Q3'24 Update
Document number: 831868

Real-time at the Edge Gold Deck (public version[1])

Time Coordinated Computing

intel®

[1] An enhanced version of this Gold Deck with additional information regarding Intel's Real-Time offering is available for customers under NDA at RDC #627170

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- Performance results are based on testing as of dates shown in configurations and may not reflect all publicly available updates. See backup for configuration details. No product or component can be absolutely secure.
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- Results have been estimated or simulated.
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- Market factors driving a transformation towards a SW defined world and the role real-time plays
- Time Coordinated Computing
  - Software defined real-time usages
- Intel's solution for Time Coordinated Computing (TCC)
- IEEE* Time Sensitive Networking (TSN)
- NEX products supporting Time Coordinated Computing
- Supplemental information

Real-time Taxonomy, Challenges and Opportunities

Drivers for the Industrial Transformation

Market Factors

Custom products
Green mfg

The Human Element

Changing workforce
Changing nature of human work

Security

Cyberattacks on rise
Networked enterprise systems

Disruption

Geopolitics
Pandemic

Drivers for transformation in Audio-Video (AV)

Including digital signage, broadcast, and professional AV

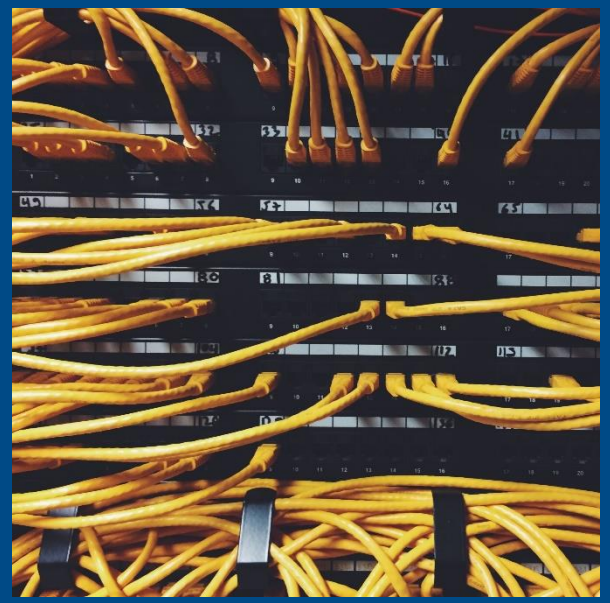
Connectivity at scale

Venues increase in scale and complexity

Cabling cost

AV/IT convergence

Security of systems



Flexibility and reuse of space

Live venues used for multiple diverse applications

Office space and conference rooms must be multifunction

“Broadcast” from anywhere

Global disruption

Supply chain

Pandemic changes to public spaces and offices

Office space and conference rooms must be multifunction

“Broadcast” from anywhere

Common themes from transformation across markets

Shift to portable, software defined workloads

Shift to secure, converged networks

Common themes from transformation across markets

Shift to portable, software defined workloads

Shift to secure, converged networks

These trends are not new. Intel has been leading these transformations in IT and datacenter

