Building a gateway to the Internet of Things

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Connectivity can add great value to many embedded applications. In industrial systems, for example, end equipment can communicate with remote sensors, other end equipment, and a centralized management console to improve reliability and productivity. Extending connectivity beyond the LAN out to the WAN is often referred to as the Internet of Things (IoT) or the Internet of Everything (IoE). For many applications, attaching devices to the IoT cloud provides additional benefits to the entire ecosystem – end customers, service providers and equipment OEMs.

The IoT will include not just new devices specifically designed for IoT compatibility but also systems that are already in place today and operate outside of the IoT cloud. However, the path to creating a ubiquitous cloud of interconnected devices requires a means for devices that are not IP-based to connect without having to bear the cost of a full Ethernet or Wi-Fi interface with accompanying protocol stack. This can be achieved through the use of gateways that bridge these devices to the Internet in the context of real-world applications. In addition, adding intelligent and embedded control to gateways can simplify IoT device design by providing access to shared processing resources.

While this white paper focuses on implementing connectivity for IoT applications, it offers insights into the design of any application requiring embedded Internet connectivity. Key topics addressed include implementing IP connectivity, security, disparate node aggregation, power and cost.

The connectivity challenge

Many strides have been made in advancing IoT technology in industrial applications because of the value gained in connecting end equipment for automation, system reliability and centralized management. While developed for industrial applications, many of these advances are applicable to all types of embedded systems, including wearables, medical monitors, security devices, residential and commercial HVAC, and a myriad of evolving consumer applications.

For many engineers, the greatest challenge in designing for the Internet of Things (IoT) is connectivity. Implementing robust and secure access to the Internet or Wide Area Network (WAN) is outside their range of experience. To make design even more difficult, developers need to support access to multiple devices that are limited in their processing capability. Connectivity must also be added in a way that does not adversely impact overall system cost or power efficiency.

The diversity of end points a gateway must support raises design concerns as well. Directly connecting a simple node like a pressure sensor to the Internet can be complex and expensive, especially if the node does not have its own processor. In addition, different types of end equipment support varying interfaces. To collect and aggregate data from a disparate set of nodes requires a means for bridging devices with a range of processing capabilities and interfaces together in a consistent and reliable way.

Gateways offer an elegant means for simplifying the networking of “things.” They achieve this by supporting the different ways nodes natively connect, whether this is a varying voltage from a raw sensor, a stream of data over I2C from an encoder, or periodic updates from an appliance via Bluetooth®. Gateways effectively mitigate the great variety and diversity of devices by consolidating data from disparate sources and interfaces and bridging them to the Internet. The result is that individual nodes don't need to bear the complexity or cost of a high-speed Internet interface in order to be connected.

Simple versus embedded control gateways

There are several ways to implement an IoT gateway, depending upon the application. Two common approaches are a simple gateway and an embedded control gateway. Both provide consolidated connectivity by aggregating data from multiple end points. In general, a simple gateway organizes and packetizes the data for transport over the Internet. It is also responsible for distributing data back to end points in applications where two-way communications is advantageous or required.

Note that a gateway is different from a router. A router manages similar traffic, and it connects devices that share a common interface. For example, the devices that connect to a home router all use IP. In contrast, because a gateway functions as a bridge, it must be able to route different types of traffic, aggregate data from varying communication interfaces and convert these streams to a common protocol for access across the WAN. Some devices might use IP natively while others might use PAN-based protocols like Bluetooth, ZigBee or 6LoWPAN. Nodes that are simple sensors may need to be connected to an ADC to convert their raw analog voltage to a digital value before transport.

An embedded control gateway extends the functionality of a simple gateway by providing processing resources and intelligence for handling local applications. This can take the form of shared processing resources where the gateway performs tasks that would otherwise occur on nodes.

For example, an embedded control gateway could evaluate and filter sensor data as well as implement high-level management tasks. After evaluating and filtering sensor data, a gateway could determine whether a critical threshold has been passed. If so, it could then trigger an alarm that is passed up through the network to alert an appropriate manager.

