



# Adoption of PCIe® Technology in IoT Applications

PCI-SIG® Webinar Series

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# Meet the Speakers



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# Agenda



- Introduction to IoT segments
- Introduction to PCI-SIG® and PCI Express® Technology
- PCIe Technology in Edge Computing
- PCIe Technology in Test Equipment
- PCIe Technology in Industrial and Embedded PCs
- PCIe Technology in Automotive
- Conclusions and Call to Action





# IOT: TRANSFORMING THE WAY WE LIVE AND WORK





# ADDRESSES THE NEEDS OF VERTICAL MARKETS

Retail



Manufacturing



Smart Cities



Energy and Utilities



Transportation



Public Sector



Education



Hospitality



Health and Life Sciences



Automotive



Banking



Gaming/Entertainment





# IOT IS AT THE CENTER OF OUR CHANGING WORLD

**200%**

growth of information-based products and services by 2020 compared with traditional products and services<sup>1</sup>

**79.4**

Zettabytes (ZB) of data in 2025 generated by 41.6 billion connected IoT devices or things<sup>2</sup>

**62%**

of developers deem IoT "very important" to digital strategies<sup>1</sup>

**>55%**

percentage of all data forecast to be generated by IoT in 2025<sup>3</sup>

**50%**

of data will be created and processed outside the data center or cloud by 2022<sup>4</sup>

**43%**

share of AI tasks taking place on edge devices (vs. cloud) in 2023<sup>5</sup>

**>USD 300B**

annual B2B IoT revenue by 2020<sup>6</sup>

1. IDC Worldwide Digital Transformation Predictions, November 2015, ([link](#)); 2. IDC Forecast, June 2019, ([link](#)); 3. DataAge 2025, November 2018, ([link](#)); 4. Gartner, December 2018 ([link](#)); 5. ABI Research, May 2018 ([link](#)); 6. Forbes, December 10, 2017 ([link](#))



# BUSINESSES NEED TO MODERNIZE



**70%** of enterprises will run varying levels of data processing at the IoT edge by 2023<sup>1</sup>

**70%** of IoT deployment will include AI solutions for autonomous or edge decision making, supporting organizations' operational and strategic agendas by 2023<sup>1</sup>

**65%** of organizations will aggressively modernize legacy systems with extensive new technology platform investments through 2023<sup>2</sup>

**60%** of organizations will have invested in automation, orchestration, and development life-cycle management of cloud-native applications and platforms by 2022<sup>3</sup>

**50%** of large global enterprises rely on third-party service providers for help with containers, open source, and cloud-native application development by 2024<sup>3</sup>

1. [IDC FutureScape: Worldwide Internet of Things 2020 Predictions](#)
2. [IDC FutureScape: Worldwide Digital Transformation 2020 Predictions](#)
3. [IDC FutureScape: Worldwide Cloud 2020 Predictions](#)

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# PCI-SIG®: An Open Industry Consortium



Organization that **defines the PCI Express® (PCIe®) I/O bus specifications and related form factors**

