SmartEdge Platform – Wireless Communications

Gordon Walsh, Senior Security Architect, Industrial ASIC BU

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Introduction

When it comes to Wireless Communications, the Internet of Things ecosystems have a broad and continually evolving choice of protocols. These protocols typically fall into the following categories based on the supported transmission distance:

- Wireless Personal Area Networks (WPAN): typical coverage area of 10s of meters
- Wireless Local Area Networks (WLAN): typical coverage area of 100s of meters
- Wireless Wide Area Networks (WWAN): typical coverage area of 100s of meters to 10s of kilometres

This whitepaper will discuss Wireless Sensor Networks (WSNs) and the major wireless communication protocols that make up each of the above network categories. Emerging protocols will also be covered since the Internet of Things has a been a major driver for recent developments in this area.

Finally, the integration of Wireless Communication Protocols into a System on Chip (SoC) will be discussed.

Wireless Sensor Networks

A Sensor Network (SN), sometime called Sensor/Actuator Network (SAN), can be described as a network of nodes that cooperatively sense and optionally control the environment, enabling interaction between persons or computers and the surrounding environment.

A Sensor Network is built of “Nodes” (up to hundreds or even thousands) with each Sensor Node typically consisting of the following components:

- Senor(s)
- Sensor Interface(s)
- A Microcontroller
- A Communication Interface
- An Energy Source (e.g. battery, energy harvesting…)

Note: Actuators and Actuator Interfaces are common but are not always present in a Sensor Node.

A Wireless Sensor Network (WSN) uses radio as the Communication Interface and a Wireless Sensor Node will typically integrate a Radio Transceiver and an Antenna.

Within the IoT a variety of radios and network topologies are used to create WSNs. There is no one-size-fits-all solution. Nonetheless, once capacity and coverage have been sorted, two key requirements that prevail are low power and reliability. The following are some factors that affect reliability:

- Physical Objects: Concrete and steel walls are particularly difficult for radio signals to pass through. The use of a sub-GHz frequency spectrum helps to reduce the effects of physical objects: signal attenuation generally increases at higher frequencies, higher frequencies generally fade more quickly and as frequencies decrease the angle of diffraction increases, allowing sub-GHz signals to bend farther around an obstacle
- Radio Frequency Interference: Many wireless technologies share the same frequency band, e.g. the 2.4 GHz unlicensed ISM band is used by many wireless protocols as well as microwave ovens. The use of a licensed band can help to greatly reduce the number of potential interferers.
- Electrical Interference: Advances in wireless technologies and in electrical devices have reduced the magnitude of this type of interference.
- Environmental factors such as rain, fog and lightning can weaken signals.

A transmitter’s signal strength (its travel range) is directly related to its output power. However, local regulations limit the maximum transmit power to ensure that all radios have equal access to the frequency band. The choice of radio protocol can also affect the radio reliability. For example, the use of a narrowband communication technology provides very good noise suppression while also providing range measured in kilometres.

Protocols

Wireless Personal Area Networks (WPAN)

It should be noted that modern WPAN protocols typically support a mesh network type. A mesh network allows the communication between two devices to travel (or hop) across one or more other devices in the network effectively increasing the range of communication beyond what the base wireless protocol supports.

Bluetooth

Bluetooth is a wireless technology standard for exchanging data over short distances. Bluetooth is managed by the Bluetooth Special Interest Group and was ratified as the IEEE 802.15.1 standard in 2002.

Version 4.2 of the standard (released on 2 December 2014) introduced some new features of interest to the IoT including but not limited to Bluetooth Low Energy (BLE), Secure Connection and the Internet Protocol Support Profile (IPSP) that allows IP packets to be sent and received by Bluetooth Smart devices (See **6LowPAN**). BLE essentially offers a second radio version with low power consumption of a magnitude of 1-50% of that of a Classic Bluetooth radio.

Version 5 of the standard was unveiled on 16 June 2016 and devices with support for Bluetooth 5 are slowly appearing in the market. Bluetooth 5 enhancements of interest are the additional BLE modes of operation:

- BLE 2M: doubling of the speed at the expense of range
- BLE Long Range: increasing the range up to fourfold at the expense of data rate.

