mipi alliance

# *Enabling the IoT Opportunity*

WHITE PAPER

**September 2020**

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# MIPI Alliance—Enabling the IoT Opportunity

## Executive Summary

**IN BRIEF**

***MIPI interfaces are used to connect sensors, cameras, displays and other key electronic components. Readily available and used ubiquitously within smartphones, many MIPI interfaces can be highly beneficial for use in IoT devices that require high bandwidth, low power consumption and low electromagnetic interference.***

The Internet of Things (IoT) and its unprecedented integration of the physical, social and digital worlds are set to enhance the lives of virtually every citizen on the planet and unleash global economic growth. Technological advances in the electronics, telecom and software industries underpin the rollout of the IoT. Expanded wireless connectivity, smaller, faster and more power-efficient electronic components and more capable software are fueling a highly competitive IoT device market that is expected to double in size to over 24 billion devices by 2025.[1] It is essential that developers understand the technology building blocks available to them and make the best choices to ensure technical and commercial success.

MIPI Alliance's specifications can help developers produce winning IoT device designs, with a portfolio of physical layer, protocol layer, software, test and debug specifications that are already ubiquitous for connecting sensors, cameras, displays and other key components in smartphones. A whole ecosystem of components, software and tools has developed around the use of MIPI's interfaces delivering high bandwidth, low power consumption and low electromagnetic interference (EMI). MIPI is augmenting its portfolio with the launch of a new generation of specifications and software tools for helping IoT developers optimize device designs, including:

- The recently released MIPI I3C interface (the successor of the hugely successful I2C interface) that is specifically designed to connect the latest sensors, actuators and controls
- The MIPI A-PHY physical layer specification, which meets the needs of specific IoT use cases requiring long reach (up to 15m), high reliability and low latency
- New software resources for a variety of specifications, including a Linux-based I3C host controller interface driver, and additional software discovery and configuration tools

More information on MIPI Alliance and its specifications can be found at **www.mipi.org**

[1] *https://data.gsmaintelligence.com/research/research/research-2020/iot-connections-forecast-the-impact-of-covid-19*

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# 1. Introduction

This white paper describes MIPI specifications that are most relevant to the rapid growth of the IoT over the next five years. It is intended to show how the specifications can help satisfy key engineering design goals such as low hardware/development costs, very low power consumption, long product life-cycles and security. After reading the paper, technical design engineers and managers should have a high-level understanding of the relevant MIPI specifications and be able to determine which specifications are potentially applicable to their target IoT device designs.

# 2. Defining the "Internet of Things"

## 2.1. What is the Internet of Things?

There is no uniform industry definition for the IoT, despite efforts within the research and academic communities. The principal challenge being wrestled with when trying to agree upon a definition is how to resolve and encapsulate the huge, diverse set of potential IoT use cases covering the huge, diverse set of industries enveloped by the IoT.

For the purpose of this paper, we will assume a simple, high-level definition suggested by the Gartner research and advisory company:

> *"The Internet of Things (IoT) is the network of physical objects that contain embedded technology to communicate and sense or interact with their internal states or the external environment."* [2]

## 2.2. The IoT Opportunity

The IoT offers the vision of a hyper-connected world where practically all physical objects and people seamlessly interconnect, exchanging data and making insightful decisions using artificial intelligence for the benefit of both individuals and society as a whole. Many IoT services already are widely adopted in the market today, with use cases covering virtually all sectors including automotive, consumer electronics, enterprise, healthcare, industrial, smart buildings, smart cities, smart homes and utilities.

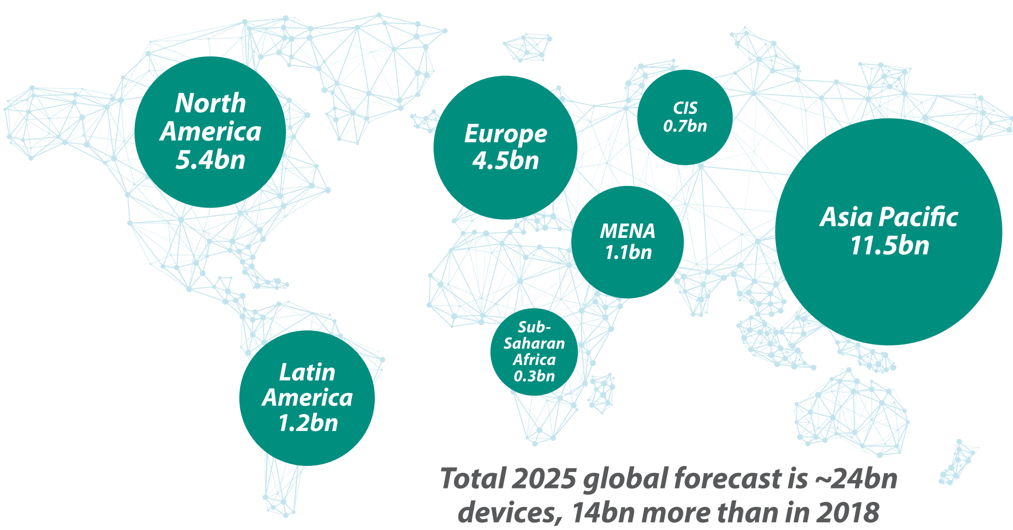



*Figure 1* Global IoT Connections by 2025 (Estimated). Source GSMA Intelligence[3]

[2] *https://www.gartner.com/en/information-technology/glossary/internet-of-things*
[3] *GSMA Intelligence IoT connections forecast: rise of enterprise, December 2019*

*Note: GSMA Intelligence definition for IoT is "Devices capable of two-way data transmission (excluding passive sensors and RFID tags). It includes connections using multiple communication methods such as cellular, short range and others. It excludes PCs, laptops, tablets, e-readers, data terminals and smartphones".*

While the ultimate scale and impact of the IoT is not in doubt, the timescale for such a vision to be realized is in question. In the past, a key factor inhibiting growth was the need for widespread and cost-effective, machine-centric wireless connectivity, but solutions are quickly becoming ubiquitous with the advent of today's wide-area 4G and 5G cellular networks. IoT-centric connectivity is also becoming mainstream, including low-power-wide-area technologies such as LTE-M (Long Term Evolution for Machines), NB-IoT (Narrowband IoT) and LoRaWAN (Long Range Wide Area Network), and local area wireless technologies such as Bluetooth® LE, Wi-Fi®, Zigbee®, Z-wave® and Thread®. Future 5G network upgrades—introducing support for massive machine type communication (mMTC), ultra-reliable low-latency communications (URLLC) and ultra-high device densities—will be deployed in the coming years to accelerate IoT market growth.

With IoT-optimized, wireless network connectivity in place globally, new key factors influencing the growth of IoT services have taken the fore:

- A valid business case—Can sufficient value be generated from the service?
- Technical feasibility—Can a solution be developed within the power, size and cost constraints defined within the business case?
- Market adoption—Can the end customer realize the value of the service?

MIPI specifications, through adherence to critical technical and commercial attributes for the smartphone industry (and described in **Section 3** of this paper), help IoT developers address many of the challenging power, size and cost constraints demanded of their devices by many new and emerging IoT business cases.

## 2.3. The IoT Market

The IoT market is expected to rapidly grow in all industry sectors over the next five years. According to the Ericsson Mobility Report[4] published in June 2020 and the GSMA Intelligence IoT Connections Forecast[5] published in June 2020 (which includes the impact of the COVID-19 pandemic on the IoT market as shown in Figure 2), the number of IoT device connections across all IoT markets is forecast to exceed 24 billion devices by 2025. This figure includes all types of IoT devices from all industry sectors and across both consumer and enterprise applications.

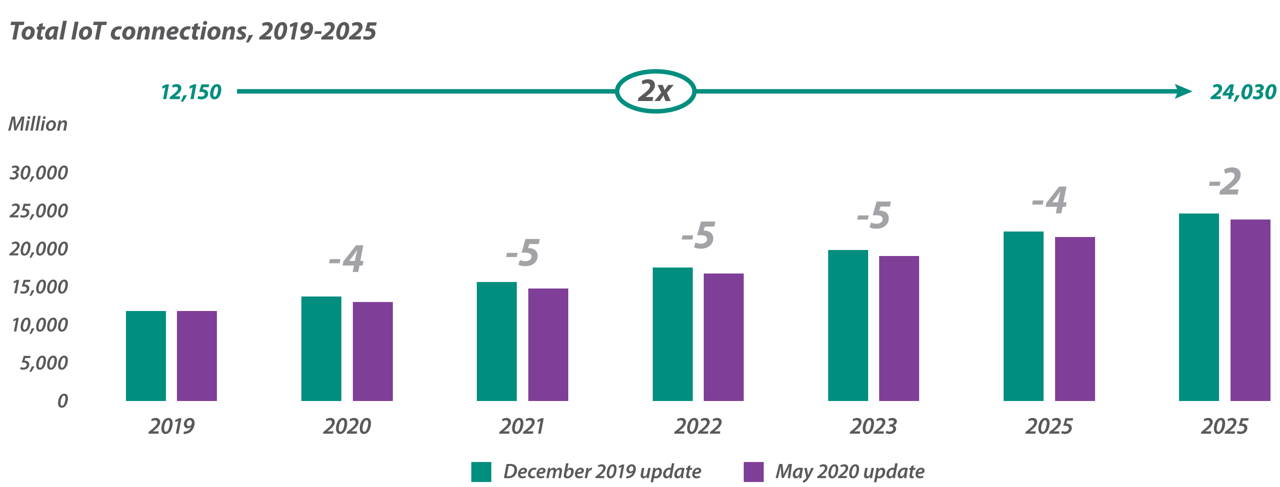



*Figure 2* IoT connections 2019 to 2025 (includes impact of COVID-19 on the market) Source: GSMA Intelligence[5]



[4] *https://www.ericsson.com/en/mobility-report/reports*
[5] *https://data.gsmaintelligence.com/research/research/research-2020/iot-connections-forecast-the-impact-of-covid-19*

The breakdown of these headline figures by IoT market sector is also highly relevant to ascertain which sectors and use cases are driving significant growth. According to the GSMA Intelligence report[6] the principal sources of growth in consumer IoT are forecast to come from smart home, consumer electronics, wearables and smart vehicles sectors, as shown in Figure 3.

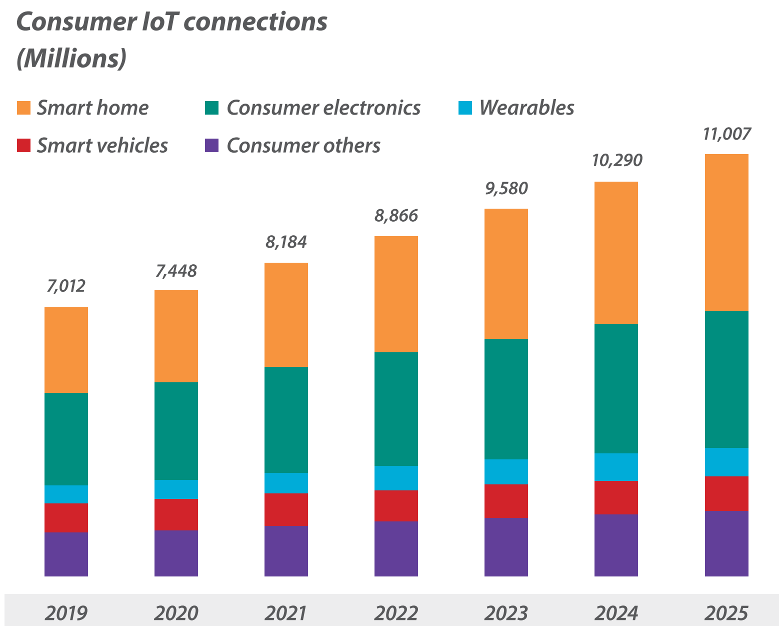



*Figure 3* Consumer IoT connections (adjusted to include impact of COVID-19) Source: GSMA Intelligence [6]

In the enterprise IoT market, the GSMA Intelligence report[7] forecasts that the key areas of growth are in the smart buildings, utilities, retail, smart city, manufacturing and health sectors, as shown in Figure 4.

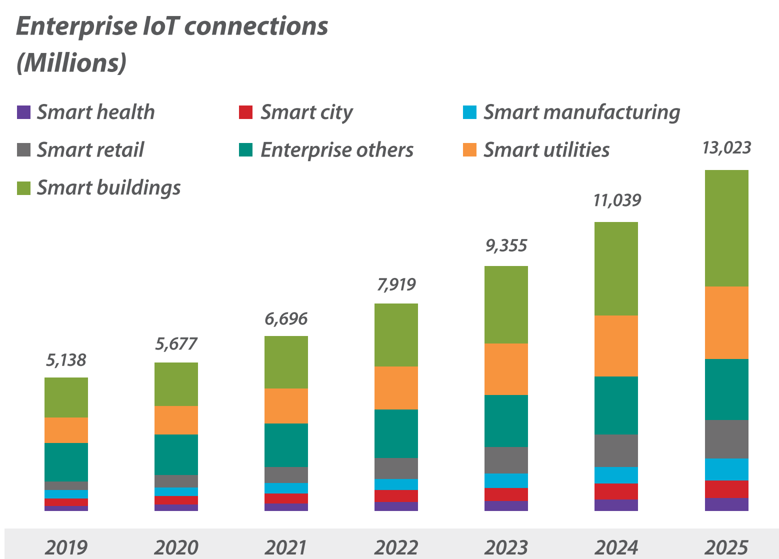



*Figure 4* Enterprise IoT connections (adjusted to include impact of COVID-19) Source: GSMA Intelligence[7]

[6 & 7] *https://data.gsmaintelligence.com/research/research/research-2020/iot-connections-forecast-the-impact-of-covid-19*

### 2.3.1. Consumer IoT Categories

This section provides an overview of some consumer IoT vertical sectors and categories where use of MIPI specifications is highly applicable. This section is not intended to be a definitive guide to each vertical sector but to give a little more detail on the types of IoT devices that fit in each sector.

| *Consumer IoT Category* | *Included IoT Device Types* |
|---|---|
| *Smart Home* | • Large home appliances (e.g., refrigerators, washing machines and dryers)<br>• Small home appliances (e.g., coffee machines and personal care devices)<br>• Home hubs<br>• Home automation (e.g., robot vacuum cleaners and smart lightbulbs)<br>• Home security (e.g., smart doors, doorbells and intruder detection)<br>• Heating, ventilation and air conditioning (HVAC) monitoring and control |
| *Consumer Electronics* | • Games consoles<br>• Portable gaming devices<br>• Set-top boxes<br>• Media streaming devices<br>• Home video conferencing devices<br>• Smart speakers<br>• Extended reality (XR) headsets<br>• Smart TVs<br>• Cameras |
| *Wearables* | • Fitness trackers<br>• Smartwatches<br>• Smart earbuds and headphones<br>• Augmented reality (AR) glasses<br>• Smart clothing and shoes |
| *Smart Vehicles* | • Embedded (by original equipment manufacturer (OEM)) smart vehicle services*<br>• Aftermarket smart services<br>• In-car entertainment<br>• Connected bikes, scooters, etc. |
| *Other Consumer IoT* | • Trackers—child, elderly and pet<br>• Non-professional drones<br>• Non-professional robots<br>• AR/virtual reality (VR) headsets<br>• Non-prescribed health devices |

*Note: Embedded (by OEM) smart vehicle services are excluded from this paper because they are covered in another MIPI Alliance white paper, "Driving the Wires of Automotive."[8] Aftermarket automotive products and services are still within the scope of this paper.