**800+** member companies located worldwide

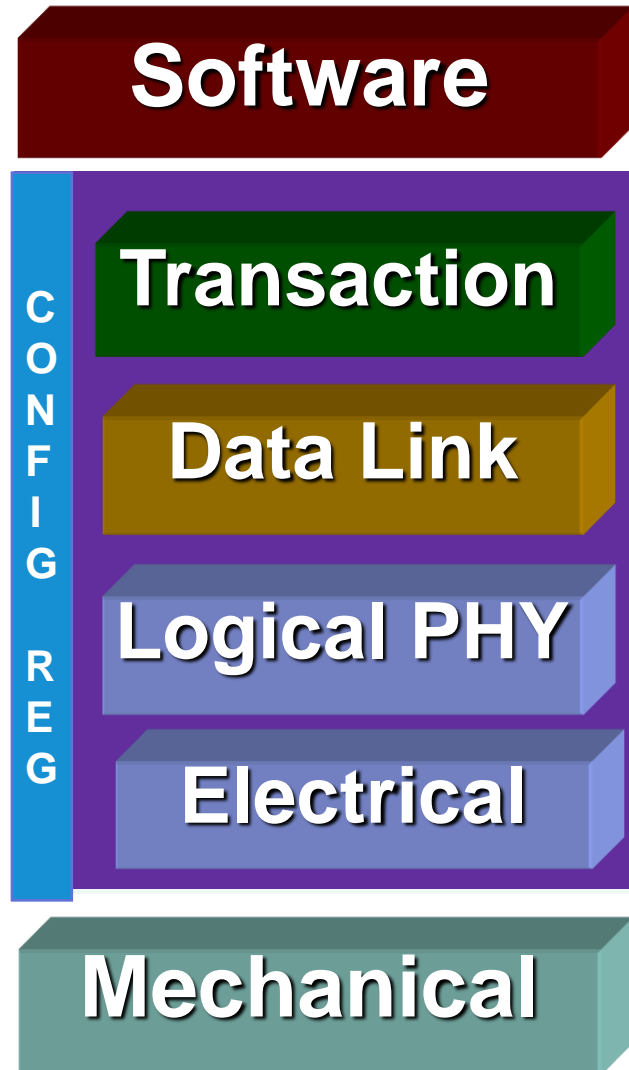
Creating specifications and mechanisms to **support compliance and interoperability**

**PCI-SIG member companies support the following usages with PCIe technology:**

- IoT (Edge, Industrial, Embedded, Automotive)
- Cloud
- Artificial intelligence
- Analytics
- Telecommunications
- Storage
- Consumer
- Mobile
- Data Center



# PCIe® Architecture Layering for Modularity and Reuse



- ⇐ PCI compatibility, configuration, driver model
- ⇐ PCIe architecture enhanced configuration model

- ⇐ Split-transaction, packet-based protocol
- ⇐ Credit-based flow control, virtual channels

- ⇐ Logical connection between devices
- ⇐ Reliable data transport services (CRC, Retry, Ack/Nak)

- ⇐ Physical information exchange
- ⇐ Interface initialization and maintenance

- ⇐ Market segment specific form factors
- ⇐ Evolutionary and revolutionary

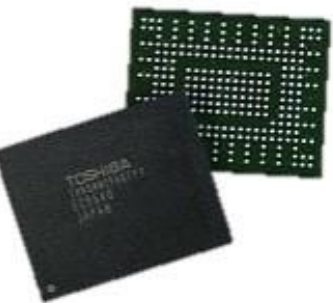
**PCIe technology has a long track record of being implemented in high volume manufacturing products (PCs) that are cost focused and reliable**



# PCIe®: One Base Specification - Multiple Form Factors

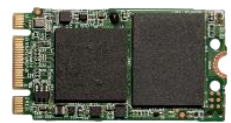


BGA



16x20 mm  
small and thin  
platforms

M.2



Smallest footprint  
(22mm x 30 to 110 mm): SSDs in boot slots, data center storage, WWAN

U.2 2.5in  
(aka SFF-8639)



SSDs x4 or 2 x2 w/ hot-plug

CEM Add-in-card



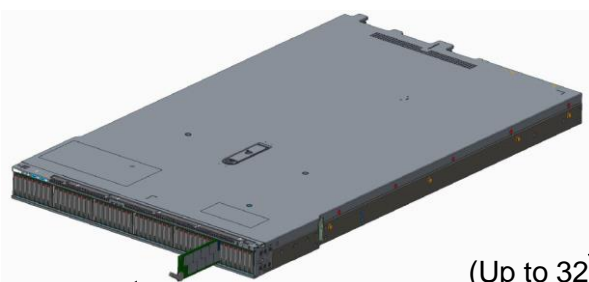
Widely used in systems w/ 4 HL options.  
Higher Power. Robust compliance program



