

White Paper

Creating Cellular IoT Applications Using the AE-CLOUD2 Kit

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Abstract

Integrating cellular for the Internet of Things (IoT) represents a new challenge for embedded developers. With the rapid changes in the cellular and IoT markets, developers need to be able to quickly understand and evaluate the new technologies introduced by cellular and IoT for their products and companies to remain relevant. This paper describes how the Renesas AE-CLOUD2 kit enables developers to rapidly evaluate emerging cellular technologies and develop embedded IoT devices using the cellular modem, Renesas Synergy™ microcontroller (MCU), and supporting sensors.

Introduction

Embedded development has undergone a transformation, and IoT has been one of the major agents behind the changes. In the past, a coffee maker had simple electronics for controlling power, heating water, or setting a timer to automatically start brewing in the morning.

Nowadays, coffee makers have features similar to smartphones such as color graphics and screens. With IoT, coffee makers now require a way to connect to the Internet and to be controllable via mobile apps.

IoT has also forced embedded developers to change the way they develop and create embedded products. Previously, developers only needed to focus on integrating sensors and

electronic peripherals with a microcontroller. With IoT, developers now need to deal with establishing an Internet connection, which requires selecting between various connectivity options such as Ethernet, Wi-Fi, and cellular, and managing the various protocol stacks required to support those options.

For embedded developers, this technical complexity combined with IoT has challenged the way they have traditionally worked. This white paper explores the evolution of cellular technologies for use with IoT, as well as how the AE-CLOUD2 kit hardware and Renesas Synergy Software Package help embedded developers create IoT devices.

Evolution of Cellular for IoT

While Wi-Fi and Ethernet are relatively mature connectivity technologies, cellular represents a new frontier for embedded developers and IoT. Prior to a few years ago, cellular was a nonstarter for many IoT applications as the power consumption and implementation costs made cellular unusable except for limited applications. Part of the limitations of cellular were because cellular networks were designed originally to be able to seamlessly transmit voice calls from a phone, where the call needed to be passed from cell tower to cell tower. This architecture required constant communication between the cell tower and the phone to ensure this level of call quality. The constant communication meant high power consumption on the part of the cellular application. The requirement for high quality communication for voice also meant that the cellular networks and data plans were priced to ensure that those voice calls could go through seamlessly.

With IoT, the use case for cellular has shifted. Rather than humans making voice calls over the air waves, now devices are transmitting small amounts of sensor data. IoT devices do not require the same quality of connection as a voice call, and many IoT applications are stationary versus moving as in the case of voice calls from a phone. In response to this changing use case for cellular, many cellular standards organizations and mobile carriers rolled out new cellular technologies targeted for IoT applications. Two new networks are CAT-M and NB-IoT, which are two different types of 4G LTE technology. CAT-M and NB-IoT reduce the power consumption of cellular by allowing IoT devices to remain in sleep mode for extended periods of time and reconnecting to the cellular network within seconds versus minutes. These new networks accomplish this optimization by using unlicensed and unused guard band frequencies between

channels of licensed cellular spectrum that allow high priced voice calls to coexist with data being sent by IoT devices.

CAT-M1 and LTE CAT-NB1 (NB-IoT) are well suited for remote or mobile applications that aren't always near a fixed Internet connection like Ethernet or Wi-Fi. Typical applications include asset tracking, wearables, parking meters, agriculture monitors, and city infrastructures. CAT-M1 is best suited for IoT applications requiring high reliability and low latency. CAT-M1 supports authentication, credentialing, and encryption, and most North American carriers have worked to deploy CAT-M1 first. NB-IoT does not support hand offs between cell towers while the device is in the connected state; instead, devices can only select and connect to a cell tower when the device connection is idle. With this mobility restriction, NB-IoT is better suited for devices and sensors that transmit data infrequently, such as those that remain in a sleep or idle mode and only periodically connect to a cell tower. Unlike CAT-M1, NB-IoT does not support voice calls. Cellular carriers in Europe have primarily deployed NB-IoT networks first.

The table below compares the technical specifications between the CAT-M1 and NB-IoT technologies.