Having an intelligent embedded control IoT gateway can reduce the complexity – and cost – of end points. Depending upon the application, this can result in significant system savings. Consider a security system with an array of sensors to which it connects. Consolidating processing, such as sensor data filtering, in the gateway enables nodes to leverage a shared resource, making each node simpler as well as lower in cost.

The same holds for enabling connectivity. IP is a complex protocol to implement with relatively high overhead for more simple IoT nodes. Instead, simple nodes can connect to a PAN using a wired connection like I2C or a wireless interface like Bluetooth. The gateway also connects to the PAN and then bridges each connection to an IP-based WAN interface like Wi-Fi or Ethernet. In both of these cases, savings include lower processing, memory and power requirements. Nodes can therefore be less expensive as well as more efficient.

When these savings are spread across a network, they add up quickly. End points that have to house their own intelligence and WAN connectivity require more complex architectures. Using a consolidated or shared architecture, the cost of each end point can be substantially reduced, more than making up for any increase in gateway cost through volume savings. Reducing the complexity of nodes also reduces overall power consumption for applications where nodes have limited battery life or operate on energy harvesting sources.

Distributed intelligence also accelerates the implementation of new applications. Consider smart appliances that use time-of-day information from the utility meter to operate off peak hours to reduce energy costs. Implementing this intelligence at the node level requires the washer, dryer and dishwasher to be able to communicate with the utility meter. When each appliance comes from a different company, the interface to use this feature will likely differ, creating interoperability issues. In addition, to take advantage of this feature, consumers would need to buy new appliances.

Enabling intelligence in a gateway addresses both interoperability issues on a local level while minimizing the changes required to connect appliances. Rather than require full intelligence in each appliance, the gateway can provide the base intelligence for all devices. This also has the advantage of consolidating management of new features for consumers; rather than needing to figure out and integrate each new appliance as it enters the home, the consumer only needs to understand how to manage the gateway. An intelligent gateway also better addresses the issues that arise from connecting disparate nodes, compared to users manually connecting each device or appliance to the Internet.

For many applications, an intelligent gateway can eliminate the need for a dedicated onsite management or control end point. For example, with an integrated LCD controller, a gateway can support a user interface so users can directly interact with nodes. Alternatively, an intelligent gateway can provide a web-based user interface – accessible through a PC, tablet or smartphone – to allow users to easily access additional built-in applications. This enables the gateway to serve as a flexible and dynamically programmable onsite control point. This in turn lowers the cost of installation of new systems as well as enables third parties to introduce new technology and devices with a significantly lower cost of entry.

Finally, a gateway can serve as a fabric between co-located nodes when Internet access is lost or temporarily interrupted. This ensures robust local connectivity without the cloud, thus increasing the reliability of the local network to maintain its intended functions.

How gateways connect

Figure 1 shows several ways that an IoT gateway can extend connectivity to nodes. In Figure 1a, nodes connect to the IoT via a gateway. The nodes themselves are not IP-based and thus cannot directly connect to the Internet/WAN. Rather, they use either wired or wireless PAN technology to connect to the gateway with a less expensive and less complex mode of connectivity. The gateway maintains an IoT agent for each node that manages all data to and from nodes. In this case, application intelligence can also be located in the gateway.

In Figure 1b, nodes connect directly to the Internet using a WAN connection such as Wi-Fi or Ethernet. The gateway serves primarily as a router; in fact, it can be simply a router when nodes have their own IoT agent and autonomously manage themselves. Figure 1c is similar to 1b except that nodes connect directly to the Internet using a PAN connection such as 6LoWPAN. In this case, the gateway serves as a translation point between the PAN and WAN.

While there are other types of nodes and architectures that an IoT-based system can be built upon, these three types provide a good representation of how IoT connectivity is currently being implemented in industrial and residential applications. Different levels of sophistication and performance may be required, depending upon the end equipment in use, but these types capture what is needed for the higher volume, lower cost range of applications.