*Table 1* Consumer IoT categories

[8] *https://mipi.org/mipi-white-paper-driving-wires-automotive*

### 2.3.2. Enterprise IoT Categories

This section provides an overview of some enterprise IoT vertical sectors and categories where use of MIPI specifications is highly applicable. Again, this section is not intended to be a definitive guide but to give a little more detail on the types of IoT devices that fit in each sector.

| Enterprise IoT Category | Included IoT Device Types |
|---|---|
| *Smart Factory* | • Inventory tracking devices<br>• Machine/robot control, monitoring and diagnostics<br>• Quality control sensors/machine vision<br>• Industrial tools<br>• Automated guided vehicles |
| *Smart City* | • Public transport services<br>• Public information points<br>• Surveillance cameras<br>• Public electric vehicle charging points<br>• Smart street lighting<br>• Environmental monitoring<br>• Parking sensors<br>• Waste management |
| *Healthcare* | • Professionally prescribed healthcare monitoring devices<br>• Remote monitoring of medical devices<br>• Emergency vehicle infrastructure<br>• Smart hospitals and remote surgery |
| *Utilities* | • Electricity/water/gas smart metering<br>• Vehicle chargers<br>• Home batteries<br>• Domestic energy harvesting (solar, wind, etc.)<br>• Energy monitoring and control |
| *Agriculture* | • Smart greenhouses<br>• Precision agriculture<br>• Autonomous agricultural machinery<br>• Livestock monitoring and tracking |
| *Retail* | • Point-of-sale equipment (cash registers, card readers, etc.)<br>• Digital signage<br>• Vending machines<br>• Automated teller machines (ATMs)<br>• Shopping beacons<br>• Stock control sensors |
| *Smart Buildings* | • HVAC control and monitoring<br>• Security cameras and sensors<br>• Smart lighting<br>• Hot-desk sensors<br>• Other office equipment |
| *Education* | • Interactive whiteboards<br>• Document visualizers<br>• Lecture recording/broadcasting devices for distance learning |
| *Other Enterprise IoT* | • Fleet management<br>• Asset tracking<br>• Applications in agriculture, oil & gas, mining and construction<br>• Professional / commercial drones<br>• Other types of remote, low-power "in-field" sensors (e.g., vibration, chemical, temperature, etc.) |

*Table 2* Enterprise IoT categories

### 2.3.3. IoT Use Cases

The scope of IoT use cases is huge, covering numerous different consumer and enterprise market sectors as described in the previous section. To help showcase the use of MIPI specifications in a variety of IoT services, we have selected nine example market sectors, each covering several IoT device use cases. A summary of use-case examples detailed later in this paper is shown in Figure 5.


*Figure 5* Summary of IoT use case examples contained in this paper

Additionally, when selecting the example IoT use cases for inclusion in this paper, we applied the following criteria:

- The IoT use case must require connected devices that use embedded electronics (such as microprocessors, sensors, actuators and communication hardware) to collect, share and act on data they acquire from their local environments.
- The IoT use case must require connectivity. The connectivity can be direct to a network access point or "multi-hop" via a gateway device and provided by public or private network.
- To avoid duplication with traditional MIPI use cases centered on mobile devices, we will exclude smartphones, tablets, laptops and other traditional personal computing devices from the IoT use cases.
- Embedded (by OEM) smart vehicle services, although within the stated IoT definition, are excluded from this white paper because the use cases are already documented in another MIPI Alliance white paper, "Driving the Wires of Automotive."[9] Aftermarket automotive products and services are still within scope.

[9] *https://mipi.org/mipi-white-paper-driving-wires-automotive*

# 3. Meeting Key IoT Needs

MIPI Alliance develops and maintains a set of interfaces and protocols to connect the key embedded electronic components within electronic devices, including those for the IoT. The mission of MIPI Alliance is simple: to provide the key interface specifications, conformance test suites, debug tools, software and other resources that developers need to create state-of-the-art, innovative, connected devices—accelerating time to market and reducing costs.

## 3.1. Technical Advantages

Aligning to this mission, MIPI specifications are developed according to a set of technical attributes to ensure they support the key design goals of the mobile and mobile-influenced markets: **high-bandwidth (highly scalable) performance, low power consumption** and **low EMI.**

### 3.1.1. High Bandwidth

MIPI specifications define high-speed, highly scalable, flexible, ultra-low-latency interfaces for connecting electronic systems and components. Key for many IoT devices, the interfaces provide highly data-efficient modes of operation to support the requirements of a wide range of imaging and sensing components, from the most advanced cameras to the most basic, low-speed sensor components. MIPI specifications enable developers to optimize their connectivity solutions to address particular use cases—whether a high- or low-bandwidth application.

### 3.1.2. Low Power Consumption

MIPI specifications have been designed from the outset to enable highly power-efficient and flexible data transmission among components. In this way, the specifications enable very low power consumption in both "active" modes where data is being sent and received, in ''active-standby" modes when data transmission is low and interrupt-driven and 'full-standby" mode when there is no data transmission.

With high energy-efficiency, MIPI specifications can enable an IoT device to be powered from a battery over many years or be powered from a constrained power source such as solar or wind energy.

### 3.1.3. Low EMI

With the drive toward designing ever-smaller devices, with the tighter packaging of components and less room for electromagnetic shielding, internal device interfaces must produce minimal levels of EMI. Many IoT devices need to meet strict EMI design goals to ensure both product reliability and to adhere to strict, sector-specific electromagnetic compatibility (EMC) regulations, particularly in health, industrial and automotive applications.

MIPI specifications help reduce EMI through a combination of factors, including low-voltage swings on high-speed physical layers and the support of slew rate control—giving developers the flexibility to adjust the EMI profile of the physical layer interface to the EMI needs of the end device. Where necessary, MIPI Alliance has developed specific solutions (such as A-PHY for the automotive industry) to meet the EMI needs of specific industry sectors.

MIPI sets lower EMI targets as new specifications are delivered and seeks to lower the EMI properties of its interfaces whenever current specifications evolve—a good example being the next revision of the MIPI SoundWire interface, SoundWire I3S (SWI3S), which targets lower EMI to minimize cross-coupling noise within audio applications.

## 3.2. Commercial Advantages

In addition to the technical attributes of MIPI specifications, they also serve to support the commercial aims of the IoT market as they **drive economies of scale,** have **low cost of ownership, reduce design complexity, aid software development,** are **5G ready** and enable **security.**

### 3.2.1. Drive Economies of Scale

A commercial benefit of leveraging MIPI hardware and software interfaces is that they ensure interoperability between the different electronic components and products that support the specifications. This interoperability, in turn, drives huge economies of scale within the market.

To ensure interoperability is achieved, MIPI Alliance develops and maintains conformance test suites that MIPI members use to test that their implementations are conformant with the specifications. This resultant interoperability provides major benefits to the IoT market:

- It removes market fragmentation and drives the industry toward common technical solutions. This, in turn, drives economies of scale within the electronics component market—eliminating unnecessary implementation costs within the vendor community, reducing integration costs within the developer community and enabling non-recoverable engineering costs to be amortized over large volumes of components rather than just a few.
- It allows customers to source the components for their IoT device designs from different vendors, based on price and performance, knowing that the overall solution design will function based on the use of compatible interfaces and protocols.
- It allows customers to dual-source components to give supply-chain flexibility and ensure continuity of supply should the supply chain be impacted.
- It drives up quality and reduces errors, through use of industrywide conformance testing processes and the use of bug reporting schemes to ensure that any errors within the specification are addressed across the industry.

### 3.2.2. Low Cost of Ownership

MIPI specifications are designed from the outset to be developer-friendly, resulting in a low overall cost of ownership. Wherever possible, MIPI Alliance aims to:

- Produce comprehensive connectivity solutions covering physical and protocol layers with associated common software components, conformance test suites and debug interfaces.
- Ensure its technical specifications are both backward and forward compatible. Use of evolutionary, "long-lived" specifications means that developers do not have to learn completely new skillsets for each new release and also enables developers to maximize any investment in existing test suites.
- Support devices that have long lifecycles and that may require developer support for many years within the market (e.g., for automotive and embedded smart building technologies), by ensuring the core specifications will be supported for long periods and that upgrade paths are readily available should they be required (e.g., if a sub-component needs to be replaced many years into a support contract).
- Ensure its specifications are subject to a well-defined, royalty-free (intellectual property rights (IPR) policy.

### 3.2.3. Reduce Design Complexity

MIPI Alliance delivers high-performance serial interfaces, using a minimum number of wire conductors to allow chip, device and module manufacturers to minimize pin counts—leading to fewer interconnections on chips and across printed circuit boards. The resulting reduced complexity cuts manufacturing costs, supports ever-tighter packaging of components inside ever-smaller devices, and reduces weight—enabling new use cases to be addressed in the IoT space.

## 3.2.4. Software Development

Use of MIPI interfaces can accelerate software development and reduce development effort.

There are large numbers of developer kits and reference design boards available from multiple vendors that support the MIPI CSI-2 and DSI-2 interfaces. These kits are supported by software development resources (drivers, open source sample code, tutorials, etc.) as described in a recent MIPI blog article[10].

The MIPI Software Working Group develops software resources to streamline the integration of MIPI protocols. These include the MIPI DisCo℠ specifications, which aid the discovery and configuration of many MIPI protocols, and a MIPI I3C HCI℠ (Host Controller Interface), which provides an open source implementation of an I3C master controller for use in system-on-a-chip (SoC) designs.

## 3.2.5. 5G Ready

MIPI Alliance is future focused, producing specifications that will meet the demands of forthcoming market and technology requirements. The MIPI white paper[11] "Making the 5G Vision a Reality: A 5G Readiness Assessment of MIPI Specifications" explains how existing MIPI specifications are capable of supporting 5G services, which will include 5G IoT devices. The paper explains how MIPI will support new 5G IoT capabilities:

- **Enhanced Mobile Broadband:** Supporting gigabit peak data rates and per-device data rates of 100 Megabits per second (Mbps).
- **mMTC:** Supporting ultra-high IoT device densities of up to 1 million devices per km2 and ultra-low power IoT communications.
- **URLLC:** Supporting safety-critical applications that have strict requirements for throughput, latency and availability

## 3.2.6. Security

There are many important security issues that need to be considered when implementing an IoT service, as described in IoT security guidelines such as ETSI EN 303 645[12], NIST IR8259a[13] and guidelines from other organizations. Virtually all the guidelines state that it is critical for IoT developers to perform security risk assessments and then implement appropriate attack-mitigation strategies for new IoT services at the outset of their development. With security always being more costly to retrofit into a design, failing to follow best practice or make the right security choices will inhibit the successful deployment of new IoT services.

Industry IoT security guidelines recommend a multi-layer approach to address common risks, meaning that security mechanisms should, wherever possible, be considered within all layers of a device's protocol stack. It is clear from the guidelines that simply adopting a traditional, internet-style security approach of implementing security only at the Internet Protocol (IP) communication layer will be insufficient to address many of the attack models that are specific to IoT services.

MIPI Alliance recognizes that security is critical to the success of many IoT use cases. These security challenges are particularly acute for the physical attack scenarios (i.e., the cases where IoT devices are physically "opened up" by the attacker and internal interfaces accessed) that many IoT devices are likely to be subjected to—particularly IoT devices that must adhere to functional safety standards.

The MIPI Security Group is overseeing the development of a MIPI security framework that will steer the development of new security capabilities across the suite of MIPI specifications—providing a pathway for IoT developers to implement multi-layer security into future IoT devices and helping them adhere to the most stringent guidelines. The initial framework will focus on the authentication of connected devices, and the confidentiality and integrity protection of messages sent from an application processor host to its suite of connected peripherals, such as cameras and displays.

While differentiated from security, the support of functional safety requirements for automotive applications and the support of content-protection requirements (such as High-Bandwidth Digital Content Protection) for display applications also are being addressed within MIPI's technical working groups.

[10] *https://resources.mipi.org/blog/developer-kits*
[11] *https://resources.mipi.org/5g-readiness-white-paper*
[12] *https://www.etsi.org/deliver/etsi_en/303600_303699/303645/02.01.00_30/en_303645v020100v.pdf*
[13] *https://www.nist.gov/publications/iot-device-cybersecurity-capability-core-baseline*

# 4. Specifications for the IoT

MIPI Alliance currently maintains numerous specifications that are beneficial to the development of IoT devices. The specifications cover physical, protocol and software layers and are applicable for use within all types of IoT devices. The specifications define interfaces that connect application processors to sensors, cameras, displays, audio, storage, actuators and other components. The majority are augmented with conformance test suites, readily available test tools, software and debug interfaces, allowing IoT developers to focus their engineering resources on product differentiation and reduced time to market, rather than on the basic development of these core underlying technical interfaces.

In short, if the answer to any of the following questions regarding an IoT device is "Yes," then the device is highly likely to benefit from the use of MIPI specifications:

- Does the IoT device require a sensor and/or actuator?
- Does the IoT device require a camera?
- Does the IoT device require a simple user interface (e.g., using switches, LEDs, small dot matrix display or buzzer)?
- Does the IoT device require an advanced display (e.g., using high-resolution display and potentially a touchscreen)?
- Does the IoT device require advanced audio (e.g., high-quality speakers and/or microphones)?
- Does the IoT device developer require debug capabilities during the design of the device?
- Does the IoT device require an integrated wireless communication capability?
- Does the IoT device require low powered interfaces (e.g., to enable extended battery-powered operation)?
- Would the IoT device benefit from reduced pin counts (e.g., to enable a compact design)?
- Is EMI a concern?

## 4.1. Mapping IoT Requirements to MIPI Specifications

Mapping the requirements for some example IoT device types that fit into the different markets mentioned in Section 3.3, it quickly becomes apparent how broadly applicable MIPI specifications are to the many different types of IoT devices, as illustrated in Table 3.

| Sector | Sector and Category | Device Type | Sensor(s) | Actuator(s) and Control | Camera | Simple UI* | Advanced Display** | Advanced Audio | Debug | Wireless Comms |
|---|---|---|---|---|---|---|---|---|---|---|
| Consumer Sector | Smart Home | Security Camera | • | | • | | | • | • | • |
| | | Smart Door | • | • | • | • | | • | • | • |
| | | Washing Machine | • | • | | • | • | | • | • |
| | | Home Hub | • | | • | • | • | • | • | • |
| | Consumer Electronics | Smart Speaker | | | • | • | | • | • | • |
| | | Portable Gaming Device | • | • | • | | • | • | • | • |
| | Wearables | Smartwatch | • | | | | • | • | • | • |
| | | Fitness Tracker | • | | | • | | | • | • |
| | Vehicle (Aftermarket) | Dashcam | • | | • | • | • | • | • | • |
| | | Insurance Tracker | • | | | • | | | • | • |
| | Other Consumer | Consumer Drone | • | • | • | • | • | | • | • |
| Enterprise Sector | Smart Buildings | HVAC Control | • | • | | • | | | • | • |
| | Utilities | Smart Meter | • | | | • | | | • | • |
| | Retail | Digital Signage | • | | • | | • | • | • | • |
| | Smart City | Environmental Monitor | • | • | • | | | • | • | • |
| | | Traffic Monitor | • | | • | | | | • | • |
| | Manufacturing | Quality Control | • | • | • | | | | • | • |
| | Health | Senior Living Monitor | • | | • | • | | • | • | • |
| | Other Enterprise Sectors | Commercial Drone | • | • | • | • | • | • | • | • |
| | | Greenhouse Monitor | • | • | | • | | | • | • |

* Simple user interface = A UI typically implemented using switches, LEDs, small dot matrix displays, etc.
**Advanced Display = Using a high-resolution display and, potentially, a touchscreen interface.

*Table 3* Examples of typical IoT device requirements

Figure 6 shows the typical use of MIPI physical and protocol layer specifications within a hypothetical, generic IoT device with wireless connectivity that requires all the capabilities stated in Table 3.