	CAT-M1 (eMTC)	NB-IoT (CAT M2)
3GPP Release	R13	R13
Downlink Peak Rate	1Mbps	250kbps
Uplink Peak Rate	250kbps (multi-tone)	20kbps (single – tone)
Number of Antennas	1	1
Duplex Mode	Full or Half Duplex	Half Duplex
Device Receive BW	1.08MHz	180 khz
Receiver Chains	1 (SISO)	1 (SISO)
Device Transmit Power	20 / 23 dBm	20 / 23 dBm
VoLTE Support	Yes	Not supported
Mobility Support	Full Mobility	No connected mobility (only idle mode reselection)
Advantage	Coverage, Peak data rate; availability	Greater flexibility in spectrum that can be utilized and mode of operation (inband, guard band, standalone), cheaper

AE-CLOUD2 Kit

To help embedded developers quickly and easily evaluate cellular technologies like CAT-M1 and NB-IoT, Renesas has created the AE-CLOUD2 kit. AE-CLOUD2 can be used by embedded developers to rapidly build IoT applications using built-in sensors for temperature, microphone,

humidity, GPS, and magnetometer, as well as the ability to connect using cellular, Ethernet, or Wi-Fi. AE-CLOUD2 comes with a BG96 cellular shield that supports CAT-M1 and NB-IoT frequencies, as well as 2G and GPS.

The cellular integration of AE-CLOUD2 allows embedded developers to quickly evaluate cellular connectivity options. Depending on the loaded firmware image, AE-Cloud2 can either connect to the Renesas Synergy Enterprise Cloud Toolbox or the IoT Cloud of your choice. The Renesas Synergy Enterprise Cloud Toolbox is a demo that allows connection to Amazon Web Services, Microsoft Azure, or Google Cloud Platform in as little as ten minutes. The Renesas Synergy Enterprise Cloud Toolbox connects to a web dashboard to visualize the sensor data.



AE-CLOUD2 Kit Benefits:

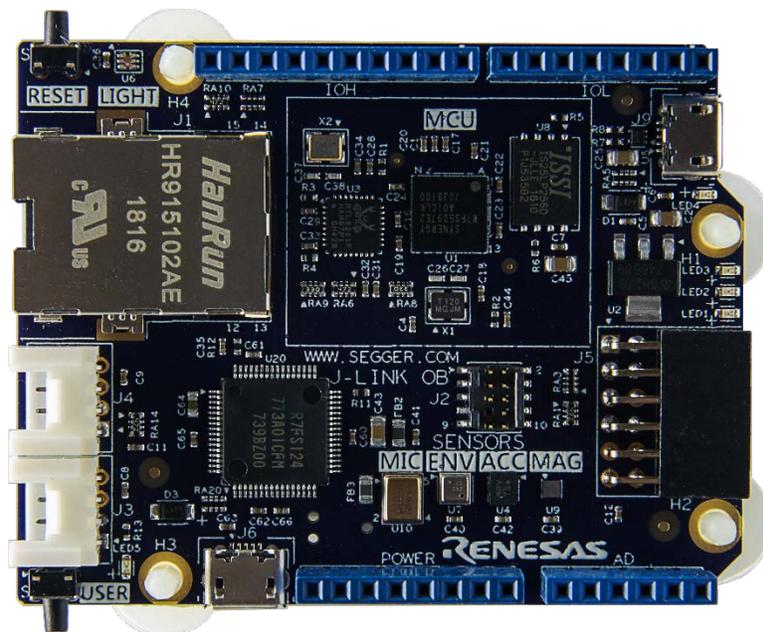
- Rapid evaluation, prototyping, and development of cloud connection applications
- Quickly and seamlessly evaluate emerging cellular technologies of CAT-M and NB-IoT
- Software support for connecting to cloud services from Amazon, Microsoft, and Google

- Certified and configured cellular development tool with cellular frequency support and certification for use anywhere in the world
- Cellular, Wi-Fi, and Ethernet connections included
- Comes with a host of sensors including GPS

The next sections will discuss the AE-CLOUD2 kit contents, RF certifications, and embedded cellular design. All these elements provide the developer the means to quickly and easily build a cellular IoT prototype or application. IoT requires the combinations of multiple technologies that span numerous disciplines. Having all these combinations included allows the developer to focus on building an end-to-end solution.