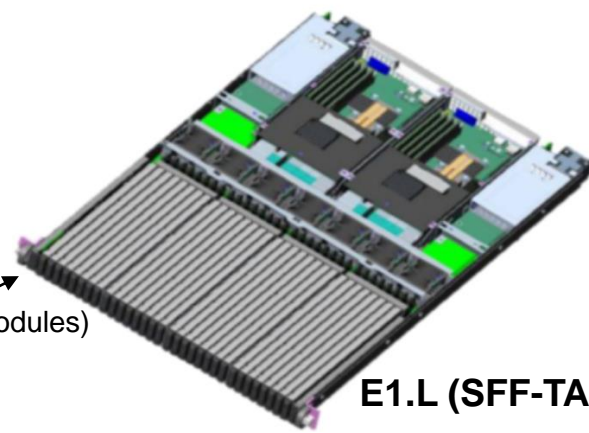
High B/W:  
hand-held, IoT,  
automotive



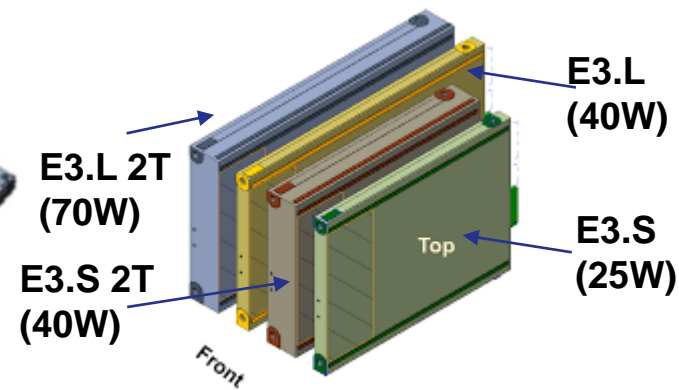
Highend still and  
motion cameras



**E1.S (SFF-TA-1006)**  
(Up to 36 Modules)



**E1.L (SFF-TA-1007,**



**E3 Form factors**

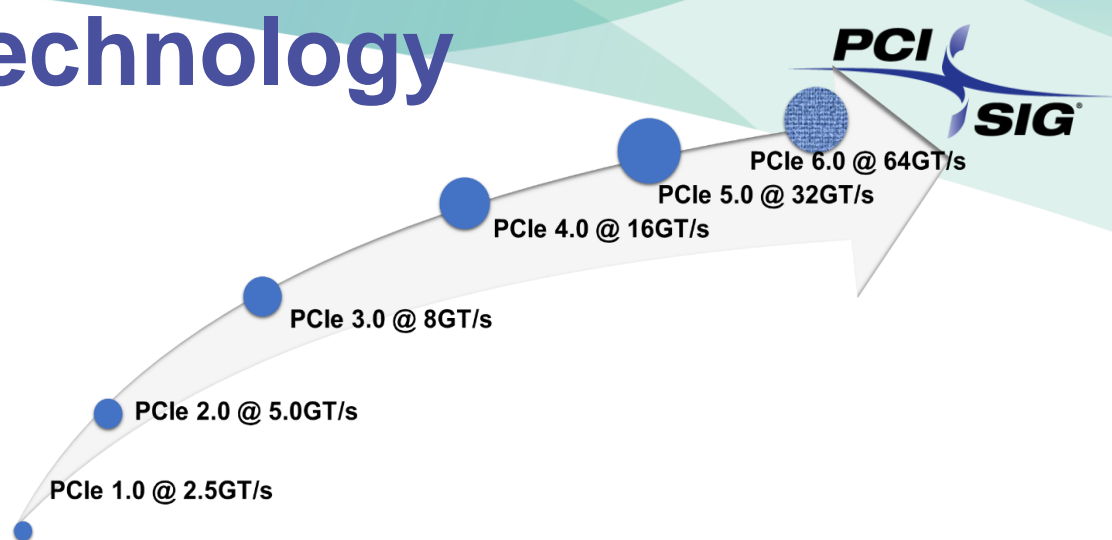
Various  
Proprietary  
FFs for HPC  
Applications  
Multi-KW cards

Enterprise and Datacenter **S**mall **F**orm **F**actor (EDSFF) family was designed for Enterprise and Datacenter applications and widely used for SSDs