Protocol Variant	Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
Bluetooth (Classic)	2.4 GHz	N (ISM band)	1 to 3 Mbps	10 to 100 meters	Low
BLE (V4.2)	2.4 GHz	N (ISM band)	1 Mbps	10 to 100 meters	Very Low to Low
BLE 2M (V5)	2.4 GHz	N (ISM band)	2 Mbps	< 50 meters	Very Low to Low
BLE Long Range (V5)	2.4 GHz	N (ISM band)	125 to 500 kbps	40 to 400 meters	Very Low to Low

ZigBee

ZigBee is an IEEE 802.15.4 based open wireless standard for a suite of high-level communication protocols used to create personal area networks with small, low-power digital radios.

ZigBee was conceived in 1998, standardized in 2003 and revised in 2006. Established in 2002, the ZigBee Alliance is a group of companies that maintain and publish the ZigBee standard. The 2006 revision improves the maximum data rates of the 868/915 MHz bands from 20/40kbps to 100/250 kbps.

The technology defined by the ZigBee specification is intended to be simpler and less expensive than other WPANs, such as Bluetooth. ZigBee is targeted at radio-frequency (RF) applications that require a low data rate, long battery life, and secure networking.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	250 kbps	10 to 100 meters	Very Low to Low
868/915 MHz	N (ISM regional bands)	20/40kbps 100/250 kbps	Up to 200 meters	Very Low to Low

Z-Wave

Z-Wave is a wireless communications protocol used primarily for home automation. It is a mesh network using low-energy radio waves to communicate from appliance to appliance, allowing for wireless control of residential appliances and other devices, such as lighting control, security systems, thermostats, windows, locks, swimming pools and garage door openers.

Before it was acquired by Sigma Designs in 2008, Zensys Inc. developed Z-Wave as a proprietary wireless standard. The standard is not open like many wireless standards, but it is available to Zensys/Sigma Designs customers. In 2012 the International Telecommunications Union (ITU) included the Z-Wave PHY and MAC layers as an option in its new G.9959 standard, which defines a set of guidelines for sub-1-GHz narrowband wireless devices.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
868/915 MHz	N (ISM regional bands)	9.6 kbps 40 kbps 100 kbps	Up to 100 meters	Very Low to Low

6LowPAN (Thread)

6LoWPAN combines the latest version of the Internet Protocol (IPv6) and Low-power Wireless Personal Area Networks (LoWPAN). 6LoWPAN was created to allow small devices with limited processing ability to transmit information wirelessly using the Internet Protocol.

The base specification (RFC 4944) was released by the now concluded 6LoWPAN IETF working group in 2007. Originally developed to enable transmission of IPv6 Packets over IEEE 802.15.4 networks 6LoWPAN has recently been updated in 2015 to support transmission of IPv6 Packets over Bluetooth networks (RFC 7668).

Thread is an effort of over 50 companies to standardize on a closed-documentation, royalty-free wireless protocol running over 6LoWPAN to enable home and building automation. The Thread Group announced the release of Thread in July 14, 2015. Thread is the main WPAN protocol to use 6LoWPAN functionality.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	250 kbps	10 to 100 meters	Very Low to Low

WirelessHART

WirelessHART is a wireless sensor networking technology based on the wireline Highway Addressable Remote Transducer Protocol (HART). of WirelessHART is backward compatible with the HART network enabling interaction with currently installed HART devices.

The protocol supports operation in the 2.4 GHz ISM band using IEEE 802.15.4 standard radios.

The standard was initiated in early 2004 and developed by 37 HART Communications Foundation (HCF) companies. The standard was ratified in September 2007.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	250 kbps	10 to 100 meters	Very Low to Low

RFID

RFID is the method of uniquely identifying items using radio waves. At a minimum, an RFID system comprises a tag, a reader, and an antenna. The reader sends an interrogating signal to the tag via the antenna, and the tag responds with its unique information. RFID tags are either Active or Passive.

Many organizations have set standards for RFID, including the International Organization for Standardization (ISO), the International Electrotechnical Commission (IEC), ASTM International, the DASH7 Alliance and EPCglobal.

RFID is considered as a nonspecific short-range device. It can typically use frequency bands without a license but the use of the UHF spectrum must be compliant with local regulations (ETSI, FHSS, FCC etc.).