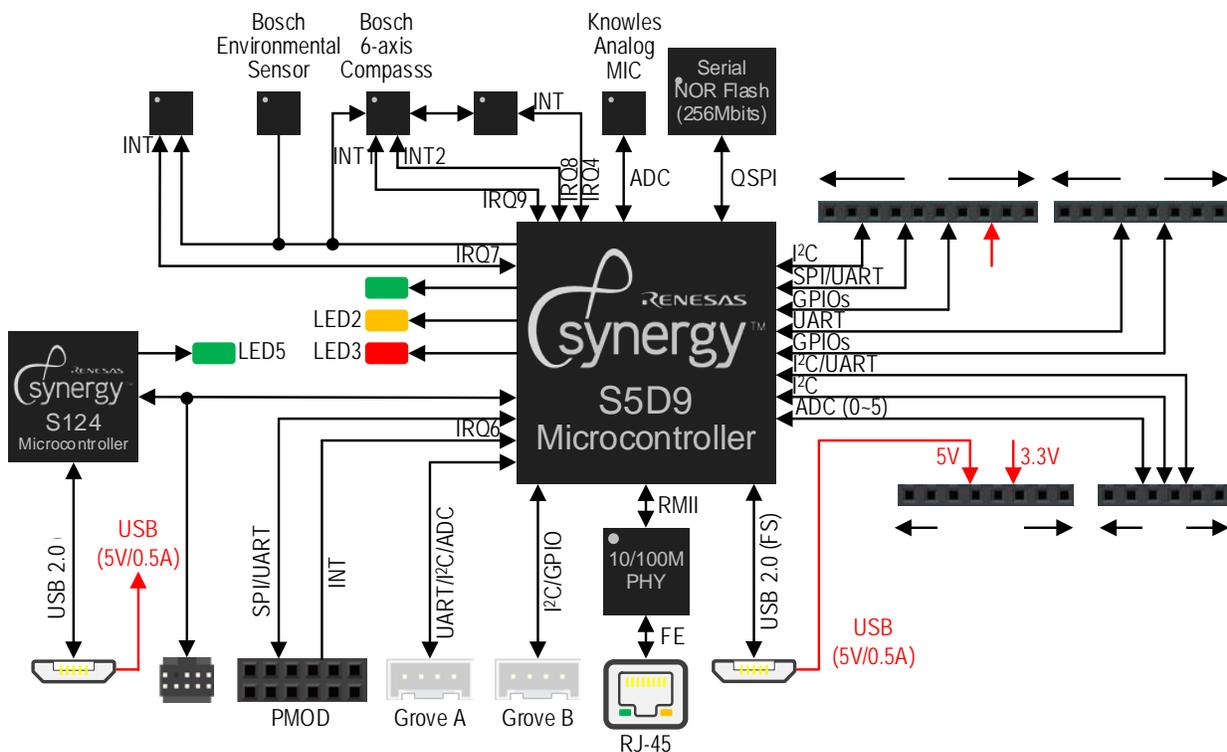
S5D9 MCU Pillar Board

The AE-CLOUD2 kit contains the Renesas Synergy S5D9 MCU Pillar board whose rich functionality makes it ideal for prototyping a wide range of IoT solutions. The picture below shows the top view of the MCU board. It is built around the versatile Renesas Synergy S5D9 MCU. The Segger J-Link On-Board, using the Renesas Synergy S124 MCU, provides a debug interface so that no external programming probes are needed. The board is highly integrated with many sensors, external flash memory, Ethernet PHY, Arduino, Grove and PMOD™ connectors, buttons, and LEDs.



MCU Board System Architecture

For IoT, having a variety of sensors and connectivity options is best for maximum flexibility, providing the ability to cover a variety of use cases and respond to quickly changing IoT market needs. The MCU represents the core of an IoT product as it drives the control and function of the embedded design. A MCU with support for a range of interface and serial protocol options is essential for communicating with whatever sensors might be required by an application. The diagram below shows the main components of the MCU board, as well as the support for various interfaces with peripheral components.



The MCU Board includes the following main components:

- The Synergy S5D9 MCU featuring 2MB Code flash/640KB RAM/64KB Data flash.
- Quad SPI Flash – the MCU flash memory is expanded with an external 32 MB memory device connected over a high-speed QSPI interface. The external flash can be used for storage of graphics and other digital assets or for execution of code in place (XIP).