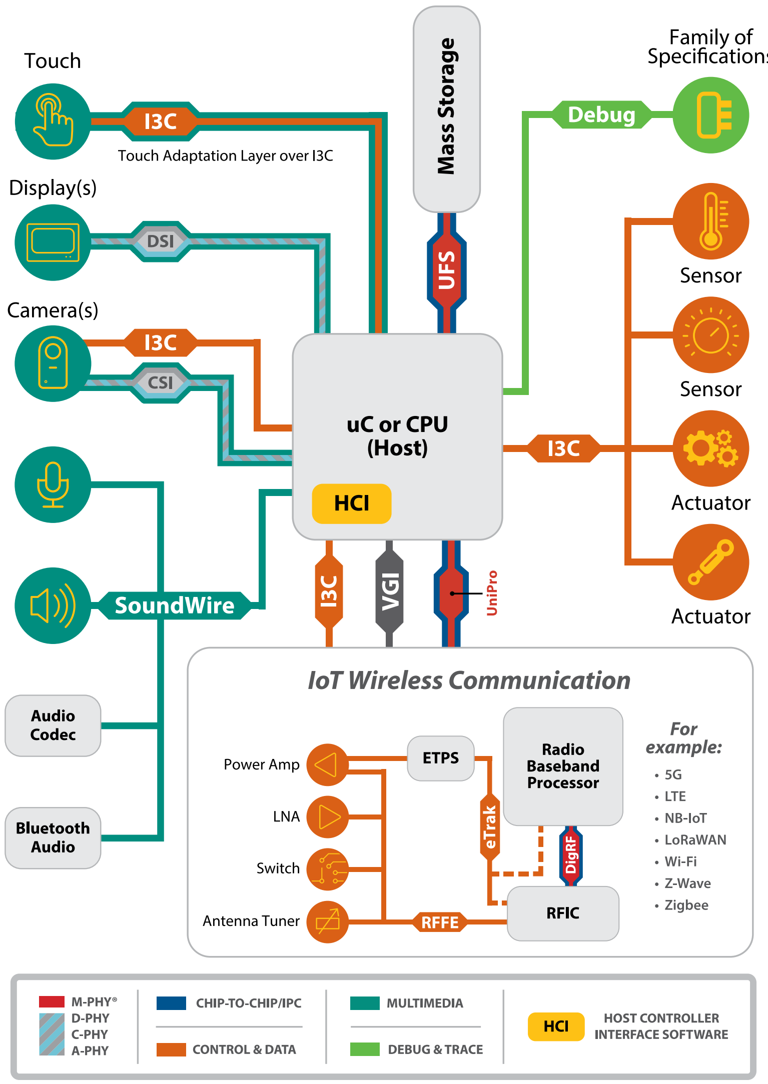



*Figure 6* Example use of MIPI specifications in a generic IoT device with cellular connectivity

## 4.2 Brief Overview of MIPI Specifications

| Application Area | MIPI Specification | Specification Description | Further Details |
|---|---|---|---|
| Physical Layer Connectivity | C-PHY℠/D-PHY℠ | High-speed, low-cost, low-power serial interfaces for cameras, displays and other sensors that have high bandwidth and bursty data communication requirements. | Annex A.1.1 |
| | A-PHY℠ | Long-reach serializer-deserializer interface providing a high-speed, low-latency, high-reliability physical layer interface for use in harsh EMI environments. Developed to meet the automotive industry's need for a highly robust, state-of-the-art interface to connect cameras, displays and other components within vehicles. | Annex A.1.2 |
| | M-PHY® | Short-reach serial interface for data-intensive applications requiring fast communications channels. Applications include connecting flash memory, RF front-ends and inter-processor communications. | Annex A.1.3 |
| Sensors, Controls & Actuators | I3C® / I3C Basic℠ (Improved Inter-Integrated Circuit) | The successor to I2C, provides a cost-effective, simple and flexible two-wire interface that can be used to connect sensors, actuators, controls and simple UI components to an application processor. | Annex A.2.1 and A.2.2 |
| Cameras & other High-Bandwidth Sensors | CSI-2℠ (Camera Serial Interface)<br>CCI℠ (Camera Command Interface)<br>CCS℠ (Camera Command Set) | CSI-2, with its companion CCI and CCS specifications, is a low- complexity, high-speed protocol intended for point-to-point data transmission between sensors with high-bandwidth requirements and application processors. Has achieved widespread market adoption within a broad range of high-performance applications using camera, sonar, lidar, infrared and ultrasonic sensors. | Annex A.2.3 |
| Advanced Displays | DSI-2℠ (Display Serial Interface)<br>DCS℠ (Display Command Set) | DSI-2, with its companion DCS specification, is a widely adopted, simple, high-speed, low-power serial protocol for connecting displays to application processors. Widely used in the smartphone and wearables (smartwatch) sectors. | Annex A.2.4 |
| | Touch℠ | Enables the fast and flexible design and implementation of touchscreen interfaces in devices that use an advanced display. | Annex A.2.5 |
| Advanced Audio | SoundWire® | Comprehensive audio interface with scalable architecture supporting advanced amplifiers and microphones, optimizing speaker protection, microphone power and performance, enabling noise cancellation and supporting always-listening audio inputs. | Annex A.2.6 |
| Flash Storage | UniPro® | Versatile, application-agnostic, transport layer used as an interface for chip-to-chip and inter-processor communications. The JEDEC Solid State Technology Association (JEDEC®) uses UniPro to provide the interconnection layer for Universal Flash Storage (UFS). | Annex A.2.7 |
| Radio Sub-systems | RFFE℠ (RF Front-End Control) | Control interface that enables radio frequency integrated circuit (RFIC) transceivers to control RF front-end components such as power amplifiers, low-noise amplifiers, filters, RF switches and antenna tuners. | Annex A.3.1 |
| | DigRF® | High-speed interface used to interconnect cellular RFICs to radio baseband processors. | Annex A.3.2 |
| | eTrak℠ | Interface between a radio transmitter and envelope tracking power supply. | Annex A.3.3 |
| Debug Tools | Debug and Trace | Suite of debug and trace interfaces used to debug application processors, device controllers, power management devices and other components. Widely implemented by the test tool vendor community, making test tools widely available within the market. | Annex A.4 |
| Software Tools | Software Integration | Provides a suite of software resources to streamline the integration of MIPI protocols. MIPI DisCo℠ (discovery and configuration) specifications include a base architectural framework and a portfolio of interface-specific specifications that unify the software discovery and configuration of many MIPI protocols. MIPI I3C Host Controller Interface (I3C HCI℠) provides an open source implementation of a I3C master controller or use in SoC designs. | Annex A.5 |
| Inter-System Connectivity | VGI℠ (Virtual GPIO Interface) | Currently in development, replaces physical general-purpose inputs/outputs (GPIOs) with virtual GPIOs based on a two- or three-wire interface. Significantly reduces the number of physical I/O pins required on both application processors and peripheral components. | Annex A.6.1 |

*Table 4* Summary of MIPI specifications applicable to IoT devices

# 5. Example Use of MIPI Specifications in IoT

This section contains a set of example IoT use cases, showing the use of applicable MIPI specifications within numerous types of IoT devices. A summary table, showing a mapping between the use case categories, device types and MIPI specifications is provided.

| Sector | Category | Section | Device Type(s) | C/D-PHY | A-PHY | M-PHY | I3C for Sensor(s) | I3C for Actuator(s) and Control | CSI-2 for Camera | I3C for Simple UI | DSI-2 for Advanced Display | SoundWire for Advanced Audio | RFFE for Wireless Connectivity | UniPro | Debug | Software |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Consumer Sector | Smart Home | 5.1 | Home Hub | • | | • | • | • | • | • | • | • | • | • | • | • |
| | | | Smart Door | • | | | • | • | • | • | | • | • | | • | • |
| | | | Home Appliance | • | • | | • | • | | • | • | | • | | • | • |
| | Consumer IoT | 5.2 | Connected Camera | • | | • | • | | • | • | • | • | • | • | • | • |
| | | | Video Conferencing | • | | | • | • | • | • | | • | • | | • | • |
| | | | Smart Speaker | | | | • | | | • | | • | • | | • | • |
| | | | Portable Gaming Device | • | | • | • | • | • | • | • | • | • | • | • | • |
| | | | XR Headset | • | | | • | | | • | • | • | | • | • | • |
| | Wearables | 5.3 | Smart Watch | • | | | • | | | | • | • | • | | • | • |
| | | | Smart Earbuds | | | | | | | • | | • | • | | • | • |
| | | | AR Glasses | • | | | • | | • | • | • | • | • | | • | • |
| | | | Connected Speakers | | | | | | | • | | • | • | | • | • |
| Enterprise Sector | Smart Factory | 5.4 | Robot with Vision | • | • | | • | • | • | • | • | | • | | • | • |
| | | | Industrial Tools | | | | • | • | | • | | | • | | • | • |
| | | | Machine Control System | • | • | | • | • | | • | • | | | | • | • |
| | | | Automated Vehicle | • | • | | • | • | • | • | | | • | | • | • |
| | Smart City | 5.5 | Smart Lighting | | | | • | • | | | | | • | | • | • |
| | | | Environmental Monitor | | | | • | | • | | | • | • | | • | • |
| | | | Surveillance Camera | • | • | • | • | • | • | • | | • | • | • | • | • |
| | | | Smart Tram | • | • | | • | • | • | • | • | • | • | | • | • |
| | | | Parking Sensors | | | | • | | | | | | • | | • | • |
| | | | Smart Waste Bin | | | | • | | | | | | • | | • | • |
| | Healthcare | 5.6 | Remote Health | • | | | • | • | • | • | • | • | • | | • | • |
| | | | Remote Surgery | • | • | | • | • | • | • | • | • | | | • | • |
| | Utilities | 5.7 | Smart Meters | | | | • | | | • | | | • | | • | • |
| | | | Smart Charger | | | | • | | | • | | | • | | • | • |
| | | | Home Battery | | | | • | | | • | | | • | | • | • |
| | | | Energy Harvesting | | • | | • | | | • | | | • | | • | • |
| | | | Energy Monitoring & Control | • | | | • | | | • | • | | • | | • | • |
| | Drones | 5.8 | Commercial Drones | • | • | • | • | • | • | • | • | • | • | • | • | • |
| | Agriculture | 5.9 | Smart Greenhouse | • | • | | • | • | • | • | • | | • | | • | • |
| | | | Precision Agriculture | • | • | | • | • | • | • | | | • | | • | • |
| | | | Auto Agriculture | • | • | | • | • | • | • | • | | • | | • | • |
| | | | Livestock Monitoring | | | | • | | | | | | • | | • | • |

*Figure 7* Mapping between IoT use case categories, device types and MIPI specifications

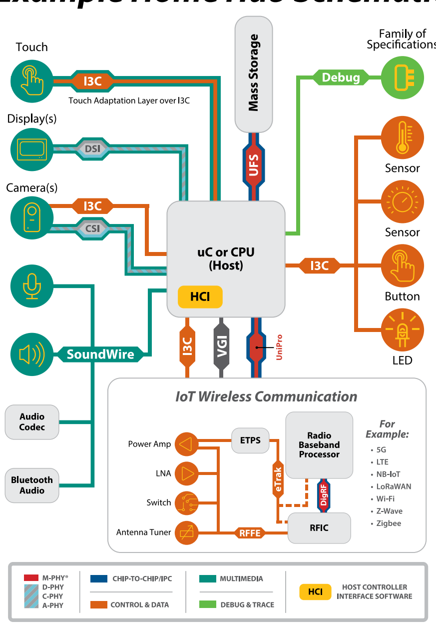
## 5.1 MIPI—In the Smart Home

USE CASES

### MIPI specifications are also applicable to many other Smart Home use cases including:

- Home Automation
- Heating, Ventilation and Air Conditioning
- Home Security


### Example Home Hub Schematic




***Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process***

### In Home Hubs:

- SoundWire to provide a shared, two-wire interface to drive codecs, microphones and speakers. Enables noise cancellation, beam steering and low-power audio 'keyword' activation
- DSI-2 over C/D-PHY to drive a low-power, high-resolution display enabling display partitioning when device is in a low-power standby mode and a touchscreen user interface using MIPI Touch over I3C
- CSI-2 over C/D-PHY as a highly scalable interface to connect high-resolution cameras, enabling low-power vision inferencing and camera control using CCI over the same connector using USL
- I3C to provide a shared, two-wire interface to connect sensors and simple UI components
- UFS over UniPro/M-PHY for fast boot and to read and write high-resolution images
- RFFE within radio communications module

### In Smart Doors:

- I3C to provide a shared, two-wire interface to connect fingerprint sensor, an actuator for the door lock and simple UI components such as dot matrix LED display. In-band interrupts can be used to enable low-power standby mode
- CSI-2 as a highly scalable interface to connect a high-resolution camera, enabling facial recognition using low-power machine vision inferencing
- SoundWire to provide a shared, two-wire interface to drive microphone and speaker, enabling low-power audio 'keyword' activation
- RFFE within radio communications module

### In Smart Home Appliances:

- I3C to provide a shared, two-wire interface to connect all internal sensors and actuators, and to connect and drive simple UI components, such as LEDs and buzzers
- DSI-2 over C/D/A-PHY to drive a low-power, high-resolution display using display partitioning when the device is in standby mode and touchscreen user interface using MIPI Touch
- A-PHY can be used in large appliances as a long-reach (≤15m) physical interface, ensuring reliable connectivity in a noisy EMI environments, reducing the need for internal EMC shielding
- RFFE within radio communications module

**LEGEND**

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

## 5.2 MIPI—In Consumer IoT

USE CASES


### In Connected Cameras:

- CSI-2 as a highly scalable interface to connect high-resolution camera sensors, using CCI for camera command and control over single MIPI C/D-PHY interface using USL
- SoundWire to drive high quality audio components such as microphones and speakers
- I3C to provide a shared, two-wire interface, to connect sensors, GPS and simple UI components, such as LEDs and buttons
- UFS over UniPro/M-PHY for storage of high-resolution images
- RFFE within cellular communications module

### In Video Conferencing Devices:

- CSI-2 as a highly scalable interface to connect high-resolution cameras, using CCI for camera command and control over single MIPI C/D-PHY interface using USL
- SoundWire to drive high-quality audio components such as multiple microphones and speakers. Enables audio beam steering and advanced noise cancellation
- I3C to provide a shared, two-wire interface, to connect sensors, and simple UI components such as LEDs and buttons
- RFFE within radio communications module

### In Portable Gaming Devices:

- CSI-2 as a highly scalable interface to connect high-resolution camera over single MIPI C/D-PHY interface
- DSI-2 over C/D-PHY to drive a high-resolution display, enabling display partitioning when device is in standby mode and a touchscreen user interface using MIPI Touch over I3C
- SoundWire to drive high-quality audio components
- I3C to provide a shared, two-wire interface, to connect sensors, GPS and simple UI components such as LEDs and buttons
- RFFE within cellular communications module

### In Smart Speakers:

- I3C to provide a shared, two-wire interface to connect sensors and simple UI components, such as LEDs and buttons
- SoundWire to provide a shared two-wire interface, to drive high-quality speakers and microphones, enabling noise cancellation, low-power 'keyword' activation, and low-EMI operation to achieve tighter packaging of components with minimal EMC shielding

### In XR Headsets:

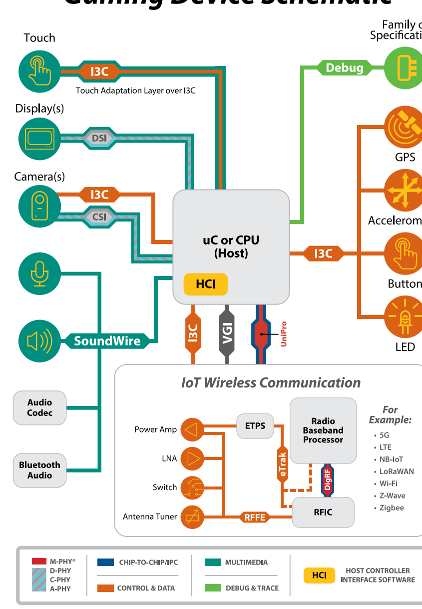
- DSI-2 over C/D-PHY to drive state-of-the-art ultra-high-resolution displays, enabling a truly immersive virtual/augmented reality experience
- I3C to provide a shared, two-wire interface, to connect sensors, and simple UI components such as LEDs and buttons
- RFFE within radio communications module