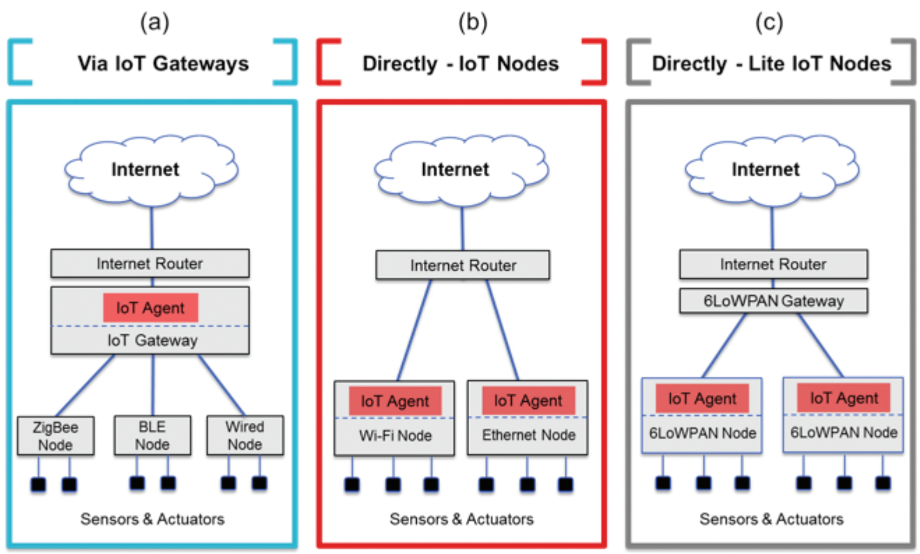

Figure 1: There are several ways that an IoT gateway can extend connectivity to nodes. (a) Nodes connect to the IoT via a gateway using a less expensive and less complex wired or wireless PAN technology. (b) Nodes connect directly to the Internet using a WAN connection such as Wi-Fi or Ethernet. (c) Nodes connect indirectly to the Internet using a PAN connection such as 6LoWPAN.

The most powerful aspect of the IoT is what we cannot see yet. The value of managing appliances for time-of-day use or simplifying security nodes is clear because these applications are near to what we already know. What is not yet obvious is how IoT technology will enable wholly new applications that we haven't imagined yet. For example, when cell phones became smart, few anticipated that they would become open platforms for apps that can do everything from tracking our calories to connecting us so quickly and intimately through Twitter and Instagram.

Today, the highest profile IoT applications are industrial, medical and security. As this technology matures, it is clear that it will completely change how we live and do business in every industry.

The TM4C129x IoT gateway MCU

Ideally, OEMs need an uncomplicated way to introduce connectivity to both new and existing designs. To facilitate the accelerated design of both simple and embedded control gateways, TI offers the TM4C129x family of IoT MCUs.

The TM4C129x MCUs are based on a 120-MHz ARM® Cortex®-M4 core with floating point capabilities, as shown in Figure 2. This allows the processor to handle several-to-many processes to offload processing for individual nodes, giving OEMs the flexibility and unprecedented freedom to develop and connect any system to the IoT.

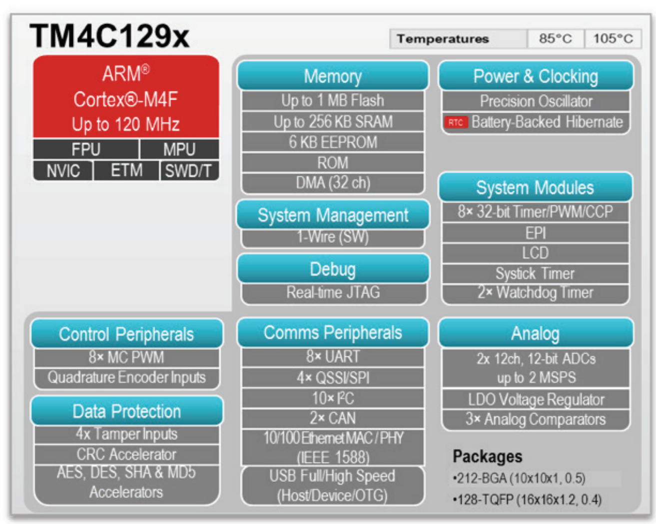

Figure 2: The TM4C129x MCUs are the industry's first ARM® Cortex®-M4 MCU with an integrated 10/100 MAC+PHY. With their extensive capabilities, they are ideal for implementing both simple and embedded control IoT gateways.