Multiple Form factors from the same silicon to meet the needs of different segments

# Evolution of PCI Express® Technology

- PCIe technology doubles the data rate every generation with full backward compatibility every 3 years
- Continuous protocol enhancements
- Ubiquitous I/O across the compute continuum: PC, Hand-held, Workstation, Server, Cloud, Enterprise, HPC, Embedded, IoT, Automotive, AI
- One stack / same silicon across all segments with different form factors, widths (x1/ x2/ x4/ x8/ x16) and data rates: e.g., a x16 Gen 5 interoperates with a x1 Gen 1!



PCIe Specification	Data Rate(Gb/s) (Encoding)	x16 B/W per dirn**	Year
1.0	2.5 (8b/10b)	32 Gb/s	2003
2.0	5.0 (8b/10b)	64 Gb/s	2007
3.0	8.0 (128b/130b)	126 Gb/s	2010
4.0	16.0 (128b/130b)	252 Gb/s	2017
5.0	32.0 (128b/130b)	504 Gb/s	2019
6.0 <u>(WIP)</u>	64.0 (PAM-4, Flit)	1024 Gb/s (~1Tb/s)	2021*

\* - Projected \*\* - bandwidth after encoding overhead

PCIe continues to deliver bandwidth doubling for six generations spanning 2 decades! An impressive run!

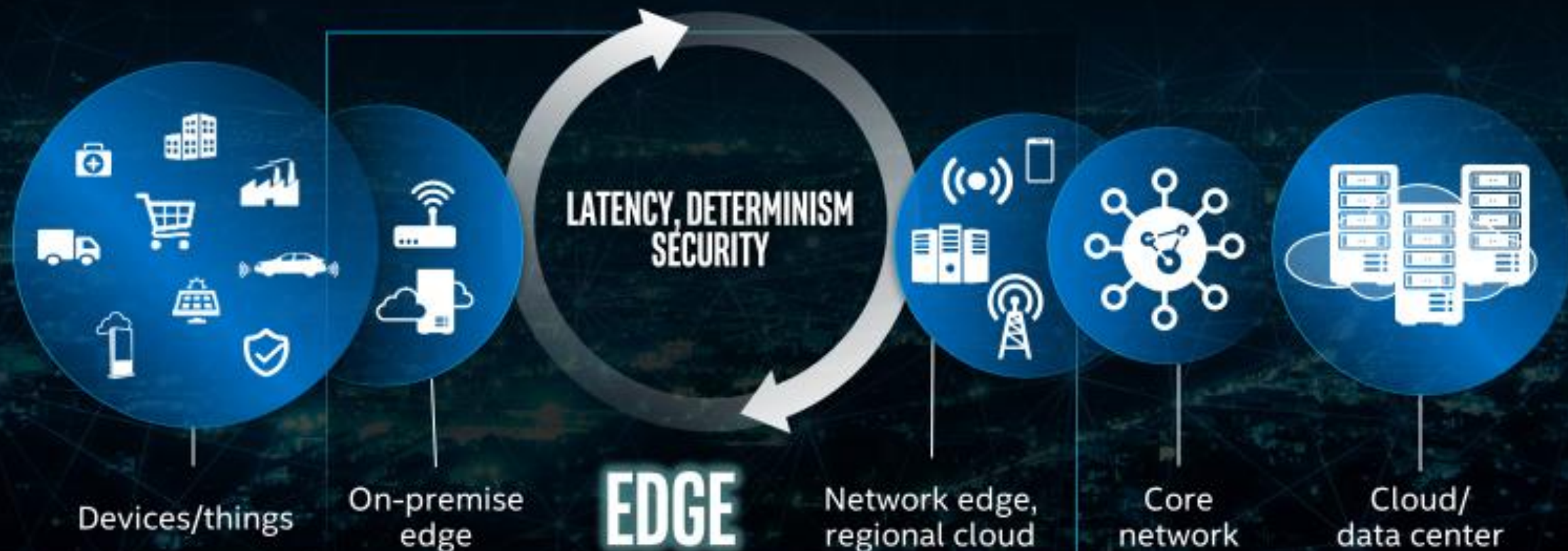


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# END TO END IOT SYSTEM ELEMENTS