### LEGEND

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

*Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process*

### *Example Portable Gaming Device Schematic*



## 5.3 MIPI—In Wearables

USE CASES

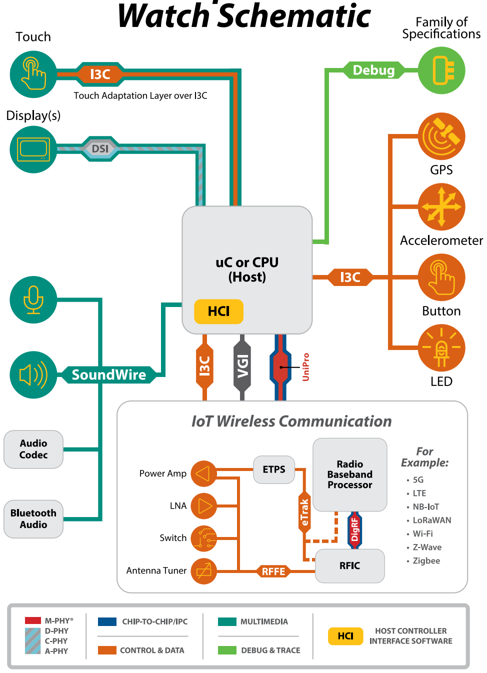

### In AR Glasses:

- DSI-2 over C/D-PHY to drive an advanced, high resolution heads-up display, enabling low-power 'Smart Region of Interest' mode when watch is in standby mode
- CSI-2 over C/D-PHY to connect a high-resolution camera, enabling low-power vision inferencing
- SoundWire to provide a shared, two-wire interface, to drive speakers and microphones, enabling noise cancellation, low-power 'keyword' activation, and low-EMI operation to achieve tighter packaging of components with minimal EMC shielding
- RFFE within radio communications module

### In Smartwatches:

- DSI-2 over C/D-PHY to drive an advanced high-resolution display, enabling low-power 'Smart Region of Interest' mode when watch is in standby mode
- MIPI Touch to enable touchscreen user interface
- C-PHY physical interface, reducing line and pin counts and generating low EMI, allowing smaller devices requiring less EMC shielding
- I3C to provide a shared, two-wire interface, to connect heart-rate, motion and other sensors and simple UI components such as LEDs and haptics
- SoundWire to drive advanced audio components such as microphones and headsets
- RFFE within radio communications module

### Example Smart Watch Schematic




### In Smart Earbuds:

- I3C to provide a shared, two-wire interface, to connect sensors and simple UI components such as LEDs and buttons
- SoundWire providing a shared, two-wire interface, to drive high-quality speakers and microphones, enabling noise cancellation, low-power 'keyword' activation, and low-EMI operation to achieve tighter packaging of components with minimal EMC shielding

### In Smart Sneakers:

- I3C to provide a shared, two wire interface to connect:
  - Simple UI components such as small dot-matrix displays, LEDs and switches
  - Motion and pressure sensors
  - Motor actuators

*Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process*

**LEGEND**

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

## 5.4 MIPI—In the Smart Factory

USE CASES


### In Robots with Machine Vision:

- CSI-2 over C/D/A-PHY as a highly scalable interface to connect ultra-high-resolution cameras enabling low-power vision inferencing and machine vision
- A-PHY can be used in large machines as a long-reach (≤15m), ultra-reliable physical interface, to link the robot to its control system in a noisy EMI environment
- I3C to provide a shared, two-wire interface to drive the sensors and actuators used to enable the robot

### In Machine Control Systems with Advanced UIs:

- DSI-2 over C/D/A-PHY to drive a high-resolution display
- MIPI Touch over I3C to enable an advanced touch-screen-based user interface
- I3C to provide a shared, two-wire interface to connect simple UI components such as push buttons, LEDs and buzzers
- A-PHY as a long-reach (≤15m), ultra--reliable physical interface to link a control panel to the rest of the system in a noisy EMI environment, such as a factory

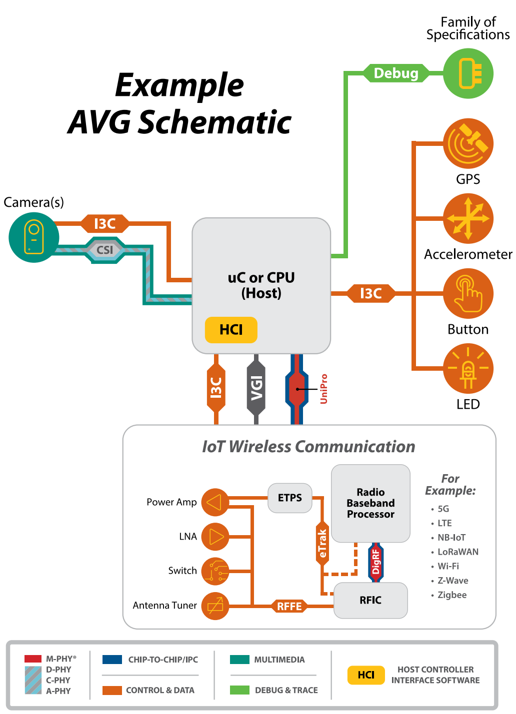
### In Automated Guided Vehicles (AGVs):

- CSI-2 over C/D/A-PHY as a highly scalable interface to connect multiple ultra high-resolution cameras, enabling low-power vision inferencing and machine vision for the AGV to navigate around the factory and avoid obstacles
- A-PHY as a long-reach (≤15m), ultra-reliable physical interface, to link components within the AGV in a noisy EMI environment
- I3C to provide a shared, two-wire interface to drive the sensors and actuators required to control and drive the AGV
- RFFE within radio communications module

### In Industrial Tools:

- I3C to provide a shared, two-wire interface to connect switches, actuators driving motors, vibration sensors and simple UI components such as LEDs and buzzers
- RFFE within radio communications module

### *Example AVG Schematic*




*Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process*

*Use of MIPI specifications can aid product compliance to functional safety standards such as IEC 61508*

**LEGEND**

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G: IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

## 5.5 MIPI—In the Smart City

USE CASES

### In Smart Lighting:


- I3C to provide a shared, two-wire low-power interface to connect sensors to the application processor and supporting in-band interrupts to enable active sleep mode, with sensors waking the application processor only when required
- RFFE within cellular communications module

### In Environmental Monitoring


- I3C to provide a shared, two-wire low-power interface to connect sensors and actuators to the application processor and supporting in-band interrupts to enable active sleep mode, with sensors waking the application processor only when required (critical for devices powered from constrained power supplies)
- RFFE within cellular communications module

### In Public Safety Surveillance Cameras:


- CSI-2 as a highly scalable interface to connect high-resolution cameras, using CCI for camera command and control over single MIPI C/D/A-PHY interface using USL
- SoundWire to drive high-quality audio components such as multiple microphones and speakers. Enabling advanced noise cancellation
- RFFE within cellular communications module

### In Smart Trams:


- CSI-2 over A-PHY to connect high-resolution cameras, DSI-2 over A-PHY to drive high-resolution displays, and MIPI Touch to enable touchscreen user interfaces
- A-PHY as a ultra-reliable, long reach (≤15m), EMI hardened physical interface to connect cameras, displays and sensors within the tram to a central control unit
- RFFE within cellular communications module

### In Smart Parking Sensors:


- I3C to provide a shared, two-wire low-power interface to connect sensors to the application processor; in-band interrupts to enable active sleep mode, with sensors waking the application processor only when required (critical for devices powered from solar power)
- RFFE within cellular communications module

### In Smart Waste Bins:


- I3C to provide a shared, two-wire, low-power interface to connect an ultrasonic sensor to the application processor; in-band interrupts to enable active sleep mode, with sensors waking the application processor only when required (critical for devices powered from a constrained power supply such as solar)
- CSI-2 over C/D-PHY to connect a camera to sense waste type and sort into the appropriate receptacle
- RFFE within cellular communications module

*Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process*

*Use of MIPI specifications can aid product compliance to functional safety standards such as IEC 61508*

**LEGEND**

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G — IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

# 5.6 MIPI—In Healthcare



## In Remote Healthcare Monitoring - Enabling Independent Living and Better Health Outcomes:

- DSI-2 over C/D-PHY to drive advanced high resolution displays, enabling low-power 'Smart Region of Interest' mode when devices are in standby mode
- MIPI Touch to enable touchscreen user interface
- CSI-2 over C/D-PHY as a highly scalable interface to connect advanced high-resolution cameras - enabling low-power vision inferencing and machine vision
- C-PHY physical interface, reducing line and pin counts, and generating low EMI – enabling smaller devices requiring less EMC shielding
- I3C to provide a shared, two-wire interface to connect heart rate, motion and other sensors and simple UI components such as LEDs and haptics
- SoundWire to drive advanced audio components such as microphones, speakers and headsets – enabling audio for telemedicine applications
- RFFE within radio communications modules

**LEGEND**

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

## Enabling machine vision for remote surgery:

- CSI-2 over C/D/A-PHY as a highly scalable interface to connect advanced, high resolution cameras - enabling low-power vision inferencing and machine vision, and providing low-power modes for 'cold camera' applications
- C-PHY physical interface, reducing line and pin counts, and generating low EMI – allowing smaller devices requiring less EMC shielding

## MIPI Displays and Cameras enable microsurgery; XR Headsets enable remote surgery:

- DSI-2 over C/D-PHY to drive state-of-the-art ultra-high-resolution displays enabling a truly immersive virtual/augmented reality experience
- MIPI Touch to enable touchscreen user interface
- I3C to provide a shared, two-wire interface to connect heart rate, motion and other sensors, and simple UI components, such as LEDs and haptics
- A-PHY as a long-reach (≤15m), ultra reliable physical interface, to link the components to the rest of the system in EMI-sensitive environments

*Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process*

*Use of MIPI specifications can aid product compliance to functional safety standards such as IEC 61508*

## 5.7 MIPI—In Utilities USE CASES


LEGEND

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

### In Smart Chargers:

- I3C to provide a shared, two-wire low-power interface to connect sensors and simple UI components such as LED and switches
- A-PHY as a long reach (≤15m), reliable physical interface to connect sensors on solar panels / wind turbines to main control unit

### In Home Batteries:

- I3C to provide a shared, two-wire interface to connect sensors and simple UI components, such as LEDs and switches
- RFFE within communications module, linking device to smart grid

### In Energy Harvesting Devices:

- I3C over A-PHY to provide a shared, two-wire interface to connect sensors and simple UI components, such as LEDs and switches
- A-PHY as a long-reach (≤15m), ultra-reliable physical interface to connect sensors on solar panels/wind turbines to the main control unit

### In Energy Monitoring and Control:

- I3C to provide a shared, two-wire low-power interface to connect simple UI components such as LEDs and buttons
- DSI-2 over C/D-PHY to drive a high-resolution display, providing a rich user experience and, using "Smart Region of Interest", to reduce power consumption when device is in standby mode

### In Water, Gas and Electricity Meters:

- I3C to provide a shared, two-wire low-power interface to connect sensors and simple UI components such as dot matrix displays, LEDs, buzzers and buttons; in-band interrupts enable active sleep mode, waking the application processor only when required (critical for battery powered meters)
- RFFE within the device's radio communications module, linking the meter to the smart grid and controlling critical RF front-end components, such as power amplifiers, filters, switches and antenna tuners

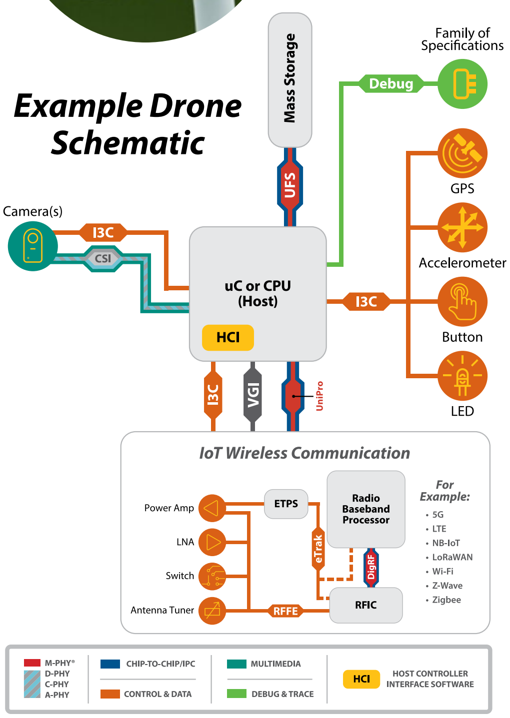
*Associated MIPI SOFTWARE and DEBUG specifications are also available to accelerate the design process*

*Use of MIPI specifications can aid product compliance to functional safety standards such as IEC 61508*

# 5.8 MIPI—In Drones

USE CASES

## Example Drone Schematic




*Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process*

*Use of MIPI specifications can aid product compliance to functional safety standards such as IEC 61508*

## In Drone Controllers (Basestations):

- DSI-2 over C/D-PHY to drive a high-resolution display to allow the operator to see high-resolution video streamed in real time from the drone
- MIPI Touch to enable a touchscreen UI
- I3C to provide a shared, two-wire interface to connect joystick controllers and switches, and drive simple UI components, such as LEDs, haptics and buzzers
- UniPro to enable UFS for localized, high-resolution video storage

## For Cellular Connectivity:

- RFFE to control RF front-end components including power amplifier, low-noise amplifier, filters, switches and antenna tuner

## For Cameras:

- CSI-2 over C/D/A-PHY as a highly scalable interface to connect advanced high-resolution cameras. Enabling low-power vision inferencing and machine vision
- C/D-PHY can be used in smaller drones where line lengths are <50cm
- A-PHY can be used in large commercial drones, as an ultra-reliable, long-reach (≤15m), physical interface in noisy EMI environments
- UniPro over M-PHY to enable UFS to store high-resolution video locally on the drone

## To Connect Sensors, Actuators and Simple UI Components:

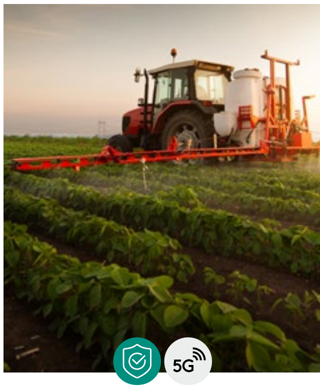
- I3C to provide a shared, two-wire, low-weight, high-speed interface to connect the critical sensors, actuator and controls required to operate the drone
- I3C can be implemented over A-PHY as an ultra-reliable, long-reach (≤15m), physical interface in noisy EMI environments with minimal EMC shielding

### LEGEND

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

# 5.9 MIPI—In Smart Agriculture

USE CASES



## In Precision Agriculture:

- I3C over C/D/A-PHY physical interfaces to connect GPS sensors, electronic compass and actuators to AI application and CPU controlling pesticide and fertilizer dosage
- CSI-2 over C/D/A-PHY to enable machine-vision applications, checking crops for pest damage or disease
- RFFE within cellular communications module

## In Livestock Monitoring:

- I3C to provide a shared, two-wire interface within livestock tracking devices connecting GPS and other sensors, to monitor animal health, activity and environmental impact; in-band interrupts used to enable low-power standby mode; and extended battery life
- RFFE within low-power, wide-area radio communications module

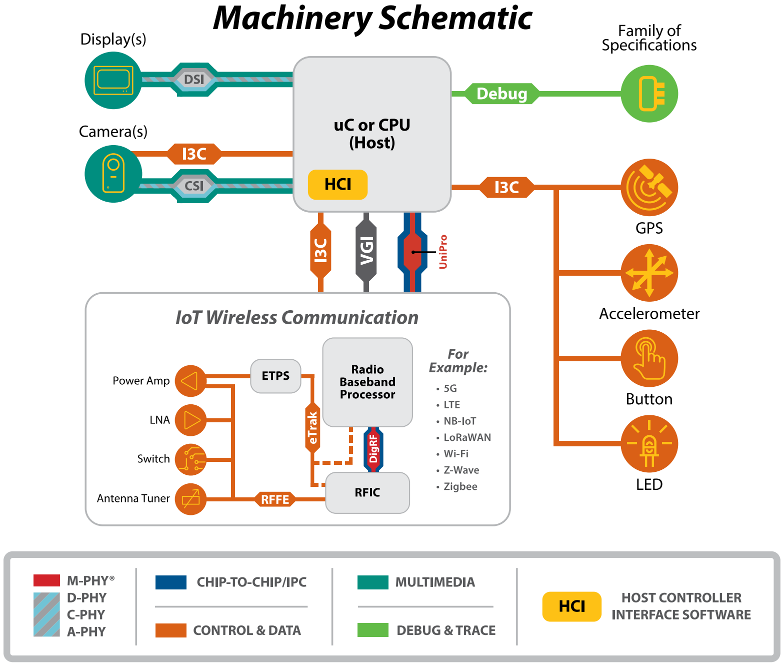
## In Smart Greenhouses:

- I3C over A-PHY to connect heat, light, moisture, CO2 and other sensors, as well as actuators controlling temperature, airflow, irrigation and nutrient levels, ensuring optimal growth conditions
- A-PHY as a long-reach (≤15m), physical interface to connect sensors and actuators to a control unit
- DSI-2 over C/D-PHY for advanced, high-resolution control panel displays

## In Automated Agricultural Machinery:

- I3C over A-PHY to connect the GPS, ultrasonic and other low-speed sensors, actuators and controls within the machine
- CSI-2 over C/D/A-PHY to connect high-resolution cameras, lidars and other high-speed sensors
- DSI-2 over C/D/A-PHY for connecting advanced, high-resolution displays
- A-PHY as a long-reach (≤15m), ultra-reliable physical interface, to enable safe operation in noisy EMI environments
- RFFE within cellular communications module

## Automated Agricultural Machinery Schematic




*Associated MIPI SOFTWARE and DEBUG specifications also available to accelerate design process*

*Use of MIPI specifications can aid product compliance to functional safety standards such as IEC 61508*

### LEGEND

- Functionally safe and secure IoT device that will benefit from MIPI's focus on safety and security
- IoT device with constrained power supply that will benefit from use of MIPI low-power interfaces
- 5G: IoT device with wide-area cellular connectivity that will benefit from MIPI's 5G preparedness
- Size-constrained, tightly packaged IoT device, benefiting from MIPI's low pin count, low wire count, low EMI interfaces

## Conclusion

The growth of the IoT presents huge opportunities to those organizations in both the consumer and enterprise sectors that can derive value from the tighter coupling of the physical, social and digital worlds. As with any new market there will be winners and losers, and a key factor in market success will be the successful design and development of the IoT devices upon which services depend. Those developing the most efficient, capable device designs will give themselves the best chance of market success.