The TM4C129x MCUs simplify IP connectivity for gateways by integrating a number of key technologies:

On-chip MAC and PHY: The TM4C129x MCU family is the first ARM Cortex-M4-based family that integrates both a 10/100 Ethernet MAC and PHY. Bringing the PHY on-chip, as shown in Figure 3, provides many benefits. Reducing component count – including passives – simplifies design complexity, leading to easier assembly, less noise from external signals and lower cost. Designs require less PCB space and error-free communications is extended beyond the 100 m cable standard. Together, these add up to an appreciable advantage compared to traditional designs using an external PHY.

Security: Many IoT applications handle potentially sensitive data. Data used for billing, for example, needs to be protected from hacking. Similarly, medical devices need to maintain the privacy of individuals. With its hardware-based cryptographic acceleration and TLS/SSL stack, the TM4C129x MCUs enable OEMs to implement strong security mechanisms with low overhead to minimize threats and maximize data protection. It achieves this by efficiently offloading security processing from nodes to the gateway to ensure proper authentication, protecting exchanges of data and safeguarding intellectual property. This enables IoT nodes to implement greater security than could be economically implemented in individual end points.

Tamper protection: For those applications that need another level of security, such as industrial or medical applications where expensive assets or a person's life may be at risk, TM4C129x MCUs offer built-in mechanisms to protect gateways from being hacked and taken over. Protection features include execute-only program/code protection, read-only protection to lock individual memory blocks from modification, debug port lock out, protected EEPROM for data/password/key security, and tamper detection so systems can secure or mass erase sensitive data if the system casing is opened or otherwise breached.

Large memory resources: Because it consolidates data from multiple nodes, a gateway has to be able to handle parallel streams. With 256 KB SRAM and a full 1 MB of 100,000 cycle flash, TM4C129x MCUs have enough memory to support multiple, complex communications stacks with sufficient buffering to maintain system robustness. 6 KB of EEPROM is also available for storing useful and vital application data that needs to be protected, including keys, passwords, configurations, monetary values and critical thresholds.

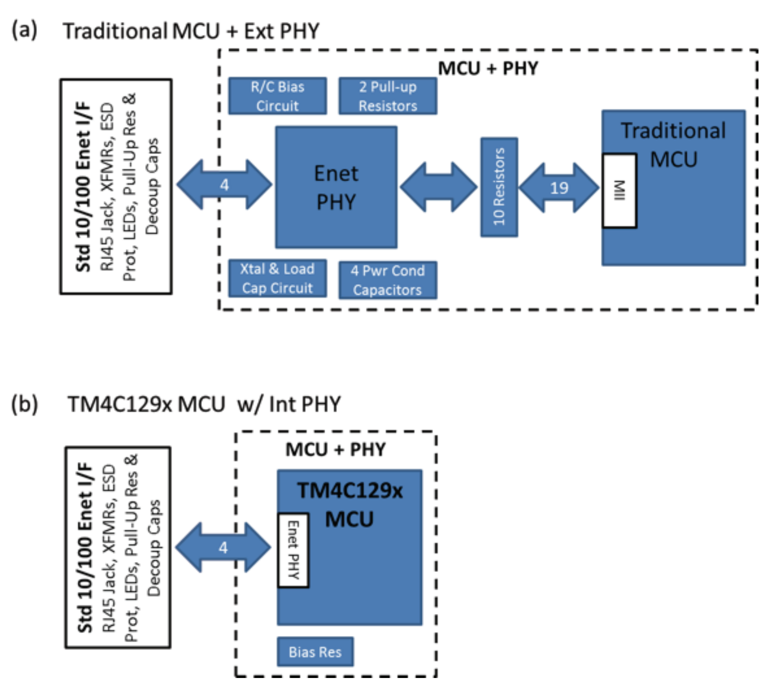

Figure 3: A traditional Ethernet link (a) requires an external PHY, numerous passives, and other components. By integrating the PHY, (b) TM4C129x MCUs reduce a system's board space needs, energy consumption and cost.

Extensive connectivity capabilities: TM4C129x MCUs support a wide range of peripherals and interfaces. For example, with their ten I2C ports, TM4C129x MCUs can directly connect to many nodes or sensors without the added cost of a multiplexor.