Active RFID tags contain their own power source giving them the ability to broadcast with a read range of up to 100 meters. Typical Active RFID frequency ranges are listed below:

Radio Frequency	Licensed Band	Typical Data Rate	Approx. Range	Relative Power Consumption
433 MHz 860 to 960 MHz (UHF)	(Region Dependent)	100 kbps	Up to 100 meters	Very Low

Passive RFID tags do not have their own power source. Instead, they are powered by the electromagnetic energy transmitted from the RFID reader. Because the radio waves must be strong enough to power the tags the range is reduced compared to Active RFID. Typical Passive RFID frequency ranges are listed below:

Radio Frequency	Licensed Band	Typical Data Rate	Approx. Range	Relative Power Consumption
125 kHz to 134.2 kHz 140 kHz to 148.5 kHz (LF)	N	~ 1 kbps	Less than 1 meter	Very Low
13.56 MHz (HF)	N	25 kbps	Up to 1.5 meters	Very Low
433 MHz 860 to 960 MHz (UHF)	Region Dependent	100 kbps	Up to 10 meters	Very Low

NFC

NFC is a specialized subset within the family of RFID technology. Specifically, NFC is a branch of High-Frequency (HF) RFID, and operates at the 13.56 MHz frequency. NFC is designed to be a secure form of data exchange, and an NFC device is capable of being both an NFC reader and an NFC tag.

The standards and protocols of the NFC format is based on RFID standards outlined in ISO/IEC 14443, FeliCa, and the basis for parts of ISO/IEC 18092.

Some NFC devices can read Passive HF RFID tags that are compliant with ISO 15693.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
13.56 MHz (HF)	N	106 kbps 212 kbps 424 kbps	Up to 20 centimeters	Very Low

Wireless Local Area Networks (WLAN)

Early WLAN development included industry-specific solutions and proprietary protocols, but at the end of the 1990s these were replaced by standards, primarily the various versions of IEEE 802.11 (more commonly known by the brand name WiFi®).

Various protocol versions are defined by the 802.11 specs, the existing and emerging WiFi® protocols are described below.

802.11

The original version of the standard IEEE 802.11 was released in 1997 and clarified in 1999 but is now obsolete. Legacy 802.11 was rapidly supplanted by 802.11b and subsequent protocol versions.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	Up to 2 Mbps	Up to 10 meters	Medium

802.11a

Originally described as clause 17 of the 1999 specification, the OFDM waveform at 5.8 GHz is now defined in clause 18 of the 2012 specification.

While the original amendment is no longer valid (none of the subsequent protocols are backwards compatible with 802.11a), the term 802.11a is often used by manufacturers to describe interoperability of their systems at 5 GHz or 54 Mbps.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
5 GHz	Region Dependent	Up to 54 Mbps	Up to 45 meters	Medium

802.11b

802.11b uses the same media access method defined in the original standard. The dramatic increase in throughput of 802.11b (compared to the original standard) along with substantial price reductions led to the rapid acceptance of 802.11b as the definitive wireless LAN technology.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	Up to 11 Mbps	Up to 90 meters	Medium

802.11g

In June 2003, the third modulation standard 802.11g was ratified. 802.11g attempted to combine the best of both 802.11a and 802.11b and is fully backward compatible with 802.11b.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	Up to 54 Mbps	Up to 90 meters	Medium

802.11n

802.11n is a 2009 amendment to the IEEE 802.11 2007 standard. It improves upon the previous 802.11 standards by adding multiple-input multiple-output antennas (MIMO) to improve network throughput. Support for 5 GHz bands is optional. It is backward-compatible with 802.11b/g.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	Up to 195 Mbps	Up to 150 meters	Medium
5 GHz	Region Dependent	Up to 450 Mbps	Up to 70 meters	Medium

802.11ac

802.11ac is a 2013 amendment to the IEEE 802.11 2012 standard. It improves upon the previous 802.11 standards by adding support for simultaneous connections on both the 2.4 GHz and 5 GHz bands. It is backward-compatible with 802.11b/g/n.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	Up to 450 Mbps	Up to 150 meters	Medium
5 GHz	Region Dependent	Up to 1300 Mbps	Up to 70 meters	Medium

802.11ah (Wi-Fi HaLow™)

IEEE 802.11ah (Wi-Fi HaLow - pronounced "HEY-Low") was published in 2017 as an amendment of the IEEE 802.11 2012 standard. The WiFi Alliance sees HaLow playing a large role in the IoT. It uses license exempt bands that exist below 1 GHz to provide extended range Wi-Fi networks, compared to conventional Wi-Fi networks operating in the 2.4 GHz and 5 GHz bands.