In this paper, we reviewed the requirements of the devices expected to drive huge growth within the IoT market over the next five years. We found that the need for flexible, low-power and highly efficient solutions to connect the sensors, cameras, displays, audio and other components would be critical to the design of these devices. We then reviewed the current MIPI specifications, developed for use primarily within mobile devices, and found that the key technical attributes and commercial benefits of the MIPI specifications matched closely with the key design requirements of these key IoT devices:

- MIPI physical layer specifications (**C-PHY** / **D-PHY** / **M-PHY** / **A-PHY**) are applicable for use across a huge range of IoT devices to connect sensors, cameras, displays and enable Universal Flash Storage and inter-processor communication.
- MIPI I3C is universally applicable for use in all IoT devices that require sensors, actuators and controls.
- MIPI CSI-2 and its associated control interface should be the de-facto choice of camera (and other high-bandwidth sensor) interface for IoT devices.
- MIPI DSI-2 and its in-band control protocol should be the clear choice of display interface for IoT devices.
- MIPI SoundWire should be the leading choice of audio interface for IoT devices.
- MIPI debug and trace interfaces and MIPI software-integration resources will accelerate any IoT device development.

More information on MIPI Alliance and its specifications can be found at **www.mipi.org**

## Annex A. Overview of MIPI Specifications

MIPI Alliance maintains numerous specifications across the physical, protocol and software layers that are beneficial to the development of IoT devices. Figure 8 shows the typical use of the key MIPI physical- and protocol-layer specifications within a hypothetical, generic IoT device with cellular connectivity.

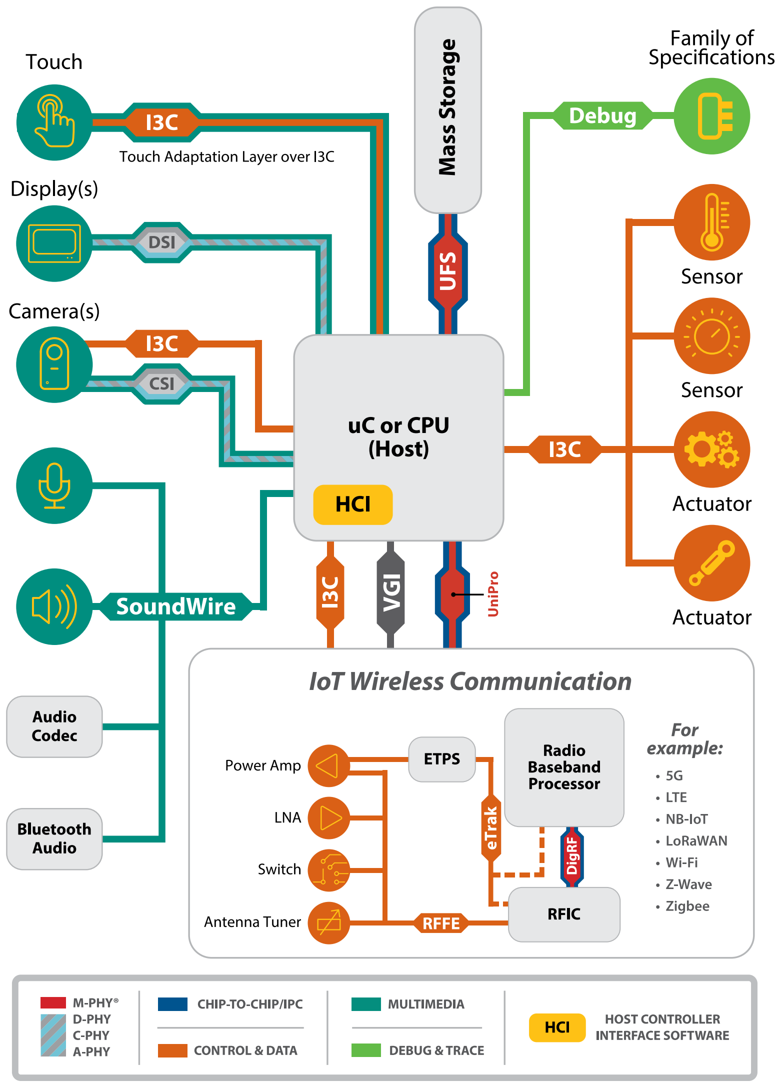



*Figure 8* Example use of MIPI specifications in a generic IoT device with cellular connectivity

## A.1. Physical Layer (PHY)

All IoT devices are built from numerous interconnected, embedded electronic components. The physical layer (PHY) that connects them is at the heart of any device design. The most successful designs are based upon PHY specifications that support the key design goals of the target device.

MIPI Alliance has defined a family of four PHY specifications delivering high performance, low-power operation and low EMI for efficient, cost-optimized IoT applications. A brief overview of the MIPI specifications, with specific emphasis on their applicability within IoT devices, follows.

| *MIPI Physical Layer Specification* | *Description of Typical IoT Device Usage* | *Typically Used With* | *Features* |
|---|---|---|---|
| *C-PHY* | Short- to medium-reach physical layer for cameras, high-bandwidth sensors and displays | MIPI CSI-2<br>MIPI DSI-2 | • High speed<br>• Low power<br>• Embedded clock<br>• Symbol rate encoding by ~2.28 |
| *D-PHY* | Short- to medium-reach physical layer for cameras, high-bandwidth sensors and displays | MIPI CSI-2<br>MIPI DSI-2 | • High speed<br>• Low power<br>• Simple clock forwarding<br>• Differential encoding |
| *M-PHY* | Short-reach physical layer, used with UniPro, to enable Universal Flash Storage and inter-processor communication | MIPI UniPro | • Very high speed<br>• Low power<br>• Full duplex (dual simplex) |
| *A-PHY* | Long-reach, high-reliability physical layer interface for cameras, high-bandwidth sensors and displays | MIPI CSI-2<br>MIPI DSI-2 | • High speed<br>• High RFI noise immunity<br>• High reliability |

*Table 5* Summary of MIPI physical layer specifications

## A.1.1. MIPI C-PHY and D-PHY

**IN BRIEF**

*MIPI C-PHY and D-PHY are both high-speed, low-cost, low-power serial interfaces for cameras, displays and other sensors that have high-bandwidth and bursty data communication requirements.*

MIPI C-PHY and D-PHY both provide high-speed, low-cost and low-power serial interfaces for cameras, displays and other types of sensors that have high bandwidth (greater than 80MHz) and potentially bursty data communication requirements (e.g., lidar, radar, ultrasonic sensors, etc.)

D-PHY uses differential signaling and a source synchronous clock for scalable data lanes. It offers half-duplex behavior for applications that benefit from bidirectional communication at transmission rates up to 4.5 Gigabits per second (Gbps) per lane. Its minimum configuration requires four pins to support a clock lane and data lane but is typically implemented using a 10-pin port that supports four data lanes, one clock lane and data rates up to 18 Gbps for four data lanes. Future releases will increase the aggregated data rate to ~36 Gbps.

C-PHY uses three-phase symbol encoding, reducing the channel baud rate by a factor of approximately 2.28, for bandwidth-limited channels over a three-wire data lane. It generates low EMI and supports transmission rates up to 13.7 Gbps per lane. Its minimum configuration requires three pins, as it does not require a separate clock lane, but is typically implemented using a nine-pin port that supports three data lanes and data rates up to 41.1 Gbps.

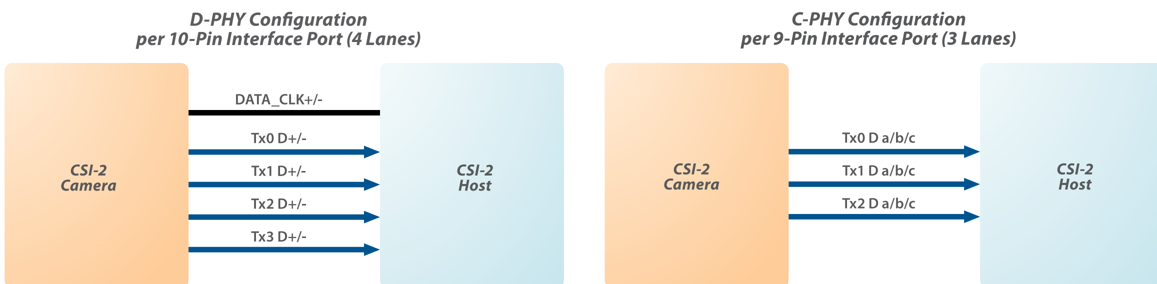



*Figure 9* Example C-PHY and D-PHY lane configurations

Key points to note with MIPI C-PHY and D-PHY:

- Support MIPI CSI-2 and DSI-2 protocol layers
- Target applications with medium to short channel lengths of less than 1m (longer channel length beyond 1m could also be supported in low-EMI environments)
- Implement high-speed and low-power modes, with fast transitions between different modes of operation
- Can be implemented on the same pins because of similarities in electrical specifications
- Support in-band signaling to negate the need to implement additional interrupt wires
- Augmented with conformance test specifications (test tools are freely available on the market from multiple vendors)
- Future evolutions of the specifications to further increase the speed of the interfaces to accommodate the bandwidth demands of future cameras, displays and other types of sensors
- Future releases to target ever-lower power consumption

## A.1.2. MIPI A-PHY

**IN BRIEF**

*MIPI A-PHY is a long-reach (≤15m) SerDes interface providing high speed, low latency and high reliability connectivity for harsh-EMI environments. It provides a highly robust interface to connect sensors, cameras, displays and other components within large or distributed IoT devices.*

MIPI A-PHY is a long-reach serializer-deserializer (SerDes) physical layer interface providing high speed, low latency, long reach and high reliability connectivity for harsh-EMI environments. It was developed to meet the automotive industry's need for a highly robust, functionally safe interface to connect cameras, displays and other components within vehicles. It is applicable for use in IoT applications where long channel lengths are required to connect components, especially those within noisy EMI environments. Typical IoT use cases could include large devices that are required to operate reliably within a noisy environment, such as in manufacturing and healthcare, as well as devices that contain components generating high levels of EMI, such as large home appliances and large commercial drones. A-PHY typically will be used in two configurations:

- As a long reach, highly reliable interface to directly connect components (cameras, displays, etc.) that offer native support for A-PHY, eliminating the use of non-standardized, long-distance bridging components and interfaces and reducing cost, weight, power consumption and improving reliability
- As a long-reach, highly reliable interface to bridge between components (cameras, displays, etc.) that use MIPI C-/D-PHY physical interfaces, eliminating the use of proprietary, long-reach protocols

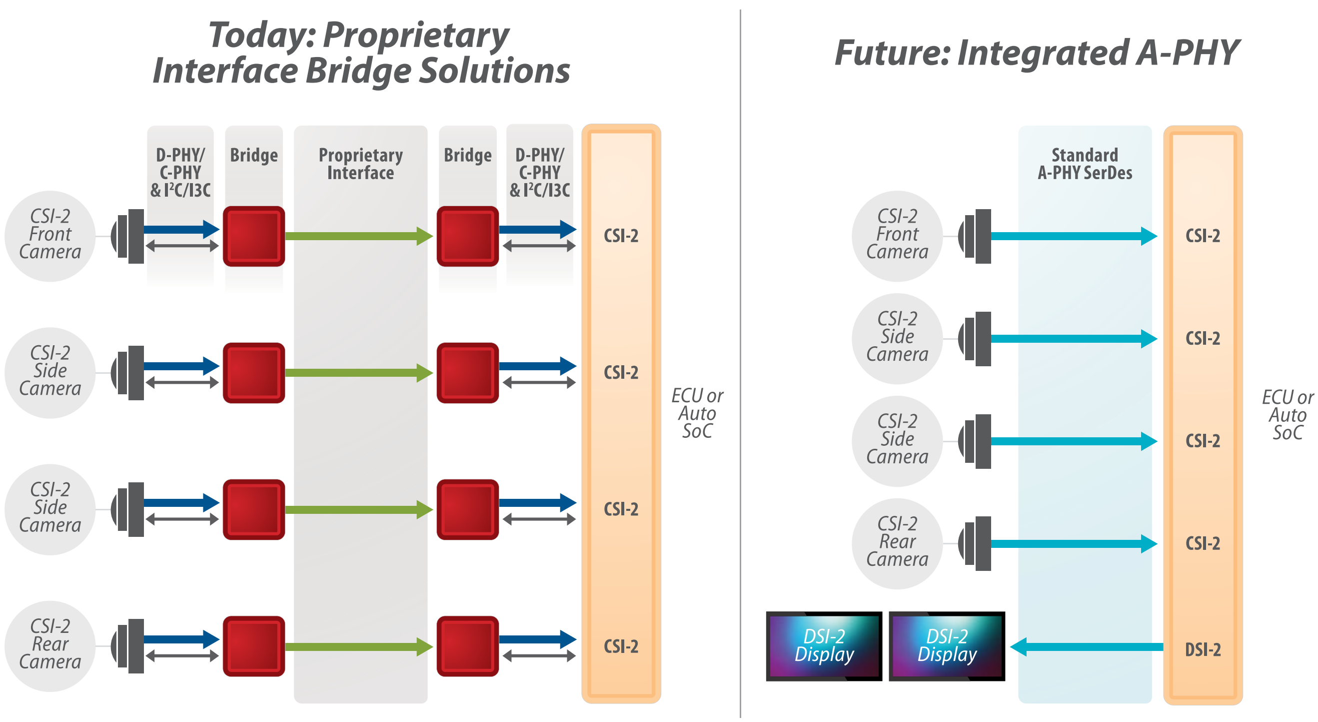



*Figure 10* Proprietary bridging solution vs. native A-PHY integration

Core attributes of MIPI A-PHY:

- Supports MIPI CSI-2 and DSI-2 protocol layers and other approved industry protocols
- Implemented over a single cable, with optional power delivery, for lengths up to 15 meters
- Supports five speed gears (2, 4, 8, 12 and 16 Gbps), with a roadmap to 48 Gbps and beyond
- High reliability, ultra-low packet error rate of < $10^{-19}$, with high resilience and ultra-high immunity to EMI effects by virtue of a unique PHY-layer retransmission system
- Complexity focused at the receiver side (i.e., toward the main CPU within the system), rather than the transmitter (i.e., sensors), concentrating the processing and power consumption within the central components of the system
- High-bandwidth support negates the need for data compression over the interface, reducing complexity and minimizing data loss should it occur
- Supports safety-critical applications and can aid compliance with standards such as IEC 61508[14]
- Designed to handle EMC degradation within system components, due to thermal cycling, etc., over long product lifecycles
- Eliminates the need for bridge integrated circuits (ICs) for long channel lengths

## A.1.3. MIPI M-PHY

**IN BRIEF**

***MIPI M-PHY is a short-reach serial interface for data-intensive applications requiring fast communications channels. Applications include connecting flash memory, RF front-ends and IPC.***

MIPI M-PHY is a serial interface for data-intensive applications that require fast communications channels. The specification targets applications that have a need for low complexity, low pin counts, lane scalability and power efficiency. Key applications include connecting application processors to flash memory, connecting RF front-ends and providing inter-processor communications (IPC).