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- User-defined LEDs – the user-defined LEDs are useful in indicating the current state of the firmware. The three LEDs have different colors for easy identification.
 - USB device interface – the S5D9 MCU includes one USB interface operating in full speed. The USB device connector is used to power the board.
 - PMOD interface header – the board includes one 12-pin PMOD header that can be configured by jumper to provide either 3.3V or 5V on its power pins. The header enables interfacing with other devices over SPI or UART.
 - Grove connectors – the Grove connectors are compatible with the Seeed Studio's line of peripheral modules that includes a very large selection of sensors and actuators. One of the Grove connectors can be configured to communicate over UART, and the other is dedicated for I²C interface.
 - J-Link On-Board Segger debugging probe based on the Renesas Synergy S124 MCU.
 - JTAG interface that is available on a 10-pin connector (J20), which is compatible with a Segger debugging probe.

The board includes several sensors and connectivity options that allow users to create an IoT application that can monitor and report sensor data. Having an application that can monitor and report data helps customers understand the concept and value of the application. Monitoring also serves as a fundamental starting point as it allows a user to know the current condition of the environment on which you are trying to gather more information. With a variety of on-board sensors and connectivity options, a developer can build applications for many different markets and use cases. The connectivity options and on-board sensors are described as follows:

- **Wi-Fi:** GT202 Wi-Fi module
 - The Wi-Fi board is based on the GT202 module. It incorporates the Qualcomm® Atheros QCA4002 device. The QCA4002 is a system-on-a-chip (SoC), implementing the 802.11 b/g/n communication standards. It is optimized for low-power embedded applications with single-stream capability for both transmit and receive streams. The SoC has an integrated network processor with a large set of TCP/IP with IPv4/IPv6-based services. They can be accessed via a high-speed SPI interface, which is accessible on a 12-pin PMOD header. The GT202 Wi-Fi module integrates the QCA4002 SoC on a carrier board, which brings out three different host connectivity options:
 - SPI Interface through the PMOD connector – used for interfacing with the AE-CLOUD2 MCU board and power supply source. This interface provides fast communication speed and access to the full networking functionality.

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- SDIO/UART Interface – used for rapid prototyping and low communication speeds (not utilized by the AE-CLOUD2 kit)
 - USB Interface/Hostless – used for fast prototyping, diagnostic, and alternative power supply (not utilized by the AE-CLOUD2 kit)
 - **RJ45 Ethernet Connector:** Hanrun Electronics, Ltd. P/N: HR915102AE
 - AE-CLOUD2 features standard Ethernet connector RJ45 with built-in magnetics. The PHY is connected to the MCU via RMI interface.
 - **Accelerometer, Gyroscope and Magnetometer:** Bosch Sensortec - BMI160 and BMM150
 - BMI160 is an extremely small low-power and low-noise 6-axis accelerometer and gyroscope.
 - The integrated accelerometer provides all functionalities of Bosch's Sensortec leading-edge 12-bit digital accelerometer, including a 32-frame FIFO buffer that stores acceleration data.
 - The interface to the MCU is based on the I²C protocol.
 - **Environmental Sensor:** Bosch Sensortec – BME680
 - The BME680 is a digital 4-in-1 sensor with gas, humidity, pressure, and temperature measurement based on proven sensing principles.
 - The interface to the MCU is based on the I²C protocol.
 - **Ambient Light Sensor:** Renesas - ISL29035
 - The ISL29035 is an integrated ambient and infrared light-to-digital converter with an I²C bus interface. Its advanced self-calibrated photodiode array emulates human eye response with excellent IR rejection. The on-chip 16-bit ADC is capable of rejecting 50Hz and 60Hz flicker caused by artificial light sources. The Lux range-select feature allows users to program the Lux range for optimized counts/Lux.
 - The interface to the MCU is based on the I²C protocol.

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- **MEMS Microphone:** Knowles SPM0687LR5H-1
 - The SPM0687LR5H-1 is a miniature high-performance, low power, top-port silicon microphone. It consists of an acoustic sensor, a low noise input buffer, and an output amplifier.
 - The device has the following main features:
 - 20 dB of Gain
 - Low current consumption
 - Max RF protection
 - Ultra-stable performance
 - Omnidirectional

Arduino-Compatible Expansion Headers

For IoT, developers often use Arduino shields to quickly evaluate new hardware options for their application. The S5D9 MCU board has Arduino-compatible headers that enable developers to expand the board features using the large ecosystem of Arduino Shields. Most of the interface signals are connected directly to the MCU pins, which allows the configuration to change according to the needs of the application. The cellular support for the AE-CLOUD2 kit is provided through the expansion made possible by the included Cellular Arduino shield.