HaLow will not carry the very high data throughput levels that can be accommodated by 802.11ac or other 802.11 variants. However, it provides many features that will enable it to be used in applications where longer distances are needed and where low power requirements are key.

HaLow is also expected to compete in areas which are today serviced by the WPAN wireless protocols. HaLow devices are expected to have similar levels of energy consumption to WPAN devices with the added benefit of wider coverage range.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
< 1 GHz	N (ISM regional bands)	150 kbps to 347 Mbps	Up to 1 kilometer	Low

802.11ax

IEEE 802.11ax is the successor to 802.11ac, and will increase the efficiency of WLAN networks. Currently in development, this project has the goal of providing 4x the throughput of 802.11ac.

Wireless Wide Area Networks (WWAN)

Sigfox

Sigfox is a proprietary cellular style network that has been set up to provide low power low data rate, and low-cost communications for remote connected devices.

The idea for Sigfox is that for many M2M applications that run on a small battery and only require low levels of data transfer, then WiFi’s range is too short while cellular is too expensive and consumes too much power.

Sigfox utilizes a wide-reaching signal that passes freely through solid objects, called Ultra-Narrowband and requires little energy, being termed Low-Power Wide Area Network (LPWAN).

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
868/915 MHz	N (ISM regional bands)	100 bps	Up to 50 kilometers	Very Low

LoRaWAN

LoRaWAN is a Low-Power Wide Area Network with features that support low-cost, mobile, and secure bi-directional communication for Internet of Things (IoT), machine-to-machine (M2M), and smart city, and industrial applications.

LoRaWAN is optimized for low power consumption and is designed to support large networks with millions and millions of devices. LoRaWAN uses Chirp Spread Spectrum modulation to achieve the low power consumption and long range.

Innovative features of LoRaWAN include support for redundant operation, geolocation, low-cost, and low-power - devices can even run on energy harvesting technologies enabling the mobility and ease of use of Internet of Things.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
868/915 MHz	N (ISM regional bands)	300 bps to 50 kbps	Up to 15 kilometers	Very Low

Ingenu RPMA

Random Phase Multiple Access (RPMA) is a proprietary LPWAN technology stack developed by Ingenu. The company was founded in 2008 in San Diego, California by former engineers of Qualcomm and was originally named On-Ramp Wireless.

In September 2015, Ingenu announced a buildout of "the Machine Network", a public purpose built long range Low-Power Wide Area Network targeting M2M and IoT applications using the RPMA wireless protocol.

Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
2.4 GHz	N (ISM global band)	Up to 624 kbps for uplink Up to 156 kbps for downlink	Up to 20 kilometers	Low

NWave Weightless

Weightless a set of LPWAN open wireless technology standards for exchanging data between a base station and thousands of machines around it. Weightless is managed by the Weightless SIG, or Special Interest Group, and was revealed to the public on 7 December 2012.

There are currently three published Weightless connectivity standards Weightless-W, Weightless-N and Weightless-P. Weightless W is a low power wide area network designed to operate in the TV whitespace. Weightless-N is an uplink only, ultra-narrow band technology operating in licence exempt sub 1GHz ISM band. Weightless-P is the main focus of the Weightless SIG as it is a truly bi-directional, narrow band technology.

Protocol Variant	Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
Weightless-W	400 to 800 MHz	Y (TV whitespace)	1 kbps to 10 Mbps	5 kilometers	Low
Weightless-N	868/915 MHz	N (ISM regional bands)	100 bps	5 kilometers	Very Low
Weightless-P	169 / 433 / 470 / 780 / 868 / 915 / 923 MHz	N (ISM/SRD regional bands)	200 bps to 100 kbps	5 to 10 kilometers	Very Low

LTE-M

LTE-M (also referred to as LTE Cat-M or Cat-M1) is a stripped-down version of the Long-Term Evolution (LTE) cellular communication standard that was released in Q1 of 2016 as part of 3GPP's Release 13.