MIPI M-PHY uses a differential signaling with an embedded clock. It provides two transmission modes with different bit signaling and clocking schemes intended to enable optimum power efficiency over a broad range of data rates. The peak transmission rate is 11.6 Gbps on one lane and 46.4 Gbps over four lanes. The high bandwidth per lane can reduce the number of lanes required.

Core attributes of M-PHY:

- Supports the MIPI UniPro protocol layer (see Section A.2.7), as well as other industry protocol layers such as JEDEC Universal Flash Storage (UFS), PCI-SIG M-PCIe and USB Implementer Forum (USB-IF) SuperSpeed Inter-Chip (SSIC)
- Supports only short line lengths of less than 10cm
- Widely used within the smartphone industry for interfacing to UFS, enabling fast data storage and retrieval for high-resolution video and enabling fast device boot times
- Future releases to further increase the data rate (to ~24 Gbps) and remove unused legacy features to further simplify the implementation of the specification
- Has supporting conformance test suite (test tools are readily available)



[14] *https://www.iec.ch/functionalsafety/*

## A.2. Protocol Layer

A basic property of all IoT devices is that they interact, in some shape or form, with the physical world around them. The fundamental electronic building blocks that provide the critical link between the physical and the digital worlds fall into one of the following groups:

- **Sensors:** The IoT use cases described in Section 2.3 use a multitude of different sensors to link to the physical world around them. This includes the use of temperature and humidity sensors, accelerometers and biometric, light, gas and distance sensors, among others.
- **Actuators:** The use of actuators so that devices can perform physical actions based upon the data they collect and process is a key requirement of many IoT use cases. Actuators typically being used control diaphragms, motors, solenoids, pistons and valves.
- **Controls:** The ability for IoT devices to control other electronic systems (or subsystems) that typically utilize a separate application processor is a key requirement for many IoT services, particularly when the device needs to fit within a larger system or solution.

Many IoT devices also need to provide a user interface so that they can integrate with human users. For the purpose of this document, we split the types of user interfaces into three categories:

- **Simple User Interface:** Provides a user interface consisting of tri-state LEDs, simple dot matrix displays and push button switches.
- **Advanced User Interface:** Provides an advanced user interface consisting of high-resolution displays and potentially a touchscreen interface.
- **Advanced Audio:** Provides high-quality audio (microphones and speakers).

Some IoT devices may also need to incorporate important subsystems such as cellular modems or support large amounts of non-volatile flash memory:

- **IPC:** The IoT device's main application processor communicates to another major system that contains its own microprocessor.
- **Flash Storage:** High-speed, reliable, flash memory data storage.

It is essential to many IoT developers that these building blocks be integrated into an IoT device design in a simple and cost-effective manner. MIPI specifications can help the IoT developer achieve this goal, as shown in Table 6.

| ***MIPI Protocol Specification*** | ***Description and Typical IoT Device Usage*** | ***Sensors*** | ***Actuators*** | ***Controls*** | ***Camera*** | ***Simple UI**** | ***Advanced Display***** | ***Advanced Audio*** | ***Inter-Processor Comms*** | ***Flash Storage*** |
|---|---|---|---|---|---|---|---|---|---|---|
| ***CSI-2, CCI and CCS*** | Serial interface protocol for connecting and controlling cameras and other high-bandwidth sensors (lidar, radar, sonar, ultrasonic, etc.) | • | | | • | | | | | |
| ***DSI-2 and DCS*** | Serial interface protocol and command set for connecting and controlling high-resolution displays | | | | | | • | | | |
| ***I3C (and I3C Basic)*** | General-purpose data bus protocol and interface for connecting sensors, actuators and simple UI components, and for the control of advanced components such as cameras | • | • | • | | • | | | • | |
| ***SoundWire*** | Digital audio and control protocol, and interface to connect audio components | • | | | | | | • | | |
| ***Touch*** | User interface set of protocols enabling and controlling touch user interfaces | | | | | | • | | | |
| ***UniPro*** | Data transport protocol to enable UFS and IPC | | | | | | | | • | • |

* Simple UI = Typically implemented using switches, LEDs, small dot matrix displays, etc.
** Advanced UI = Typically using a high-resolution display and, potentially, a touchscreen interface.

***Table 6*** Overview of MIPI protocol layer specifications

### A.2.1. MIPI I3C: Supporting Sensors, Actuators, Controls and Simple User Interfaces

**IN BRIEF**

***MIPI I3C is the natural successor to I2C and provides a cost-effective, simple, low-latency, flexible two-wire interface that can be used to connect sensors, actuators, controls and simple UI components to an application processor. It is highly efficient and supports ultra-low-power IoT services.***

The MIPI I3C specification is a cost-effective, simple and highly flexible solution that can be used to connect sensors, actuators, controls and simple UI components to an application processor as shown in Figure 11.

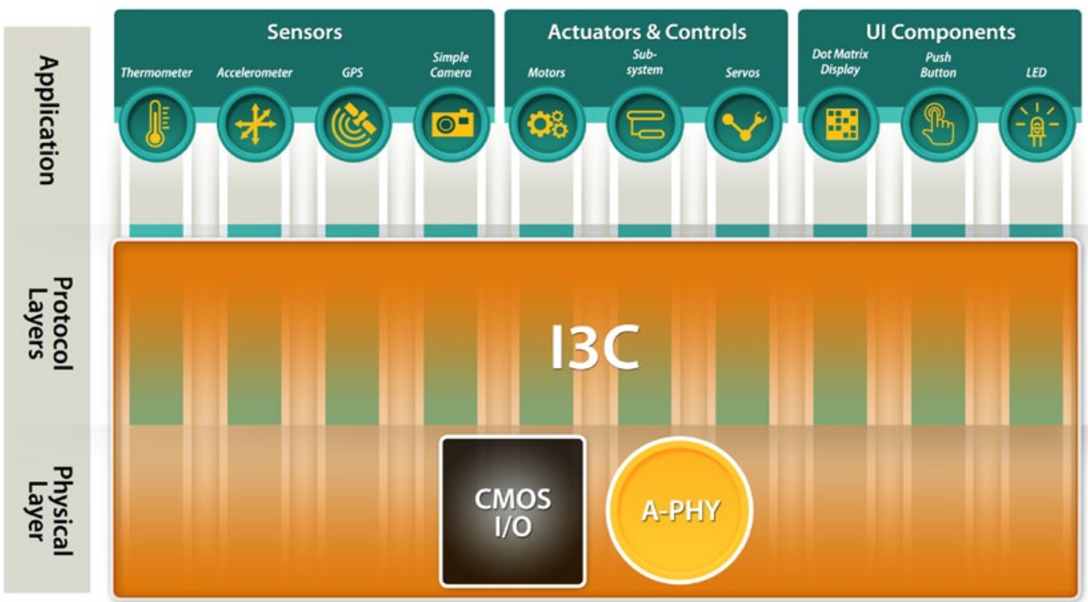



*Figure 11* Use of MIPI I3C to connect sensors, actuators, controls and simple UIs

MIPI I3C provides performance, power and pin-count improvements over legacy interfaces such as I2C, serial peripheral interface (SPI) and universal asynchronous receiver-transmitter (UART). It incorporates all the key attributes of these legacy interfaces, providing a unified, high-performance, very-low-power solution that delivers a robust and flexible upgrade path for current I2C, SPI and UART implementers. It also replaces the need to use cumbersome GPIO interfaces.

To meet the key technology requirements described in Section 3 of this paper, the MIPI I3C specification has been developed to provide the following attributes:

- MIPI I3C is implemented using complementary metal oxide semiconductor (CMOS) I/O using a two-wire interface to minimize pin counts and number of signal paths between components as shown in Figure 11.
- I3C enables designs that use significantly less wires compared to designs that use legacy SPI interfaces as shown in Figure 12
- It's designed to consume low amounts of energy per bit transported. A comparison of I3C's raw power consumption, compared to the legacy I2C interface, is shown in Figure 13.
- "Sleep mode" and in-band interrupts allow sensors to wake up the application processor only when necessary, to conserve power consumption.
- It enables the use of power-efficient, high-speed batch data transfer, allowing components to send infrequent bursts of data, minimizing the energy consumption of the host processor.
- It offers a typical data rate of 10 Mbps with options for higher-performance, high-data-rate modes that provide speeds in excess of 30 Mbps (for single-lane mode).

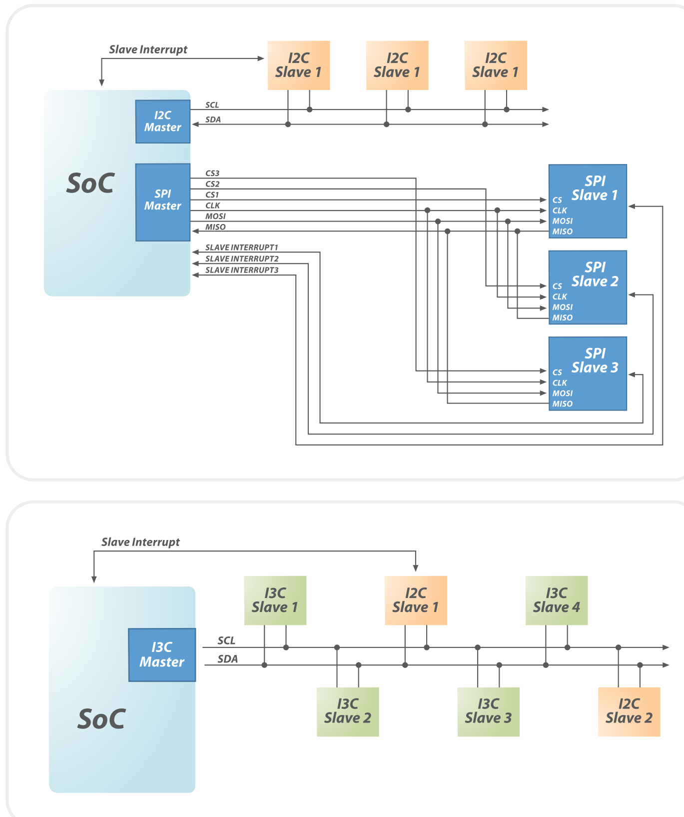



*Figure 12* Reducing complexity with I3C vs. use of SPI interfaces

- Synchronous and asynchronous time-stamping improve the accuracy of applications that use signals from various sensors.
- It is backward compatible with I2C and allows mixed use of I2C and I3C components within a device. Compatibility with future versions of I3C will also be maintained.
- An I3C conformance test suite is in development, ensuring interoperability and compatibility between different vendors' solutions—something that other interfaces, such as SPI, lack.
- Feature enhancements are underway, such as long reach that will extend path lengths from centimeters to in excess of 1 meter, lower power consumption and lower pin counts.

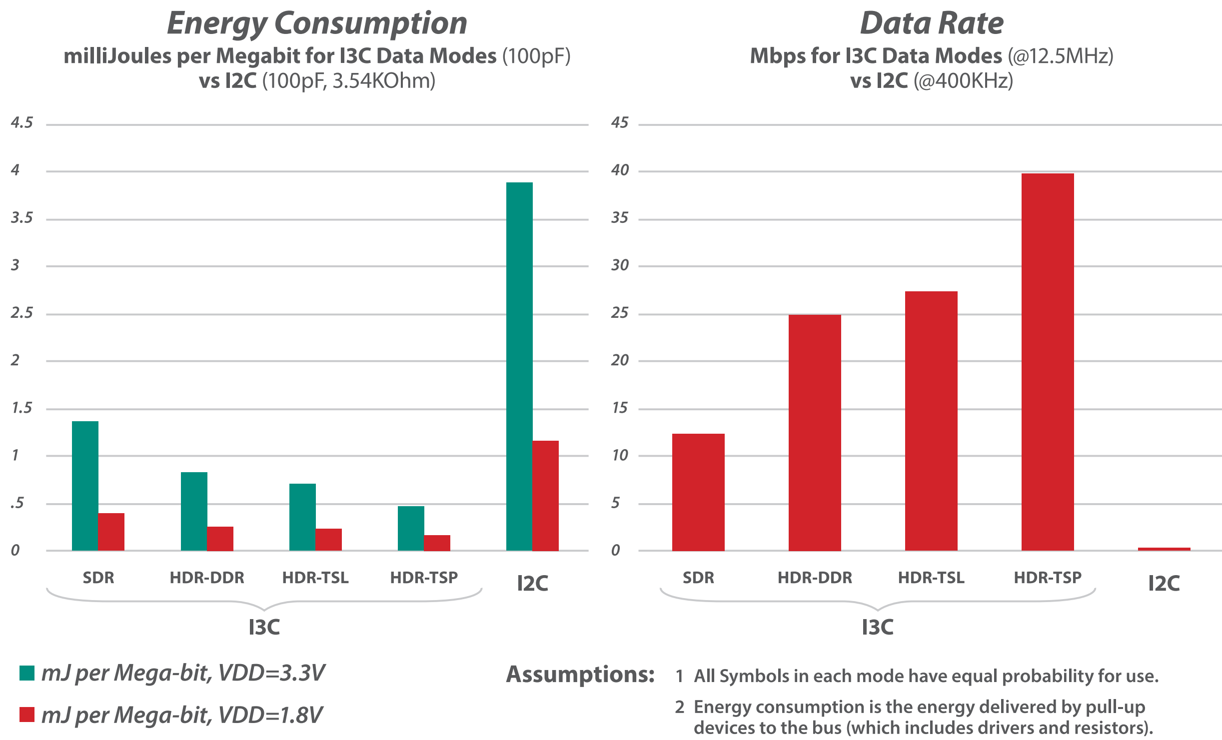



*Figure 13* Energy Consumption and Raw Data Rate: I3C vs. I2C

MIPI software resources include a Host Controller Interface designed to speed sensor integration. MIPI I3C HCI provides an open source implementation of an I3C master controller for IoT developers looking to develop bespoke SoC designs.

## A.2.2. MIPI I3C Basic: A Publicly Available Subset of I3C

Based on a subset of the functionality defined within the full MIPI I3C specification, MIPI I3C Basic is a separately maintained specification that bundles the most commonly used I3C features for developers. The system-integrator community can efficiently use these capabilities as an alternative to I2C. MIPI I3C Basic is available for implementation without MIPI membership and is intended to facilitate a royalty-free licensing environment for all implementers.

## A.2.3. MIPI CSI-2: Supporting High-Bandwidth Cameras and Other Sensors

**IN BRIEF**

*MIPI CSI-2, with its companion CCI and CCS specifications, is a low-complexity, high-speed protocol intended for point-to-point data transmission between sensors with high-bandwidth requirements and application processors. It has achieved widespread market adoption within a broad range of high-performance applications using camera, sonar, lidar, infrared and ultrasonic sensors.*

The rapid advancement of camera and other image sensor technologies, offering enhanced image quality and lower component costs, is a key technology enabler for many IoT use cases. Drones performing detailed aerial reconnaissance; cars using cameras, radars and lidars to become ever-more autonomous; industrial robots using high-resolution image processing to perform quality control, and advanced facial recognition within security or surveillance systems are among the example IoT use cases being enabled by new imaging technologies.

The MIPI Camera Serial Interface-2 (CSI-2) specification, with its companion Camera Command Interface (CCI) and Camera Command Set (CCS) specifications, is a low-complexity, high-speed protocol primarily intended for point-to-point image transmission between sensors with high-bandwidth requirements and application processors. It has already achieved widespread market adoption for its ease of use and ability to support a broad range of high-performance imaging applications using camera, sonar, lidar, infrared and ultrasonic sensors.