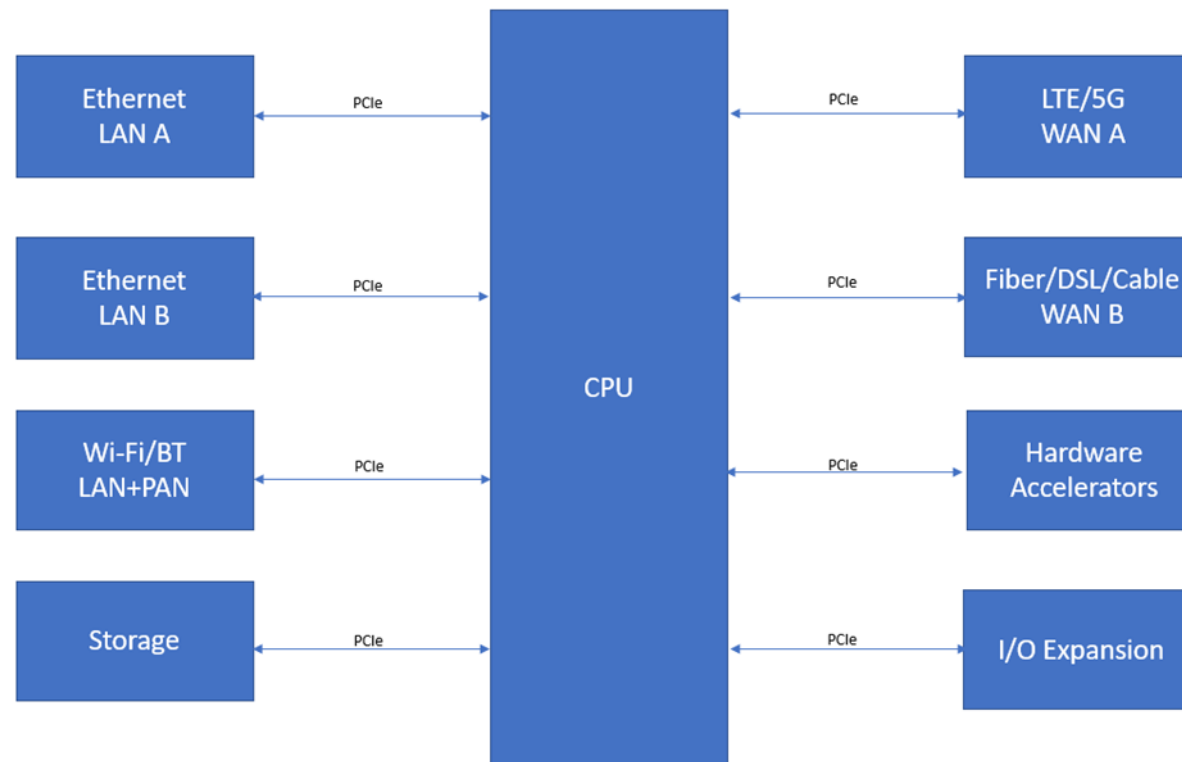


Connectivity and AI are major accelerants for IoT



# Edge Computing: Basic Approach

- Evolution and extension of cloud computing
  - Environment ripe for new applications, services, and overall business model innovation
- Data placement optimization: place data closer to source of data or point of service delivery
  - Faster decision making with stringent quality of service expectations
- PCIe is the interconnect of choice



