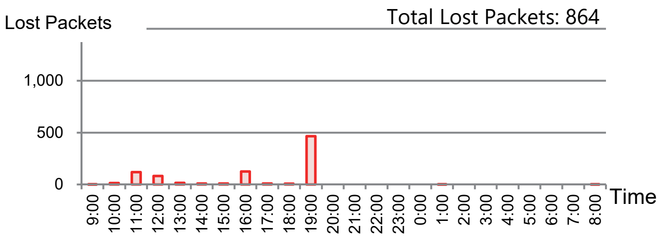

Figure 16 Packet Loss (with Retransmit/Recovery Enabled)

Table 2 shows the analog communications error rate. With the retransmitting and recovery functions enabled, there is clear improvement in the bit error rate (BER) which reduces to 3.03×10^{-5} a result of the effects of the jitter absorption function and packet retransmit and recovery functions.

Based on technical reference materials[2), 3)] published by NTT East and NTT West, the BER for analog leased lines when using a 4800 bit/s modem is about 1×10^{-5} (reference value), which approximates our measured value.

Table 2 Analog Communications BER

	BER
Retransmit/Recovery Enabled	3.03×10^{-5}
Retransmit/Recovery Disabled	2.45×10^{-4}

Note: This result is from one measured data set and is not a guaranteed value.

6 Functions

Table 3 lists the main specifications of the Adaptive Gateway models.

7 Conclusions

This article describes the features and technologies of the NN4000 Adaptive Gateway series.

Cutting costs for updating existing infrastructure as well as communications operating costs are key issues for national and local governments as well as for business. It is impossible to implement every IT technology advance over short time periods and IP conversion of analog leased lines to low-cost LTE helps make best cost-effective use of existing social infrastructure.

References

1) Ministry of Internal Affairs and Communications, White Paper on Telecommunications, 2018 (in Japanese)

2) NTT East reference materials on general leased-line services (in Japanese)

3) NTT West reference materials on general leased-line services (in Japanese)

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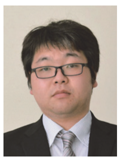

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Table 3 Specifications

	Function			NN4001A	NN4002A	NN4003A	NN4004A
1	Analog Line Interface	No. of Ports		1			
		Frequency Band		300 Hz to 3400 Hz			
		Communications Method		2- or 4-line method			
		Sampling Method		8 kHz/8 bit			
		Encoding Method		μ-law			
		Interface		Connector			
		I/O Impedance		600-Ω balanced (nominal)			
		2W	Input Level	0 dBm			
			Output Level	−8 dBm			
		4WS	Input Level	0 dBm			
		4WR	Output Level	0 dBm			
		Level Adjustment	Input Level	0 to −15 dBm (SPAD)			
			Output Level	0 to −15 dBm (RPAD)			
2	LAN Port	No. of Ports		1			
		Interface		RJ-45			
		Ethernet Standard		10BASE-T/100BASE-TX (Auto Negotiation)			
		Max. Frame Length		1518 byte (VLAN Tag not supported)			
3	WAN Port	No. of Ports		1			
		Interface		RJ-45			
		Ethernet Specification		10BASE-T/100BASE-TX (Auto-Negotiation)			
		Max. Frame Length		1518 byte (VLAN Tag not supported)			
4	LTE Line[1]	Supported Carriers	NTT Docomo	—	○	—	○
			KDDI	—	—	○	○
		Communications Method		—	FDD-LTE		
		No. of Antennas		—	2	2	4
		Max. Communications Speed[2]		—	Category 4 Down 150 Mbit/s (theoretical) Up 50 Mbit/s (theoretical)		
		Supported Frequency Band		—	Band 1, 19	Band 1, 18	Band 1, 18, 19
5	Communications Quality Improve Functions	Jitter Absorption		90 ms to 990 ms (30-ms steps)			
		Packet Retransmit		Using UDP			
		Packet Recovery		Using FEC			
		Line Redundancy		Redundancy for any 2 lines			
6	VPN Function			IPsec, IP tunnels			
7	Console Port			RS-232C using φ2.5 mm mini-pin jack			
8	SD Card Slot			1			
9	Network Administration Functions			Ping, Traceroute, Telnet, SNTP, SYSLOG			

Note 1: Using LTE lines requires a communications contract with a carrier. The service area is based on the contracted lines.

Note 2: Theoretical value based on specifications and not guaranteed communications speed.