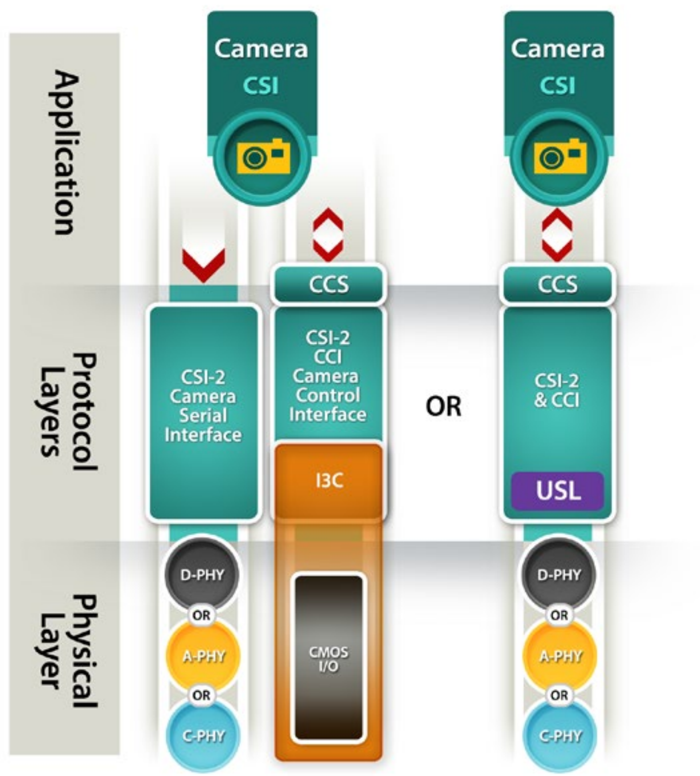



*Figure 14* MIPI camera and imaging specification stacks

Key points of note with the present Version 3.0 of MIPI CSI-2:

- Can be implemented on top of the C-PHY, D-PHY and (in the next release) the A-PHY physical layers
- Lane-scalable performance, delivering up to 41.1 Gbps using a three-lane (nine-wire) MIPI C-PHY interface or 18 Gbps using four-lane (10-wire) MIPI D-PHY interface
- Supports RAW-16 and RAW-24 color depth and optimizes intra-scene high dynamic range (HDR) and signal-to-noise ratio (SNR) to enable advanced vision capabilities
- Supports multi-sensor applications through the optional use of up to 32 virtual channels, accommodating the proliferation of different image sensors with data types
- Features a highly power-efficient "active mode" using Smart Region of Interest (SRoI) capability
- Offers Latency Reduction and Transport Efficiency (LRTE) feature to remove the need for dual voltage channels, reducing wires, lowering power consumption and enabling longer channel lengths
- Offers Unified Serial Link (USL) feature to encapsulate command and control connections between a sensor module and application processor, negating the need for a separate control interface and reducing the number (and weight) of wires needed to integrate a camera into a device
- Offers Pseudo-Random Binary Sequence (PRBS) scrambling features to reduce PSD (power spectral density) emissions for low RFI and lower power applications, enabling low heat dissipation (cold camera) use cases, as required for medical-imaging applications
- Offers Differential Pulse Code Modulation (DPCM) compression to reduce bandwidth and deliver superior SNR images devoid of compression artifacts, enabling edge detection for both mission-critical and other machine-vision applications.
- Companion CCI specification enabling a control mechanism for switching of sensor modes and settings (CCI can be connected using a USL within the CSI-2 transport or via a physically separate I2C/I3C control interface)
- MIPI CCS defining a standard set of functionalities for controlling image sensors, enabling the rapid integration of camera functionalities in a "plug-and-play" fashion
- Widely supported by numerous developer kits, such as Raspberry Pi and many others as described in a recent MIPI blog[15]
- CSI-2, CCI and CCS all supported with companion conformance test suites

Features coming in the next release of the CSI-2 specification (v4.0) and its companion specifications:

- Always-On Sentinel Conduit (AOSC) enabling ultra-low-power, always-on inferencing by integrated or external digital signal processor solutions, allowing a low-power IoT device to be always on, always monitoring its surrounding environment and waking the application CPU only when a relevant event happens. AOSC will enable MIPI CSI-2 frame transport and bidirectional control using a two-wire I3C solution, with intuitive scaling options
- RAW-28 capture for mission-critical, real-time perception autonomous applications
- Functional Safety specification to ensure integrity of the CSI-2 frames used to make mission-critical decisions by autonomous systems, meeting ISO-26262 requirements
- Adaptation Layer specification enabling both integrated and discrete CSI-2 transport solutions leveraging the A-PHY long-reach SerDes supporting up to 15m



[15] *https://resources.mipi.org/blog/developer-kits*

## A.2.4. MIPI DSI-2: Supporting Advanced Displays

**IN BRIEF**

***MIPI DSI-2, with its companion DCS specification, is a widely adopted, simple, high-speed, low-power serial protocol for connecting displays to application processors. It is widely used in the smartphone and wearables (smartwatch) sectors.***

MIPI Display Serial Interface-2 (DSI-2) is a widely adopted, simple, high-speed, low-power serial protocol for connecting displays to application processors. For its ease of use and ability to support a broad range of applications, DSI-2 has already achieved widespread market adoption in the smartphone and wearables (e.g., smartwatches) sectors.

MIPI DSI-2 supports a full range of display formats and resolutions, from low-resolution compact displays to large, ultra-high-definition (4K and 8k) displays. The interface supports IoT use cases that require a rich user interface such as video gaming devices, VR headsets, drone base stations and industrial control-panel applications.

MIPI DSI-2 is augmented by the MIPI Display Command Set (DCS) specification. DCS is used to configure resolution, width and brightness. Use of DCS reduces time to market and design costs by simplifying the connection of display components from different manufacturers.

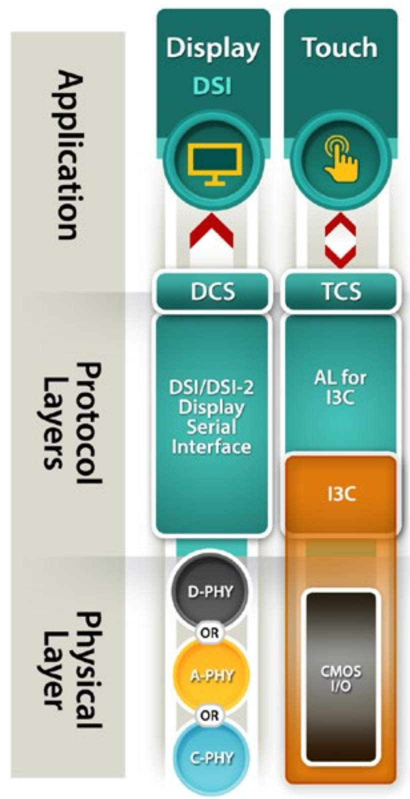



*Figure 15* MIPI advanced display and touch UI specification stacks

Key points of note with the present Version 1.1 of DSI-2:

- Supports VESA Display Compression-M (VDC-M) and VESA Display Stream Compression (VESA DSC) standards, giving developers the choice of either codec depending on their bandwidth and power requirements
- For a 30-bit image, VDC-M can enable compression ratios of up to 5:1, while maintaining visually lossless viewing with no attendant loss of bandwidth
- Can be implemented with MIPI D-PHY, C-PHY and the new A-PHY physical layers
- Very low wire and pin requirements, requiring only a single C-PHY or D-PHY serial lane to drive a display vs. multiple lanes for other types of parallel interfaces
- Very low power, leveraging an intrinsically low-power, high-speed interface with power-saving protocol features including suspend mode, low-power mode, and in-band low-power bi-directional control
- Multiple logical channels through the same interface for support of display partitioning, lowering power consumption for devices that need to update just part of the display in a low-power mode (for example, a smartwatch display updating just the clock part of the display)
- Supports data scrambling to lower EMI and reduce the need for shielding components
- Already implemented in many commonly available IoT developer kits including Raspberry Pi and others described in a recent MIPI blog post[16]
- Backward compatible to the first MIPI DSI specification with the aim of maintaining forward compatibility in future releases
- Widely available conformance test suites and test tools
- Future releases of the specification will target ever-lower power consumption and lower number of wires (from typically four or five wires today down to one)



[16] *https://resources.mipi.org/blog/developer-kits*

### A.2.5. MIPI Touch: Supporting Touch For Advanced User Interfaces

**IN BRIEF**

***MIPI Touch enables the fast, flexible design and implementation of touchscreen interfaces in devices that use an advanced display.***

For IoT devices with an advanced display, the implementation of a touchscreen interface may provide an optimal user experience especially where the use of physical buttons may be undesirable—for example, in an environmentally sensitive manufacturing or clean healthcare environment. Touchscreen UIs are also highly desirable for IoT devices with complex user interface requirements such as drones, video gaming devices and smartwatches. Touch may also be an attractive UI in IoT devices where gesture-based control may be desirable, such as in a smart building access control system.

MIPI Touch enables the fast, flexible design and implementation of touchscreen interfaces in devices that use an advanced display as their primary user interface. Use of the specifications provides significant interoperability conveniences that alleviate previous challenges associated with touchscreen integration. A primary benefit is a standardized “write-once” approach that enables a developer to write a single driver that can be used across operating systems for touch implementations in a wide range of devices. MIPI Touch also provides significant performance benefits and can yield high throughput and low latency for touch-based user interfaces.

MIPI Touch uses the MIPI I3C interface. The key specifications for MIPI Touch are:

- The MIPI **Touch Command Set** (MIPI TCS℠), a set of high-level commands that harmonize the writing of device drivers across different operating systems
- The MIPI **Touch Adaptation Layer for I3C** (MIPI ALI3C℠), which translates the touch commands for use on the MIPI I3C protocol

### A.2.6. MIPI SoundWire: Supporting Advanced Audio and Other Applications

**IN BRIEF**

***MIPI SoundWire is a comprehensive audio interface with scalable architecture that supports advanced amplifiers and microphones; optimizes speaker protection, microphone power and performance; enables noise cancellation; and supports always-listening audio inputs.***

The ability to record and play back high-quality sound is a key requirement for many IoT services, from enabling advanced speech-based virtual assistants in home hubs and wearable devices such as smart earbuds, to providing an essential data-collection mechanism to physically sense the environment as required in many home security, assisted living and environmental monitoring applications. The ability to tightly integrate audio components into an IoT device to create a low-power, low-complexity, compact, yet highly capable solution is essential, and MIPI SoundWire is a key enabler to achieve these goals.

MIPI SoundWire is a digital multi-channel interface that consolidates many of the key attributes found in mobile and personal computing audio interfaces, providing a common, comprehensive interface with scalable architecture that can be used to enable audio features and functions in multiple types of IoT devices and across all market segments. The natural replacement for legacy I2S (Inter-IC Sound) and pulse-density modulation (PDM) interfaces, SoundWire consolidates all audio interfaces onto a single pair of lanes, including any controls or interrupts that may in the past have required dedicated SPI or I2C connections. It supports the use of advanced amplifiers and microphones to enable optimal speaker protection, microphone power and performance, noise cancellation and the enablement of low-power, "always-listening" audio applications.

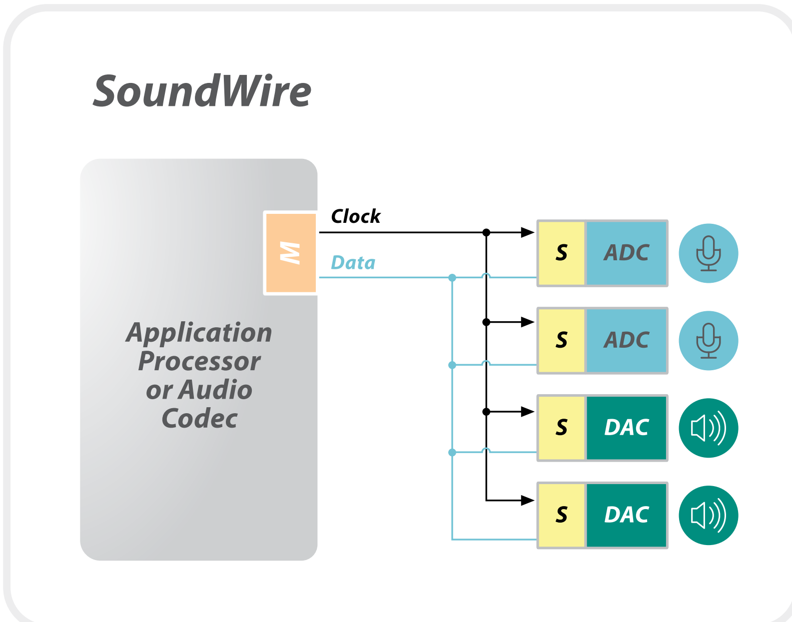



*Figure 16* Example use of the MIPI SoundWire interface

Key points of note with the present version of MIPI SoundWire:

- Provides a "single-master," low-cost, digital audio interface that can support up to 11 slave devices (microphones, speakers and codecs)
- Has a double-data rate mode (up to 24.576 Mbps), configurable frame size, optional multilane extensions, PCM and PDM formats, multichannel data and a low gate count
- Audio components connected using a common two-wire CMOS-based physical interface with embedded command and control, negating the need for additional interfaces
- Audio channels synchronized to a sub-nanosecond level and latency is sub-millisecond, enabling advanced audio features such as noise cancellation and beam steering
- Supports both smart and non-smart audio slave devices
- Supports in-band signaling, clock-stop and interrupt features for smart audio components—enabling power-saving modes (e.g., wake on keyword) for ultra-low power applications
- Supports a "bulk data" mode for the software update of smart audio components
- The software component, MIPI DisCo Specification for SoundWire v1.0, is publicly available

The future release of the MIPI SoundWire specification, SoundWire I3S (SWI3S℠), will introduce a new physical interface that is based on Low Voltage Differential Signaling (LVDS). This new encoding mechanism will:

- Enable faster data rates (up to 76.6 Mbps) with lower voltage swings, creating less EMI and reducing interference with other sensitive components
- Improve noise immunity with lower cross coupling, reducing the need for physical EMI shielding within devices and enabling ever-smaller, more tightly packaged IoT devices (e.g., smart earbuds, smartwatches, etc.)
- Enable longer line lengths in excess of 1m, compared with the current 30-50cm limit

## A.2.7. UniPro: For Inter-Processor Communications and Universal Flash Storage

**IN BRIEF**

*MIPI UniPro is a versatile, application-agnostic, transport layer used as an interface for chip-to-chip communications and IPC. The JEDEC organization uses UniPro to provide the interconnection layer for UFS.*

MIPI UniPro is a versatile transport layer that is used to interconnect chipsets and major subsystem components. It is implemented on the MIPI M-PHY physical layer, is application-agnostic and can be used as a standalone interface for chip-to-chip and inter-processor communications.

MIPI UniPro can be implemented on as few as four wires and can deliver data rates of up to 11.6 Gbps per lane (increasing to 23.3 Gbps in the next release of the specification). It provides quality of service (QoS) features, such as dynamic link updates and link training, to ensure components interconnected with the technology operate as intended at higher data speeds.

The **JEDEC** organization uses MIPI UniPro to provide the interconnection layer for UFS components that are deployed in virtually all types of smartphones today.

Key attributes of MIPI UniPro:

- Primary role in enabling the JEDEC UFS standard
- Suitability for applications within IoT devices where a high-speed logical link layer is required to link two subsystems (for example, an IoT cellular modem to an application processor)
- Provides an application-agnostic serial line logical link layer, enabling high-speed data transmission, low power consumption and low complexity
- Provides data integrity (QoS) and dynamic data speeds based on the application's data demands, maximizing power efficiency
- Augmented with a conformance test suite with test tools widely available

## A.3. Radio Front-End Control

Connectivity to enable communication with peers and back-end service platforms is an essential part of any IoT device. For the vast majority of IoT devices, this connectivity will be enabled using a wide-area (e.g., cellular), local-area (e.g., Wi-Fi, Zigbee or Z-Wave) or personal-area (e.g., Bluetooth) radio communication technology. The successful integration of a communications technology into a design is a critical part of any wireless IoT device, and developers usually are faced with two choices:

1) To enable connectivity by integrating a general-purpose radio communication module into the IoT device design. These modules contain all the components required to enable wireless communication, such as the RF front-end components (e.g., power amplifier, switches and tuners), radio transceiver and radio baseband, in one package.