The advantage of LTE-M for M2M communications is that it works within the normal construct of LTE networks. It uses the same spectrum and base stations, works everywhere that LTE works, and enables true TCP/IP data sessions. In other words, a cellular carrier must only upload new software onto its base stations to enable LTE-M.

The major difference between LTE and LTE-M is power efficiency. The energy efficiency of LTE-M is due in large part to its ability to remain virtually "attached" to the network while not physically maintaining a connection. There are two modes that enable this:

- Power-Saving Mode (PSM): allows devices to go idle without having to re-join the network when they wake up
- Extended Discontinuous Repetition Cycle (eDRX): allows endpoints to advertise how often it will be awake for downlink.

Frequency Band	Data Rate(s)	Approx. Range	Relative Power Consumption
Range of licensed bands that vary from region to region.	Up to 1 Mbps	5 kilometers	Low to Medium

NB-IoT

NB-IoT (also referred to as Cat-M2) is low power narrowband cellular communication technology developed for the Internet-of-Things (IoT). It was released in Q2 of 2016 as part of 3GPP's Release 13.

Like LTE-M it is expected that it will be possible for cellular carriers to enable NB-IoT through a software upgrade of its base stations. However, in some situations a base stations hardware upgrade would be required which may cause some cellular carriers to stick with LTE-M. NB-IoT has limited commercial availablity since the second half of 2017.

NB-IoT focuses specifically on indoor coverage, low cost, long battery life, and enabling a large number of connected devices. Compared to LTE-M NB-IoT has a lower carrier bandwidth (200 kHz versus 1.4 MHz) which results in a much lower data rate. NB-IoT can be deployed in-band in LTE spectrum, in the guardband of LTE spectrum or standalone.

Frequency Band	Data Rate(s)	Approx. Range	Relative Power Consumption
Range of licensed bands that vary from region to region.	Up to 250 kbps	Up to 15 kilometers	Low

5G

5G is the fifth generation of mobile, cellular technologies, networks and solutions. Currently in development, it promises a major change in mobility as well as a broad enablement of IoT use cases. 5G trials started in 2017 and global rollout is expected by 2020.

The full benefits of 5G for the IoT are not fully understood since the 5G standards have yet to be finalised.

Inmarsat

Inmarsat plc is a British satellite telecommunications company. Inmarsat owns and operates a global satellite network, offering mobile and fixed communications services for maritime, enterprise, government & aviation.

With Europasat, Inmarsat also provide an S-band mobile satellite service (MSS) providing provide multi-beam pan-European Union (EU) coverage. The satellite is custom designed to offer a variety of innovative MSS services to Inmarsat's traditional and new mobile markets.

Inmarsat introduced global commercial service for Global Xpress using the Ka-Band in December 2015. Global Xpress (GX) is a globally available, high-speed broadband connectivity service.

	Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
Today	1 to 2 GHz	L-Band	Up to 800 kbps	Global	High
Beyond 2020	1 to 2 GHz	L-Band	Up to 2 Mbps	Global	High
Europasat	2.0 to 2.2 GHz	S-Band	2 to 15 Mbps	EU	High
GX	27 to 40 GHz	Ka-Band	Up to 50 Mbps for downlink Up to 5 Mbps for uplink	Global	High

Iridium

Iridium Communications Inc. is a publicly traded American company that operate the operates the Iridium satellite constellation. Iridium provide worldwide voice and data communication from hand-held satellite phones and other transceiver units.