Mechanical Dimensions

For IoT prototyping applications, a small board size often allows the developer to use the board directly as a proof of concept or a demonstration. The S5D9 MCU board size has been optimized to enable a broad range of IoT prototyping applications. The board size is smaller than a credit card, which allows the board to be placed in a larger number of locations, including inside other devices as a way to add IoT capabilities to an existing application. The smaller board size allows for more electronics to be placed into an existing space; therefore, increasing the capability of the end device. The size of the S5D9 Pillar board makes it well suited for IoT prototyping scenarios, as well as allowing the same board to be used in a production setting provided space is allowed.

Cellular Connectivity Board

When creating cellular IoT devices, developers must decide the type of cellular embedded solution to use. The typical options are to use an embedded cellular chipset, an embedded module, or an embedded device board. All embedded applications that incorporate cellular start with a chip that provides the RF radio in order to be able to connect to a cellular network. While it is certainly possible for an embedded designer to integrate a cellular chip into an embedded design, starting with a chip requires a larger investment of engineering time and effort, as well as the cost of certification of the device. Rather than using an embedded chipset, an embedded engineer can use a module, which is well suited for lower volumes due to the lower complexity and overall cost of the embedded solution. Modules are often commercially available and often the network certification has already been performed by the module manufacturer. AE-CLOUD2 uses a preconfigured cellular module to help speed up the development of the kit and to get the kit in the hands of developers sooner.

While selecting a cellular module for an embedded design can speed up development, issues can still arise when integrating the module into the embedded application. For example, integrating the cellular module can often require negotiating the technical troubleshooting between the module manufacturer, cellular chip company, mobile carrier supplying the data plan, and the IoT Cloud to which the embedded device is connecting. A common scenario that can occur is that the embedded device cannot connect to the IoT Cloud using the cellular module. The first troubleshooting step is to ensure that the correct AT command sequence is being sent to the cellular chipset. Problems with the AT command that was sent can be related to the firmware version of the cellular chipset needed to support the cellular frequencies being used. For cellular modules, problems can be related to the cellular chipset, requiring an update to the firmware to correct issues with the supported AT command set or to add support for an additional cellular carrier. Assuming the correct AT command set is being sent, then the next step is with the cellular carrier to ensure that the cellular modem, as well as the data plan, are working correctly. For connecting to the cellular network, issues that can arise include ensuring adequate network coverage and signal strength in your local area. Lastly, most cellular embedded development efforts often require the developer to be the managing party to coordinate the various technical stakeholders to troubleshoot and determine the root cause of the issues that occur.

The AE-CLOUD2 Kit provides cellular connectivity by utilizing the Quectel BG96 modem installed on an Arduino Shield board. The BG96 module supports multiple cellular standards, as well as a GPS receiver that enables the prototyping of position tracking applications. The table below describes the global frequency support of the BG96 module.

3GPP Band	Transmit (MHz)	Receive (MHz)	Cat-M1	Cat-NB1	GSM/GPRS
B1	1920~1980	2110~2170	X	X	
B2 (PCS1900)	1850~1910	1930~1990	X	X	X
B3 (DCS 1800)	1710~1785	1805~1880	X	X	X
B4	1710~1755	2110~2155	X		
B5 (GSM850)	824~849	869~894	X	X	X
B8 (GSM900)	880~915	925~960	X	X	X
B12	699~716	728~746	X	X	
B13	777~787	746~757	X	X	
B18	815~829.9	860~874.9	X	X	
B19	830~844.9	875~889.9	X	X	
B20	832~862	791~821	X	X	
B26	814~848.9	859~893.9	X	X	
B28	703~748	758~803	X	X	
B39	1880~1920	1880~1920	X		