- Two CAN
- Ten I2C
- USB 2.0 OTG with High Speed UPLI
- Eight UART
- Four Quad SSI
- 2 MSPS > 20-channel, 12-bit ADCs
- Quadrature Encoder Interface (QEI/QEP)
- Eight 16-bit advanced Pulse Width Modulation (PWM) outputs
- Up to 140 GPIO

Energy efficiency: The processing capabilities of TM4C129x MCUs enable OEMs to improve overall energy consumption by allowing power-limited nodes to offload processing to the gateway and thus spend more time in low power operating modes.

Temperature range: TM4C129x MCUs are available in both industrial (-40 to +85° C) and extended (-40 to +105° C) temperature grades to support diverse operating environments.

Flexible integration: The TM4C129x MCU family has varying memory and integration options in different packages to optimally match the processing and connectivity requirements of a wide range of applications (see Table 1). Peripherals include an optional LCD controller. The TM4C129x MCUs' high level of integration also leads to smaller PCB

Key Features

TM4C PN	FLASH (KB)	SRAM (KB)	BATT-BACKED HIBERNATE	PACKAGE	ETH MII	ETH PHY	CRYPTO	LCD	TM4C TMS SUPERSET PN
TM4C1290NCPDT	1024	256	Y	128-TQFP	–	–	–	–	TM4C1292NCPDTI3
TM4C1292NCPDT	1024	256	Y	128-TQFP	Y	–	–	–	
TM4C1294KCPDT	512	256	Y	128-TQFP	–	Y	–	–	TM4C1294NCPDTI3
TM4C1294NCPDT	1024	256	Y	128-TQFP	–	Y	–	–	
TM4C129CNCPDT	1024	256	Y	128-TQFP	–	–	Y	–	TM4C129DNCPDTI3
TM4C129DNCPDT	1024	256	Y	128-TQFP	Y	–	Y	–	
TM4C129EKCPDT	512	256	Y	128-TQFP	–	Y	Y	–	TM4C129ENCPDTI3
TM4C129ENCPDT	1024	256	Y	128-TQFP	–	Y	Y	–	
TM4C1290NCZAD	1024	256	Y	212-BGA	–	–	–	–	TM4C1299NCZADI3
TM4C1292NCZAD	1024	256	Y	212-BGA	Y	–	–	–	
TM4C1294NCZAD	1024	256	Y	212-BGA	–	Y	–	–	
TM4C1297NCZAD	1024	256	Y	212-BGA	–	–	–	Y	
TM4C1299KCZAD	512	256	Y	212-BGA	–	Y	–	Y	
TM4C1299NCZAD	1024	256	Y	212-BGA	–	Y	–	Y	
TM4C129CNCZAD	1024	256	Y	212-BGA	–	–	Y	–	TM4C129XNCZADI3
TM4C129DNCZAD	1024	256	Y	212-BGA	Y	–	Y	–	
TM4C129ENCZAD	1024	256	Y	212-BGA	–	Y	Y	–	
TM4C129LNCZAD	1024	256	Y	212-BGA	–	Y	Y	Y	
TM4C129XKCZAD	512	256	Y	212-BGA	Y	Y	Y	Y	
TM4C129XNCZAD	1024	256	Y	212-BGA	Y	Y	Y	Y	

Table 1: The TM4C129x MCU family offers a variety of configurations so OEMs can select the ideal combination of capabilities for their IoT gateway.

requirements, lower board complexity, simplified device interconnect, reduced potential for manufacturing fall-out.