Representative Edge Gateway Architecture

# Key Performance Metrics on Edge: How PCIe® Helps

Key Metrics	Usage Model	How PCIe helps
Latency and Determinism	Factory Automation, Robotics, industrial process control systems, video surveillance and security, immersive media applications, autonomous vehicles, content delivery	Load-store low-latency PCIe I/O with guaranteed delivery is needed for meeting the sub-ms to tens of ms end-to-end latency and deterministic deadline based response
Bandwidth	80+% IP traffic will be video content; End users and service providers need to process video data at the edge to reduce jitter, improve video quality and create revenue from content delivery networks, cloud gaming, video analytics (retail / smart city)	PCIe is the high bandwidth and low-latency conduit for multiple processing and data capture entities through the load-store DMA model while providing network connectivity
Data Locality/Regulatory Compliance	<ul style="list-style-type: none"> <li>- Fail-over through multiple network connectivity (e.g., wire Wan and fail-over with LTE/5G)</li> <li>- Ability to gather data from multiple sources (e.g., Bluetooth, scanner, wireless, camera)</li> <li>- High-performance Storage</li> </ul>	<ul style="list-style-type: none"> <li>- PCIe is the common glue across multiple interfaces</li> <li>- NVMe over PCIe meets the need for high-performance storage with virtualization and parallelization (e.g., 64K I/O queues, each with 64K I/O Ops) replacing SCSI/ DAS</li> <li>- Access to a wide ecosystem for a wide variety of compute, I/O devices, bridges to PCIe</li> </ul>
Acceleration Services	<ul style="list-style-type: none"> <li>- Deploy AI, ML, and DL for faster data processing</li> <li>- Vision processing Units to offload vision workload</li> </ul>	<ul style="list-style-type: none"> <li>- Wide range of high-performance accelerators on PCIe – Plug-and-Play with Load-Store access</li> </ul>



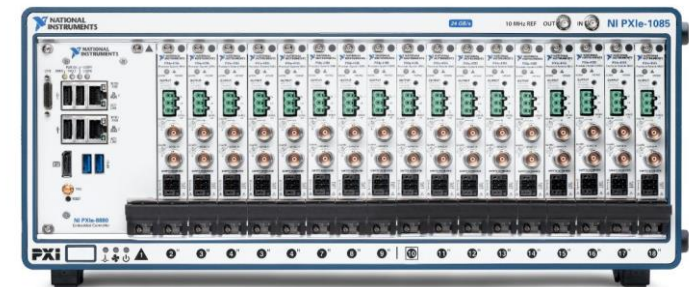
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# PCIe® Technology in Test Equipment

- Data acquisition: measure electrical (voltage, current) and physical phenomenon (temp, pressure, sound)
- PCI eXtensions for Instrumentation (PXI) systems widely used in Test Equipment
  - High-performance modular instruments and other I/O modules that feature specialized timing and synchronization for test and measurement applications
  - Uses commercial PC-based PCI Express technology while combining rugged modular packaging
  - Helps meet requirements for timing, synchronization, and throughput across High-channel-count test applications with desired measurement accuracy
- Performance challenges around I/O sampling rates, throughput, and latency can be met with PCIe and the evolution it brings to the ecosystem



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# Industrial and Embedded PCs (IPCs)

- Rugged PCs expected to operate 24x7 in harsh environments (mining, agriculture, energy distribution, plant automation, process automation) – key to 4<sup>th</sup> industrial revolution
- Examples: Supervisory Control and Data Acquisition Systems (SCADA) and Manufacturing Execution Systems (MES)
- Trend: From purpose-built hardware to commercial PC
  - Open PC architecture, hardware and software ecosystem
  - Deploy advanced video and AI technologies
  - High reliability, more data storage, more compute



(Workload Consolidation based on IPCs)

- Use of PCIe interconnect:
  - PC I/O for storage, networking, accelerator attach, even as a bridge to existing purpose-built legacy hardware with software infrastructure
  - Virtualization support for workload consolidation (IO Virtualization)
  - Precision Time Measurement (PTM) support with accurate timestamps for accurate analysis and actions, even in safety-critical apps
  - Support for Real-time OS (RTOS)
- Form Factors:
  - PCI Industrial Computer Manufacturers Group (PICMG) by Com Express, SFF, M.2
  - Low-power and fan-less designs in space-constrained environment, industrial panel-mounted PCs on surfaces or fastened to walls on cabinets, in closets
- Benefits of IPC:
  - Reduced CapEx and Opex – economies of scale
  - Regulatory compliance (e.g., FCC certification)
  - Increased efficiency with simplification of operations
  - Greater customization, reliability, scalability, longer product life cycle