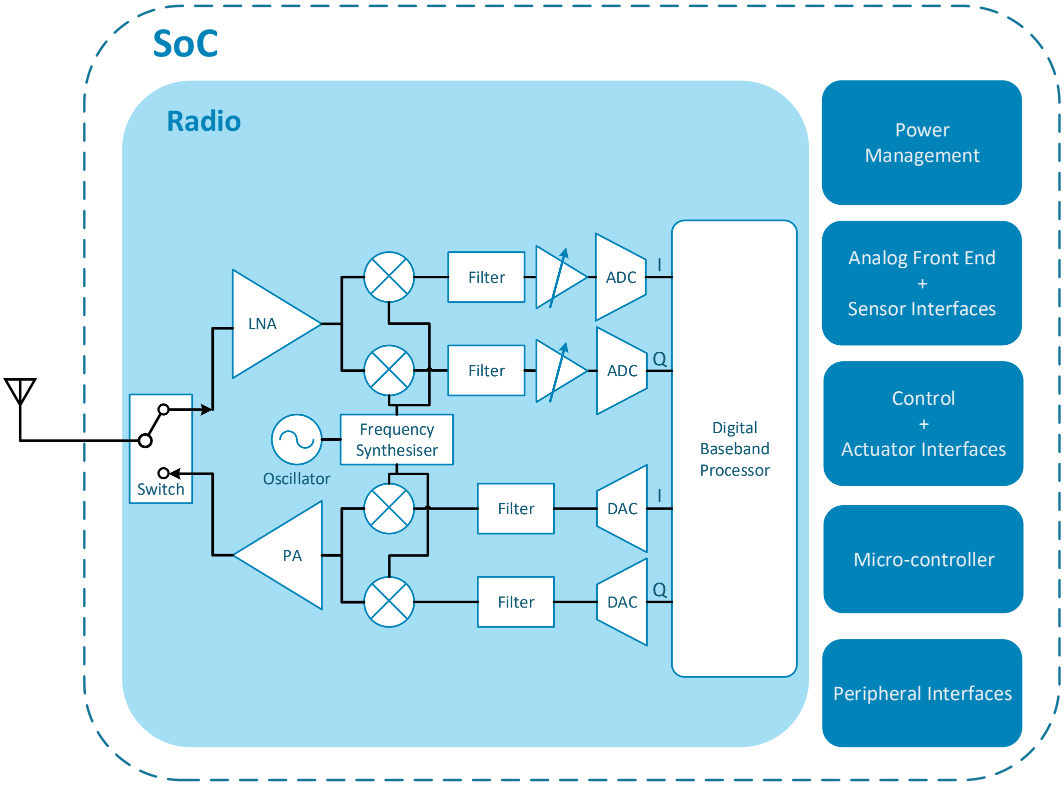
During 2017 and 2018 Iridium are launching Iridium NEXT, a second-generation worldwide network of telecommunications satellites. The constellation will provide L-Band data speeds of up to 128 kbps to mobile class terminals, up to 1.5 Mbps to Iridium OpenPort class terminals, and high-speed Ka-Band service of up to 8 Mbps to fixed/transportable terminals.

	Radio Frequency	Licensed Band	Data Rate(s)	Approx. Range	Relative Power Consumption
Iridium	1 to 2 GHz	L-Band	Up to 2.4 kbps	Global	High
Iridium NEXT	1 to 2 GHz	L-Band	Up to 1.5 Mbps	Global	High
Iridium NEXT	27 to 40 GHz	Ka-Band	Up to 8 Mbps	Global	High

SoC Integration

The development of the single chip all-CMOS GSM/GPRS/EDGE RF transceivers by companies such as Infineon, TI, Freescale and SiLabs in the mid 2000’s was the seed for integration of radio(s) into System on Chips (SoCs). Over a decade later it is very common to see integration of radio transceivers, baseband processors and power management in multi-function SoCs. Most major semiconductor foundries provide RF compatible CMOS manufacturing nodes in geometries from 180nm down to 28nm.

The diagram below shows a typical SoC with integrated radio.



Renesas' ASIC & IP division have a wide range of silicon proven IP which can be used as building blocks for an integrated radio in your custom silicon.

In addition to IP, our ASIC & IP division has substantial expertise in integrated radio design and manufacture and have the capability to integrate the radio alongside the sensing and control functions. This will ensure the correct radio capabilities are implemented in your custom silicon to support your product use case.

SmartEdge™ Platform

Renesas, formerly Dialog's SmartEdge™ platform incorporates all the Sensor AFE (Analog Front End), Calibration, Control Loop, Communication and Security elements of a smart edge device, all integrated onto a single cost-effective ASIC chip. With more than 20 years' experience designing advanced embedded mixed-signal chips for hundreds of customers in every major region, Renesas' ASIC & IP division delivers a new breed of design-centric semiconductor supplier capable of optimising its designs for every customer, yet achieving cost economies not thought possible with custom chips designs until now. Regardless of the radio protocol used, Renesas can integrate onto a single-chip the connectivity feature.

Revision History

Revision	Date	Description
1.0	Mar 01, 2018	Initial release
1.1	Dec 22, 2021	Re-brand