Ease of design

A part of the value of TM4C129x MCUs is their integration with TI's extensive software offerings and hardware portfolio. TI's goal is to make IoT device and gateway design as easy as possible. Production-enabling software is available, from TivaWare™, TI-RTOS (see Figure 4) and up through application-level code. Both hardware and software design are supported by a variety of resources

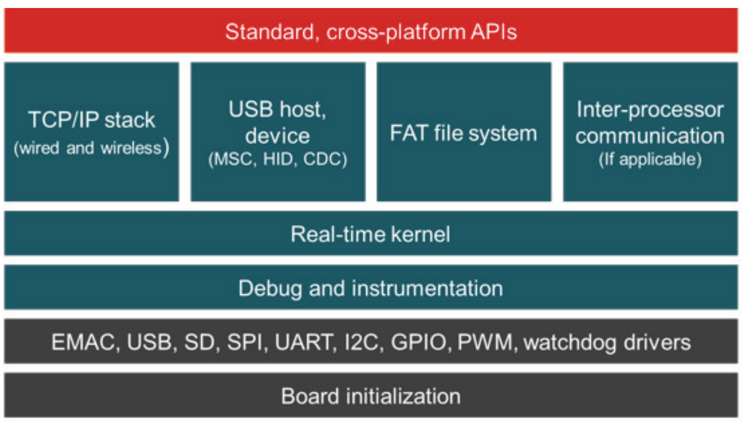

Figure 4: TI-RTOS provides a comprehensive real-time foundation for IoT applications to accelerate gateway development

from TI. With ROM-based device drivers, extensive software libraries, RTOS support, network stacks and example applications, OEMs can quickly design their own gateway and introduce IoT connectivity to a wide range of devices and applications.

Connectivity is simplified as well with software APIs enabling developers new to wireless technology to implement protocols such as Bluetooth and Wi-Fi without any low-level driver development. TI provides software building blocks for developing custom IoT agents too. These blocks are available through TI's TivaWare software, as shown in Figure 5, TI-RTOS, and numerous partners within TI's IoT cloud ecosystem. For more information on third-party support, please visit www.ti.com/designnetwork.

Developers can quickly integrate the TM4C129x MCUs with TI's wireless connectivity radio transceivers and other components to connect gateways to the Internet and nodes using multiple radio technologies. TI also has a wide portfolio of other associated products required for IoT applications, including analog components and power management ICs, among others.

Developers can evaluate the TM4C129x MCUs for themselves with the TM4C129x Evaluation Kit (EK-TM4C1294XL). Priced at $19.99, this kit is also supported by TI third party Energia and enables novice professionals to experience designing with IoT connectivity. For accelerated product design, TI also offers the TM4C129x Connected Development Kit (DK-TM4C129X). Priced at $199.00, it provides an affordable entry into IoT design with full-featured design capabilities and access

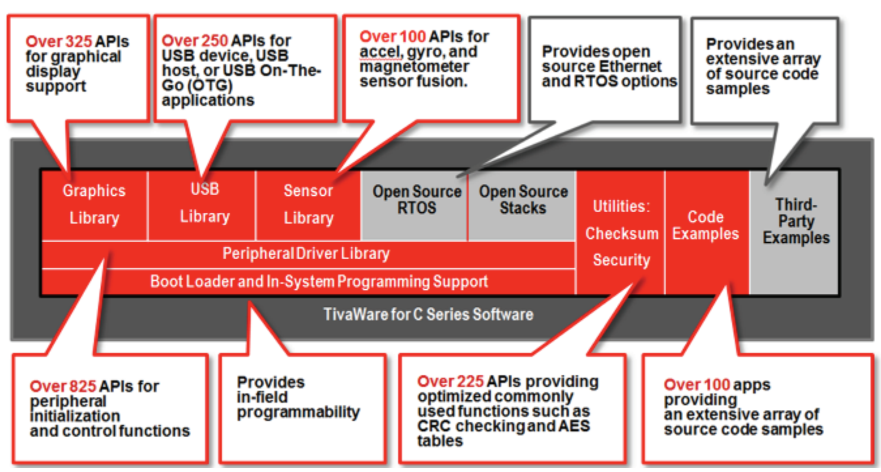

Figure 5: TI's TivaWare™ software provides a comprehensive variety of APIs to significantly simplify development of core product features.

to all chip inputs and outputs. Both kits are fully supported by the Keil, IAR, Mentor Embedded and Code Composer Studio™ integrated development environment (IDE), giving developers their choice of design environment.

TI provides a range of solutions to meet the wide variety of IoT gateway requirements. In addition to the TM4C129x MCU family for low- to mid-range gateway applications, TI offers its Sitara™ AM335x processors for mid- to high-end applications. A comparison between TM4C129x MCUs and Sitara AM335x processors is available in Table 2.