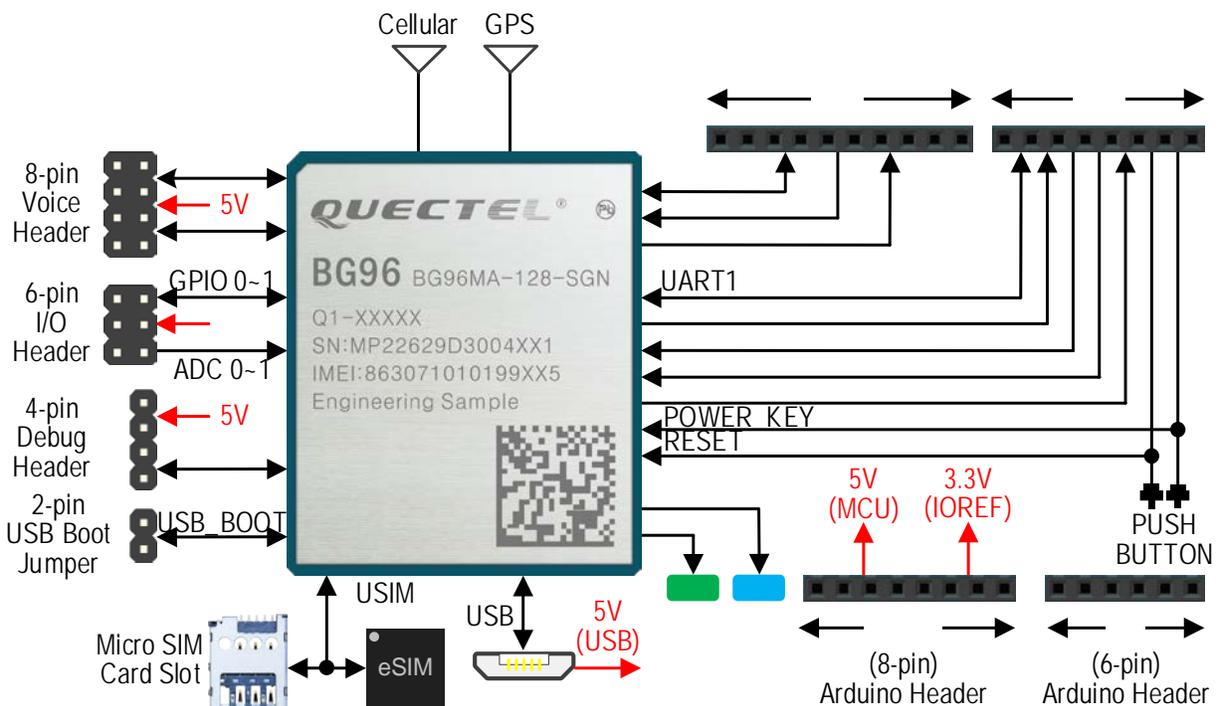
Cellular Connectivity Board



Cellular Board Block Diagram

Cellular IoT applications cover a variety of requirements and applications. With the increasingly global nature of products and the rapid change in SIM card technology, a cellular board that can support a variety of cellular frequencies becomes very important. The BG96 module provides

support for a physical SIM card or an electronic SIM (e-SIM), which allows developers to quickly test SIM cards from any mobile carrier globally. With some mobile carriers deploying CAT-M1 networks and others deploying NB-IoT networks, developers may face challenges with finding a cellular module that supports the cellular technology that has been deployed in the country. With support for both CAT-M1 and NB-IoT, the BG96 module allows developers to test cellular frequencies anywhere in the world regardless of the status of the mobile carrier's network support. The figure below shows the BG96 module connections to the main components and interfaces available for peripheral parts.



Global RF Certification

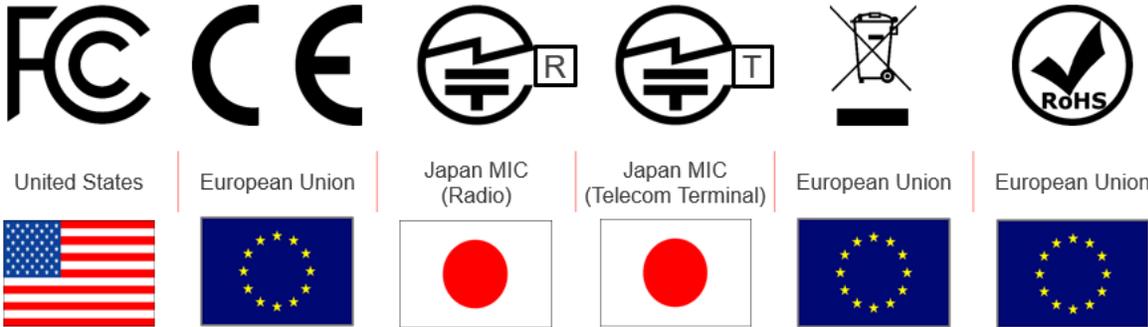
Having global RF certifications demonstrates the quality of the product, as well as compliance with the applicable laws and regulations for the geographic region. The certifications also show that a device has met specific standards related to the methods, workmanship, and materials used.