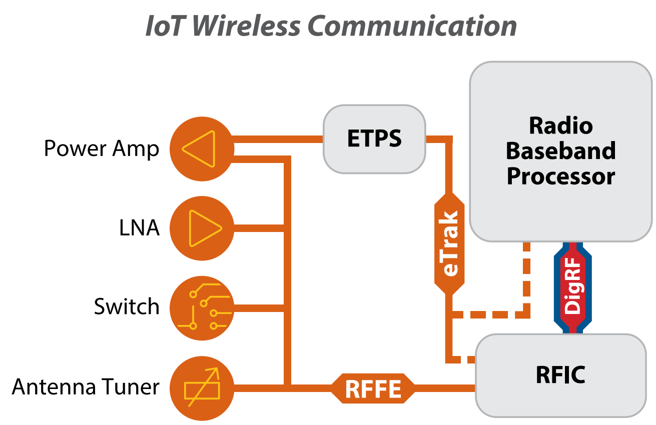


*Figure 17* Use of MIPI specifications in IoT wireless communication modules

2) To develop a fully integrated wireless connectivity solution and implement a bespoke radio subsystem using their own choice of components. This approach, which is followed by smartphone developers, requires significantly more developer resources, but results in a more tightly packaged IoT device—with potential power, size and weight advantages.

To help developers who have chosen the second approach and are looking to develop a bespoke radio communication subsystem for their IoT devices, MIPI has developed its RFFE, eTrak and DigRF interface specifications as shown in Figure 17.

### A.3.1. MIPI RFFE

**IN BRIEF**

*MIPI RFFE is a control interface that enables RFICs to control RF front-end components such as power amplifiers, low-noise amplifiers, filters, RF switches and antenna tuners.*

MIPI RFFE defines a control interface, based on a CMOS physical layer, to control RF front-end components such as power amplifiers, low-noise amplifiers, filters, RF switches and antenna tuners. RFFE is a technology-agnostic interface and can be used to enable all types of radio communication technologies including all wide area cellular technologies (e.g., 5G, 4G, etc.) and local area wireless technologies (e.g., Wi-Fi, Zigbee, Z-Wave, etc.)

RFFE is presently the de facto choice of RF front-end control interfaces within the cellular radio subsystems used within smartphones and is regularly updated by MIPI to support new use cases and market requirements—such as v3.0, which was introduced to support the next generation of 5G radio technologies and beyond.

### A.3.2. MIPI DigRF

MIPI DigRF is a high-speed interface that is used to interconnect 3G/4G cellular RFICs to radio baseband processors. Using the MIPI M-PHY physical layer, DigRF is enabled using a single link between the baseband and RFIC.

### A.3.3. MIPI ETrak: Envelope Tracking Interface

The MIPI Envelope Tracking Interface provides a point-to-point interface between a radio transmitter and an envelope tracking power supply (ETPS). Envelope tracking is used to reduce power consumption of the RF power amplifier, improving the overall power efficiency of the radio.

## A.4. Debug and Trace Specifications

**IN BRIEF**

***MIPI Alliance's suite of debug and trace interfaces are used to debug application processors, device controllers, power management devices and other components. The specifications are publicly available and have been widely implemented by the test-tool vendor community.***

The provision of high-quality, standardized debug and trace interfaces is key to helping developers simplify and accelerate their IoT device developments. MIPI Alliance has a suite of debug interfaces that can be used to debug application processors, device controllers, power management devices and other components:

The key attributes of the MIPI Debug and Test specifications include:

- **MIPI Gigabit Debug for IP Sockets (MIPI GbD IPS℠):** An adapter for debugging any remote device that is smart and connected
- **MIPI Gigabit Debug for USB (MIPI GbD USB℠):** A technology for using MIPI debug protocols over USB Debug Device Class
- **MIPI High-Speed Trace Interface (MIPI HTI℠):** A technique for exporting trace data over high-speed serial links
- **MIPI Narrow Interface for Debug and Test (MIPI NIDnT℠):** Using available ports on a device for end-product testing
- **MIPI Parallel Trace Interface (MIPI PTI℠):** A parallel trace interface with multiple data signals and a clock
- **MIPI SneakPeek Protocol (MIPI SPP℠):** A network-independent approach for debugging terminal hardware and software
- **MIPI System Software - Trace (MIPI SyS-T℠):** A universal data format for transmitting software trace and debug information between a test system and a device
- **MIPI System Trace Protocol (MIPI STP℠):** A base protocol for application-specific trace functions
- **MIPI Trace Wrapper Protocol (MIPI TWP℠):** Gathers data about system functionality and behavior for analysis

The specifications are publicly available and have been broadly implemented by the test-tool vendor community, resulting in widely available tools that can be used time and time again for different design projects.

Key attributes of MIPI debug and test specifications:

- Publicly available, allowing developers to create their own debug tools, use open-source tools or purchase ready-made tools from the test-tool vendor community
- Agnostic of the underlying transport protocol, which could be Wi-Fi, Ethernet, USB, MIPI I3C, etc. (debug bridging allows debug data to hop between different internal interfaces)
- Allow reuse of the same debug tools when designing different types of devices, be it a smartphone or IoT device, enabling developers to maximize investment in debug toolsets

MIPI Alliance recognizes that security presents a challenge for debug interfaces, with most developers following security best practices and permanently disabling any debug interfaces in their commercially deployed products to avoid misuse of the interfaces. MIPI is looking to address this specific issue in future releases of its specifications, introducing capabilities such as mutual authentication, data integrity and confidentiality between devices and their debug toolsets. This will enhance the use of remote debug with the aim of creating a solution that would allow "zero touch" in-field debug of remote IoT devices, a capability that would particularly benefit devices with long lifecycles and those that require frequent software updates.

## A.5. Software Integration Specifications

**IN BRIEF**

***MIPI Alliance provides a suite of software resources to streamline the integration of MIPI protocols. MIPI DisCo specifications, which are already integrated into many freely available Linux kernels, include a base architectural framework and a portfolio of interface-specific specifications that unify the software discovery and configuration of many MIPI protocols. MIPI I3C HCI provides an open source implementation of a I3C master controller for use in SoC designs.***

MIPI Alliance has developed software resources to help streamline the integration of MIPI interfaces. The MIPI DisCo discovery and configuration specifications include a base architectural framework and a portfolio of interface-specific specifications that unify the software discovery and configuration of many MIPI protocols described earlier in this section. This framework is already embedded into many freely available, open-source Linux kernels.

These resources enable developers to use a common software approach when implementing drivers to discover and manage different classes of components and components from different vendors. The approach not only simplifies the integration of the components, but also reduces development costs.

MIPI Alliance has made these specifications publicly available to promote development and availability of open source software:

- **MIPI Discovery and Configuration (DisCo) Specification:** The base specification, providing an architecture for discovering and enumerating devices on a system
- **MIPI DisCo for I3C℠:** Simplifies software integration of sensors that use MIPI I3C
- **MIPI DisCo for NIDnT℠ (Narrow Interface for Debug and Test):** Enables system software to enumerate and discover MIPI NIDnT debug and trace systems
- **MIPI DisCo for SoundWire℠:** Enables developers to easily discover and use MIPI SoundWire drivers
- **MIPI DisCo for CSI-2℠ (coming soon):** Simplifies software integration of cameras and sensors that use MIPI CSI-2

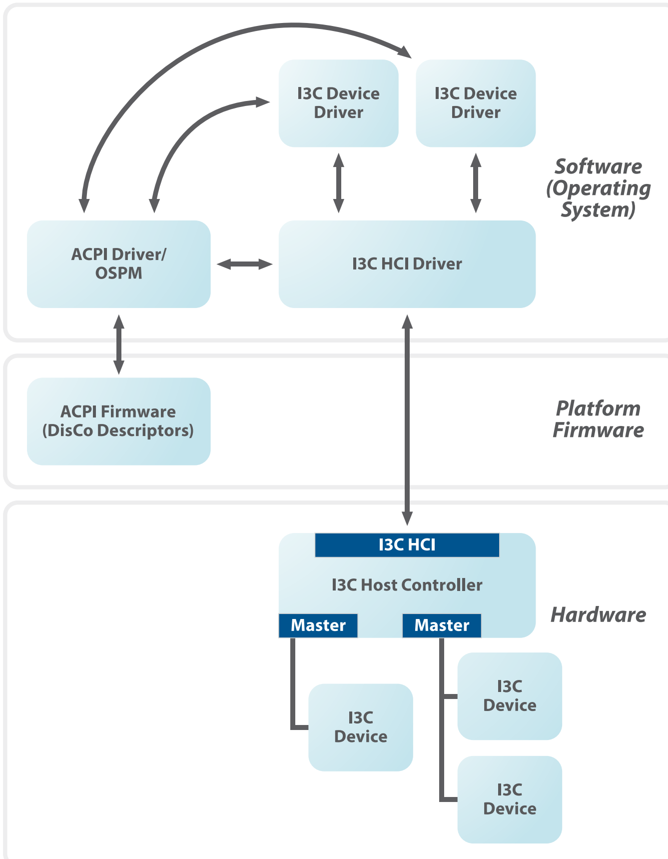



*Figure 18* Example of MIPI DisCo for I3C and MIPI I3C Host Controller Interface

Key attributes of the MIPI DisCo specifications:

- Applicable for use in IoT devices based on most flavors of fully-featured, embedded Linux kernels and other embedded operating systems (e.g., Windows IoT, Android Things, etc.)
- Utilize the Advanced Configuration and Power Interface (ACPI) standard that is already supported by many embedded operating systems
- Provide ACPI Device Descriptor Object extensions that can be used by a device operating system (OS) to simplify the discovery and configuration of MIPI SoundWire, NIDnT, I3C and (soon-to-be-released) CSI-2 components within the device.

Other MIPI software specifications include the MIPI I3C HCI, designed to speed sensor integration. The specification provides an open source implementation of an I3C master controller for IoT developers looking to develop bespoke SoC designs.

Other software currently in development include a MIPI I3C HCI Linux driver, a set of DisCo tools and a CCS toolset designed to ease integration of CSI-2.

## A.6. Other MIPI Specifications Relevant To IoT Devices

This section provides a brief overview of other MIPI specifications that may aid the design of IoT devices.

## A.6.1. MIPI VGI: Enabling Virtual GPIOs (In Development)

**IN BRIEF**

*MIPI VGI, which is currently in development, replaces physical GPIOs with virtual GPIOs based on a two- or three-wire interface. The interface significantly reduces the number of physical I/O pins required on both application processors and peripheral components.*

The aim of MIPI VGI, which is currently in development, is to replace multiple physical sideband GPIOs with virtual GPIOs based on a two-wire (asynchronous) or three-wire (full duplex synchronous) CMOS interface. The VGI architecture framework allows consolidation of low speed serial interfaces over the VGI interconnection.

The initial release of VGI is geared toward multiple sideband GPIOs and 1x HS-UART and aims to significantly reduce the number of physical I/O pins required on both application processors and peripheral components—reducing the number of associated wires and connectors between these components.

Use of MIPI VGI is likely to be key to many novel IoT use cases where the need for more optimized and tighter packaging of the electronic components within the device is essential to enable the intended use case at optimal cost. GPIO pin reduction is also especially important with the introduction of smaller silicon die sizes that are accelerating the availability of smaller chip packages and reduction in available real estate to accommodate the current large number of physical I/O pins.

MIPI VGI is architecturally simple, and the physical interface implementation could be done using similar I/O pads as used for general interfaces such as UART, I2C and MIPI I3C. In the low-speed IoT space, MIPI VGI could be used for the main interface between the baseband and modem processor to accommodate all sideband and data transmission needs.

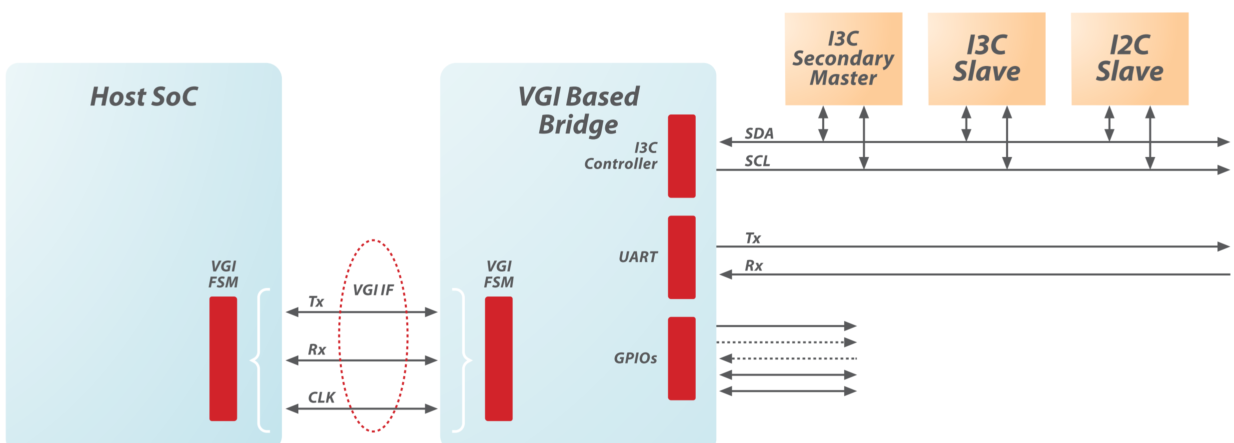



*Figure 19* Example use of MIPI VGI interface forming a bridge to GPIOs, UART and MIPI I3C interfaces

VGI could be also used for generic low-speed interfaces and sideband GPIO consolidation, with the number of interface instances being implementation-specific.

The initial VGI release will consolidate one UART and multiple GPIOs. Future VGI releases will have the option to consolidate I3C, in addition to UART and GPIOs.

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## Lead Author:

**Ian Smith**
*MIPI Alliance*

## MIPI IoT Interest Group Members:

**Karthik Gopalakrishnan**

**Michele Scarlatella**

**Wayne Ballantyne**

**Kevin Yee**
*Marketing Steering Group Chair*

## MIPI Working Group and Subgroup Leaders:

**Dale Stolitzka**
*Display Working Group*

**Enrico Carrieri**
*Debug Working Group*

**George Wiley**
*C-PHY Subgroup*

**Haran Thanigasalam**
*Camera Working Group*

**Henrik Icking**
*PHY Working Group*

**James Goel**
*Display Working Group*
*Technical Steering Group Chair*

**Jim Ross**
*RFFE Working Group*

**Kenneth Foust**
*I3C Working Group*

**Kirill Dimitrov**
*M-PHY Subgroup*

**Lalan Mishra**
*RIO Working Group*

**Lior Amarilio**
*Audio Working Group*

**Philip Hawkes**
*Security Investigation Group*

**Raj Kumar Nagpal**
*A-PHY Subgroup*
*D-PHY Subgroup*

**Ramesh Hanchinal**
*UniPro Working Group*

**Rick Wietfeldt**
*Security Investigation Group*

**Rob Gough**
*Software Working Group*

**Tim McKee**
*I3C Working Group*

*About*

mipi alliance

Founded in 2003, MIPI Alliance is a collaborative global organization serving industries that develop mobile devices and other types of mobile-influenced connected devices (e.g., IoT devices). It initially focused on specification development for camera, display and modem connectivity, but since then has introduced roughly 50 specifications for a range of other essential needs, including those for connecting application processors to modems, audio, storage, sensors, antennas, antenna tuners, power amplifiers, filters, switches, batteries and other elements. These standardized specifications have helped to facilitate interoperability among component suppliers, simplify device designs (hence, reducing cost) and optimize performance and power, while allowing manufacturers to focus on product differentiation and reduce their time to market.

Today all major chip and component vendors use MIPI Alliance specifications, with every smartphone on the market using at least one MIPI specification. MIPI specifications can also be found in an ever-broadening array of devices, going well beyond mobile handsets into wearables, medical devices, drones, industrial equipment and vehicles. The organization itself has more than 330 member companies that reflect the breadth of the mobile and mobile-influenced ecosystem, including device manufacturers, semiconductor companies, silicon IP provider companies, test equipment companies, camera and display module providers, sensor providers, automotive OEMs and Tier 1 suppliers, as well as organizations that are developing IoT solutions.

Organizations interested in joining MIPI Alliance can visit the “Join MIPI” section on the **MIPI website** to learn more.

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