The TI ecosystem also provides a comprehensive level of development support across multiple channels. These include TI field application engineers, authorized distributors, and the TI E2E™ community.

	TM4C129x MCUs	Sitara™ AM335x processors
Gateway class	Low to mid end	Mid to high end
OS	RTOS or uClinux	RTOS or Std Linux
Device class	Microcontroller	Integrated processor
CPU core	120-MHz ARM® Cortex®-M4 with FPU	Up to 1-GHz ARM Cortex-A8 with NEON coprocessor
Security	Crypto accelerators, tamper inputs	Crypto accelerators
Flash	Up to 1MB	–
RAM	Up to 256KB	64KB + 64KB
Cache	–	64KB L1 + 256KB L2
ROM	Boot and peripheral driver library	Boot
Other Mem	6KB EEPROM	128KB RAM
Ext mem I/F	General purpose	DDR + general purpose
DMA	32 channel	64 channel
LCD	Up to 24-bit display	Up to 24-bit display + ADC touch controller
PRU	–	Two
Ethernet	10/100 MAC + PHY	2-port switch 10/100/1000 MAC
CAN	Two	Two
USB	USB 2.0 OTG w/ HS UPLI	Two USB 2.0 OTG
I2C	Ten	Three
UART	Eight	Six
SPI/SSI	Four quad SSI	Two
McASP	–	Two multi-channel audio serial ports
ADC	2 MSPS 24-ch 12-bit	200 KSPS 8-ch 12-bit
MMC/SD	–	Three
GPTs	Eight 32-bit (Sixteen 16-bit) timers	Eight 32-bit timers
QEI/QEP	One	Three enhanced
Adv PWM	Eight 16-bit outputs	Six 16-bit outputs
eCAP/PWM	–	Three capture or aux PWMs
RTC	One	One
Watchdog	Two	One
GPIOs	Up to 140	Up to 128

Table 2: TI provides a range of solutions to meet the wide variety of IoT gateway requirements. In addition to the TM4C129x MCU family for low- to mid-range gateway applications, TI offers its Sitara™ AM335x processors for mid- to high-end applications.

Introducing the IoT to new applications

Embedding Internet connectivity is more than just a trend. The IoT is quickly reaching beyond niche industrial and medical applications into every market utilizing electronics. The maturity of today's connectivity solutions means developers can introduce Internet access to nearly every application through IoT gateways with minimal development effort.

TI's TM4C129x MCUs enable the design of intelligent gateways that are capable of embedded control. The ability to offload data processing and IoT management from nodes to gateway can reduce node complexity, improve power efficiency and substantially lower system cost. In addition, intelligent gateways can actually augment the processing ability of nodes and their applications to extend not just their reach but their capabilities as well.

TM4C129x MCUs provide a complete solution that makes it easier to build gateways that reliably connect devices to the IoT. OEMs can confidently design gateways that provide complete security and support a wide diversity of end points and interfaces. The TM4C129x MCU family is also designed to minimize energy consumption and reduce system cost while maximizing the capabilities of energy-sensitive systems.

The integration of hardware and software that TM4C129x MCUs offer makes it that much easier for developers to connect disparate devices simply and easily without requiring a complete redesign. Backing the TM4C129x MCU family is a full range of production software as well as the wired/wireless communications components needed.

With TI's TM4C129x MCUs, OEMs can create simple and advanced gateways to connect nearly any device to the IoT.

Additional resources:

- TM4C129x MCU: www.ti.com/tm4c129x
- Datasheets: www.ti.com/tm4c-products
- TM4C129x Connected Development Kit (DK-TM4C129X): http://www.ti.com/tool/dk-tm4c129x
- TM4C129x Training: www.ti.com/tm4c-training
- TM4C1294 Connected LaunchPad Evaluation Kit (EK-TM4C1294XL): http://www.ti.com/tool/ek-tm4c1294xl
- TM4C1294 Connected LaunchPad Training: www.ti.com/clp-training
- TI E2E™ Forum: www.ti.com/tm4c-forum
- To order samples or parts: www.ti.com/tm4c-samples
- AM3352 product folder: http://www.ti.com/product/am3352