When obtaining RF certifications, the embedded cellular device will have to go through multiple rounds of RF testing and design. For RF certification, a pre-scan is done prior to submitting a device for certification to determine if the device will pass the RF certification tests. If an embedded cellular device fails the pre-scan, the device can go through rounds of testing and debugging to pinpoint specific issues that are preventing the device from passing the RF certification testing. Often the issues are related to the amount of RF noise emitted from the device that exceeds the threshold allowed for a specific RF certification standard. While the extra testing required to obtain global RF certification can certainly affect the completion time and cost of an embedded cellular device, the benefit of having an embedded cellular device that can address global IoT use cases and customers is worth the effort.

AE-CLOUD2 has taken care of the global certifications so that the developer does not need to stop his work to consider if they are legally allowed to use their IoT prototype device in their country. These certifications also allow AE-CLOUD2 to be used by the developer for production if appropriate.

Additionally, AE-CLOUD2 comes with global certification so that the cellular connectivity can be used anywhere in the world as part of an embedded evaluation, or even as an initial prototype board. The regulatory certification markings for AE-CLOUD2 are shown below and include FCC (US), CE marking (EU), Radio and Telecom approval (Japan), Waste Electrical and Electronic Equipment Directive(EU), and RoHS compliance (EU).

AE-CLOUD2 KIT CERTIFICATIONS



Below is a list of the cellular bands and frequencies supported by AE-CLOUD2.

Cat-M1	Cat-NB1	GPRS/EGPRS	GNSS	Chipset
LTE FDD: B1/B2/B3/B4/B5/B8/B12/ B13/B18/B19/B20/B26/B28 LTE TDD: B39 (For Cat-M1 Only)	LTE FDD: B1/B2/B3/B4/B5/B8/B12/B 13/B18/B19/B20/B26/B28	850/1900MHz 900/1800MHz	GPS GLONASS, BeiDou/Compass Galileo QZSS	Qualcomm (MDM9206)

Renesas Synergy Software Package

AE-CLOUD2 enables rapid development of IoT applications using the Renesas Synergy Platform, which provides professional grade tools for building IoT products.

The embedded code for AE-Cloud2 is built using the Renesas Synergy Software Package (SSP), which includes TLS, MQTT, and Wireless Application Frameworks. The Wireless Application Frameworks provide for easy implementation for technologies like Wi-Fi, cellular, and Bluetooth® Low Energy. The NetX™ Secure TLS secures and authenticates communication between devices and the Cloud, while the MQTT for NetX Duo enables communication for devices that only send smaller amounts of data. These components provide the SSP with the means to connect to any major cloud service provider with little to no barriers to getting started.

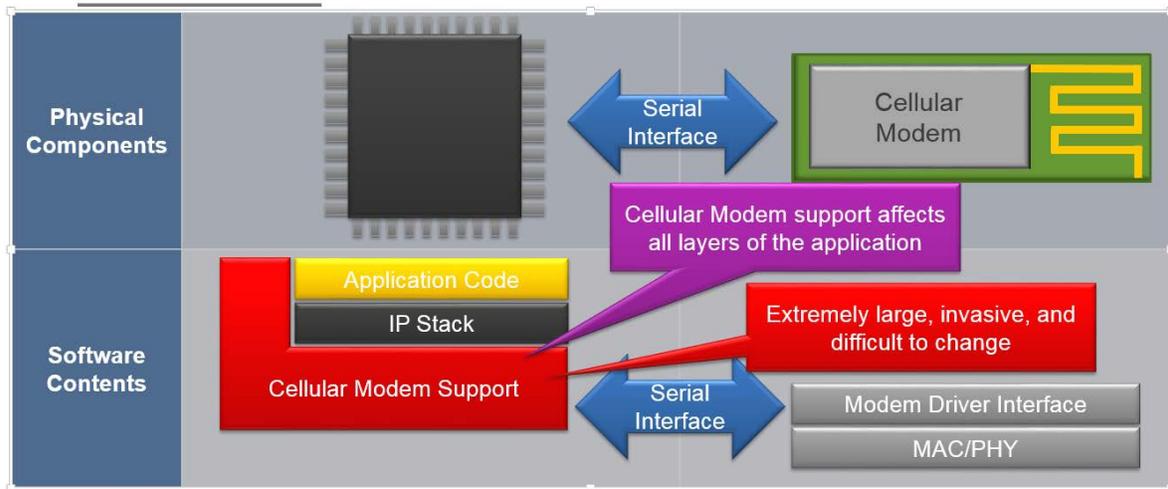
The Hypertext Transfer Protocol (HTTP) is a protocol designed for transferring content on the web. HTTP is a simple protocol that utilizes reliable Transmission Control Protocol (TCP) services to perform its content-transfer function; HTTP is a highly reliable content-transfer protocol, as well as being one of the most frequently used application protocols. All operations on the web utilize the HTTP protocol. The NetX Duo™ HTTP Client accommodates both IPv4 and IPv6 networks, while the NetX HTTP Client only supports IPv4 communications. IPv6 does not directly affect the HTTP protocol; some differences with the NetX HTTP Client are necessary to accommodate IPv6.