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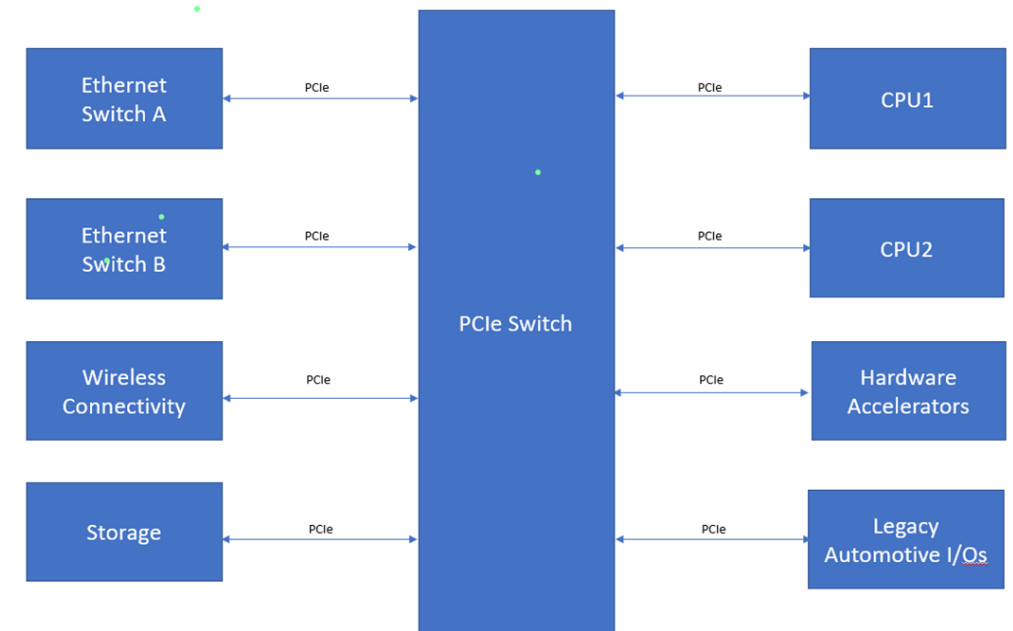
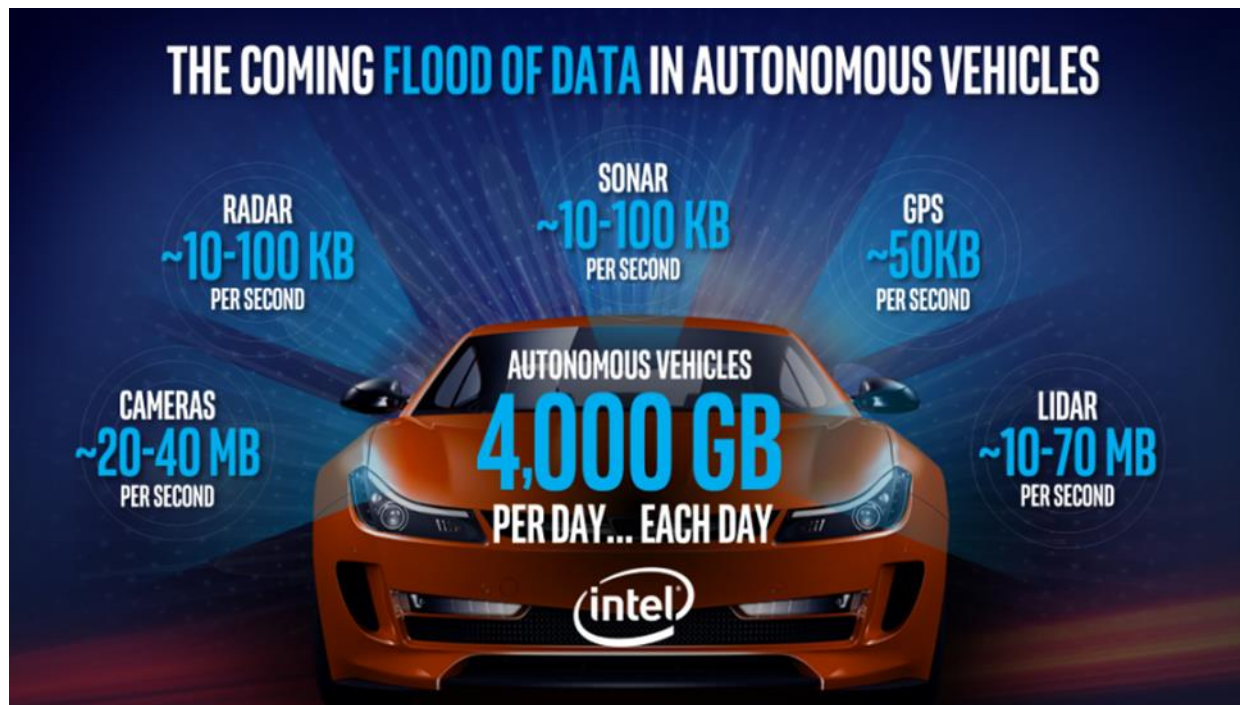