Cellular Framework

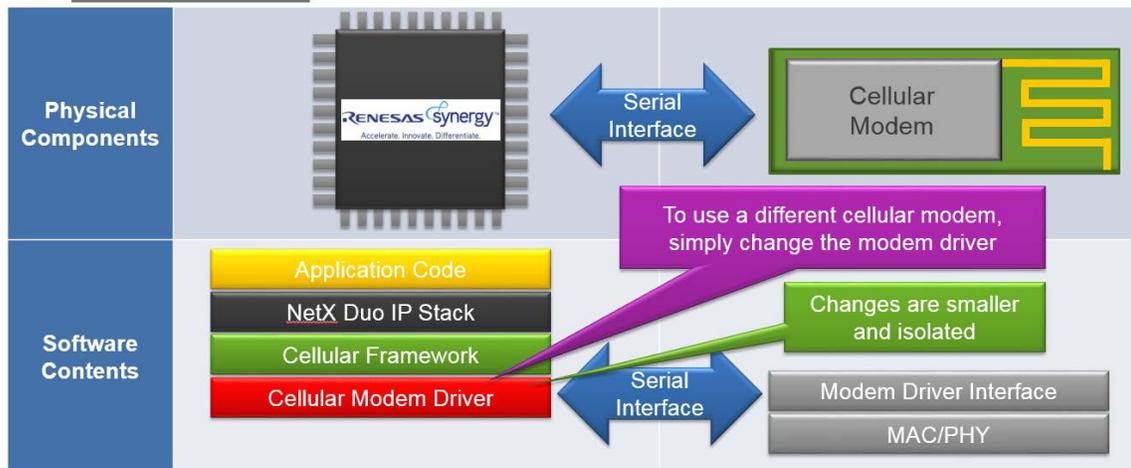
For creating cellular applications, developers often face the issue of using one cellular modem for evaluation and having to start over with another modem for production. The SSP Cellular Framework allows a developer to change to different modems with minimum code change,

which is important as it allows developers to reuse code from their evaluation for production situations. AE-CLOUD2 also uses the SSP Cellular Framework module as a high-level application layer interface for the cellular modem integration on the SSP Application Framework and provides sets of APIs to provision, configure, and communicate with the cellular network for data communication. The SSP Cellular Framework uses the SSP Application Framework (console framework) to communicate with the cellular modems with a serial interface by using AT commands internally. The SSP Application Framework also creates the serial data pipe over serial interface for the data communication, leveraging the PPP WAN protocol provided by NetX. Any TCP/IP communication can be established over this wide area network (WAN) link using the sockets, NetX application protocols, and IoT protocols such as MQTT or COAP. The Cellular Framework also provides the framework-level socket APIs to communicate with the TCP/IP stack present on-chip (inside cellular hardware module) in certain cellular hardware modules; thereby, communicating with the Internet network using the socket APIs.

WITHOUT THE CELLULAR FRAMEWORK



WITH THE SYNERGY CELLULAR FRAMEWORK



Conclusion

Building embedded cellular IoT applications requires engineers to use advanced tools to create them. For engineers to even create a prototype requires technical skills from embedded to cellular to RF certification to software to the Cloud. The AE-CLOUD2 Kit provides an encompassing way for embedded developers to quickly and easily evaluate those technologies and to build the IoT products of the future.

Next Steps

To find out more about the Renesas AE-CLOUD2 kit, go to www.renesassynergy.com/ae-cloud2

Download the Synergy Enterprise Cloud Toolbox Demo: <https://cloud.renesassynergy.com>

Download the Cloud Application Projects for Amazon Web Services, Microsoft, and Google Cloud Platform www.renesas.com/in/en/products/synergy/gallery.html

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