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# PCI<sup>®</sup> Technology in Automotive

- Several webinars have already covered this
- Automotive today is 'data center on wheels' with in-vehicle infotainment systems, advanced driver assistance systems (ADAS), vehicle to vehicle / vehicle to infrastructure (V2X) connectivity
- Multi-socket CPUs connected to GPUs, Wi-Fi, V2X modules, LTE/ 5G, vision accelerators, AI accelerators, ethernet NICs, FPGAs using PCIe



(High Performance Automotive Compute Architecture)

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# Conclusions and Call to Action



Bandwidth scaling from Data Rate	Data Rate doubles each generation in a cost-effective fashion within a constant latency and power profile with full backward compatibility
Bandwidth scaling with Link Width	Flexible link width allows scalability x1, x2, x4, x8, x16 options
Bandwidth Efficiency	Less protocol overhead resulting in up to 95% Link efficiency with large payload packets
Low Latency	Access latency in the 100ns-500ns range
Determinism	PTM for accurate timestamping
Reliability	Guaranteed reliable transport on hardware level with measured FIT (Failure in Time, which is number of failures in $10^9$ hours) practically 0 (less than $10^{-8}$ )
Direct Memory Access (DMA) Addressing	Built-in DMA without packetization
	Allows processors to access shared memory efficiently
Functional Safety	Robust CRC, Link level replay, and advanced error reporting built into Transaction and Application Layers
	Message Counter
Breadth of Technology Ecosystem	Very popular in Data Center and Computing industries
	Widely available software base and developers
	Off the shelf IP blocks, components and modules for computing and connectivity lowering cost and adding flexibility
Multiple supported interfaces/bridge chips	Ethernet TSN, MIPI, HDMI, CXL, eDP, Thunderbolt, USB, CAN and other legacy interfaces

- Benefits of PCIe® technology for IoT: huge ecosystem of available devices (AI, ML, networking, storage, wireless, etc.) with plug and play
- Ease of transition from IT world to IoT applications with PCIe
  - Off-the shelf form factor
  - Modular components
  - Debug tools
  - Developers familiar with the PC world
- Combined innovation capability of 800+ members with a track record of delivering flawlessly
- PCIe technology has a long track record of being implemented in high volume manufacturing products (PCs) that are cost focused and reliable
- Consider joining PCI-SIG® if you have not done so; be a part of this exciting journey!

(Key PCIe attributes driving optimal solutions in IoT space)



# Q&A

**Thank you for attending the PCI-SIG® webinar series.**

**More information on this topic can be found in the recently published contributed article in [Electronic Design](#).**

**Information about upcoming webinars will be available soon.**

**For more information, please visit [www.pcisig.com](http://www.pcisig.com)**