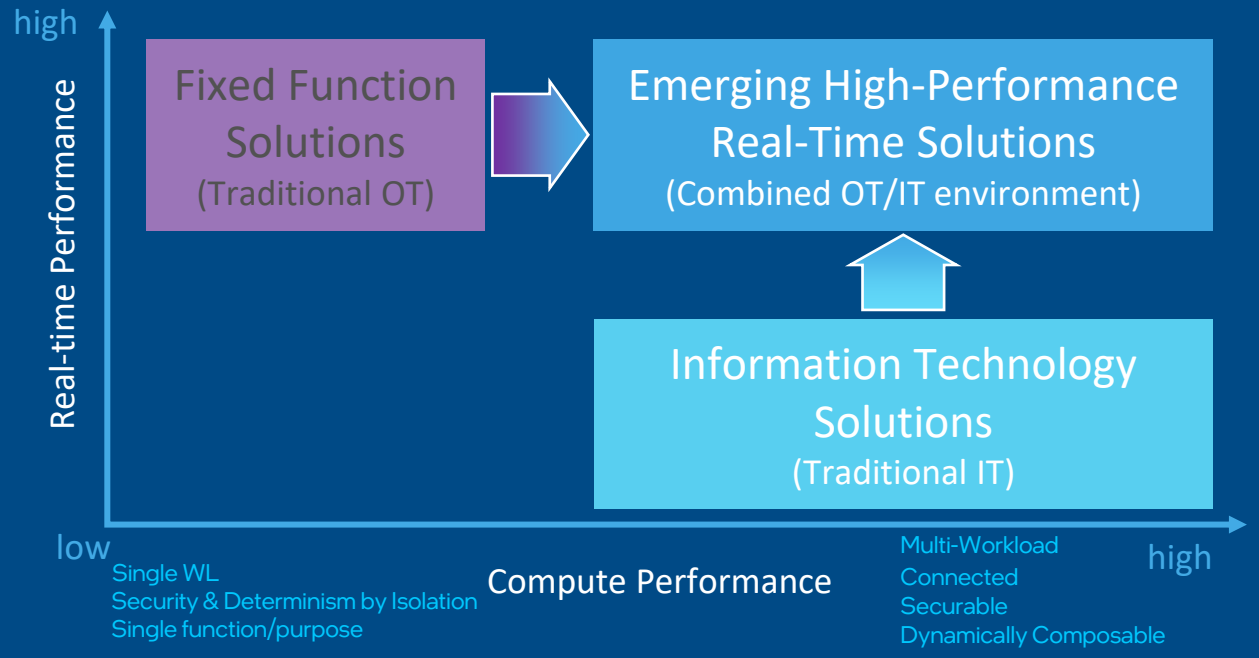
IOT EDGE

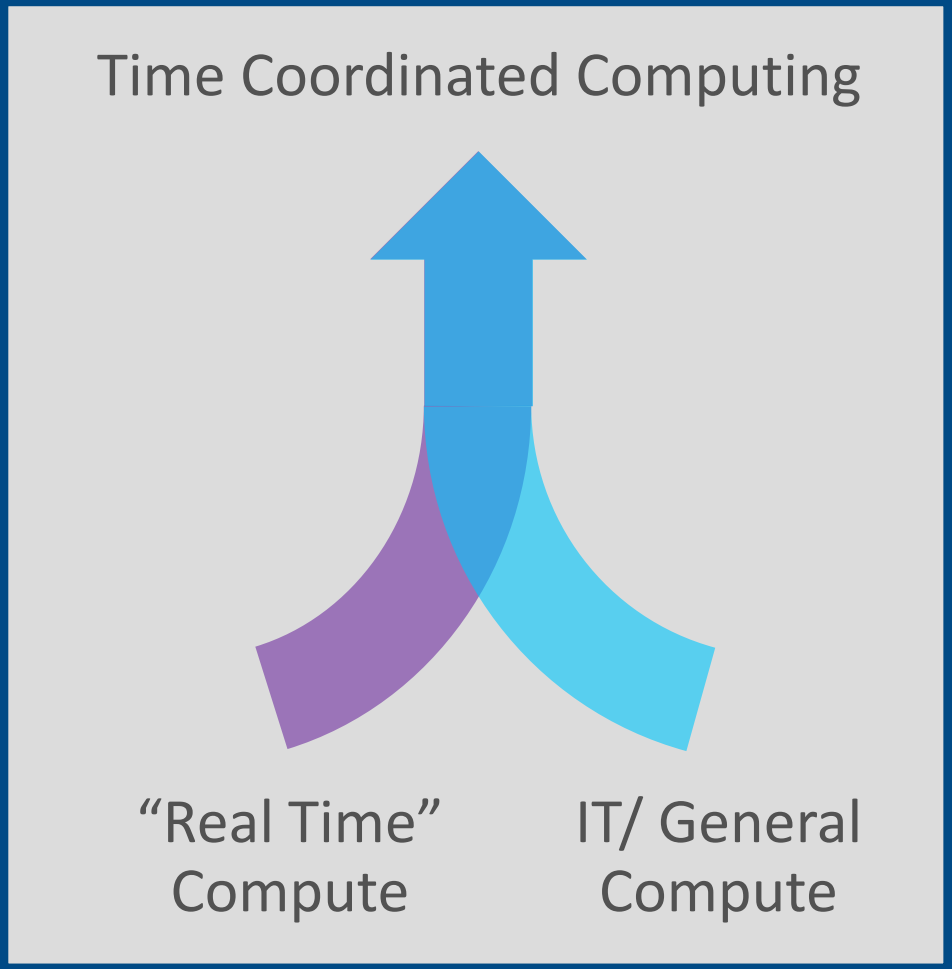
At the EDGE, many applications are *cyber-physical systems, for which precise time coordination is an essential performance requirement*

"Cyber-physical systems integrate sensing, computation, control and networking into physical objects and infrastructure, connecting them to the Internet and to each other" – NSF https://www.nsf.gov/news/special_reports/cyber-physical/

Delivering towards a transformation happening across markets – a transformation requiring new approaches

- Not "Time Performance"…but "Performance with Time"
- Make use of 'off the shelf' SW, FW, HW
- Intel Architecture is optimized for Time Coordinated Computing





Software defined usages with real-time

Customer Pain Points at the Industrial Edge

- Lack of interoperability and portability of HW, SW, IP
- Fixed function, Proprietary Devices
- Inflexible, hard to upgrade systems
- Factory Downtime due to HW/SW Updates
- Costly, HW-based Redundancy
- High learning curve for legacy systems (for example, PLCs)

Customer Needs: Increased Flexibility, Lower Costs

Increased System Scalability

Dynamically provision real-time workloads (containers, VMs) from cloud to edge with infinite scalability

High Availability

Software techniques to ensure zero downtime for production lines – for example, failover of PLC runtimes in case of HW or network outage

Reduced Maintenance Costs

Onboarding of compute nodes with zero-touch provisioning of OS and Apps. No more USB sticks!

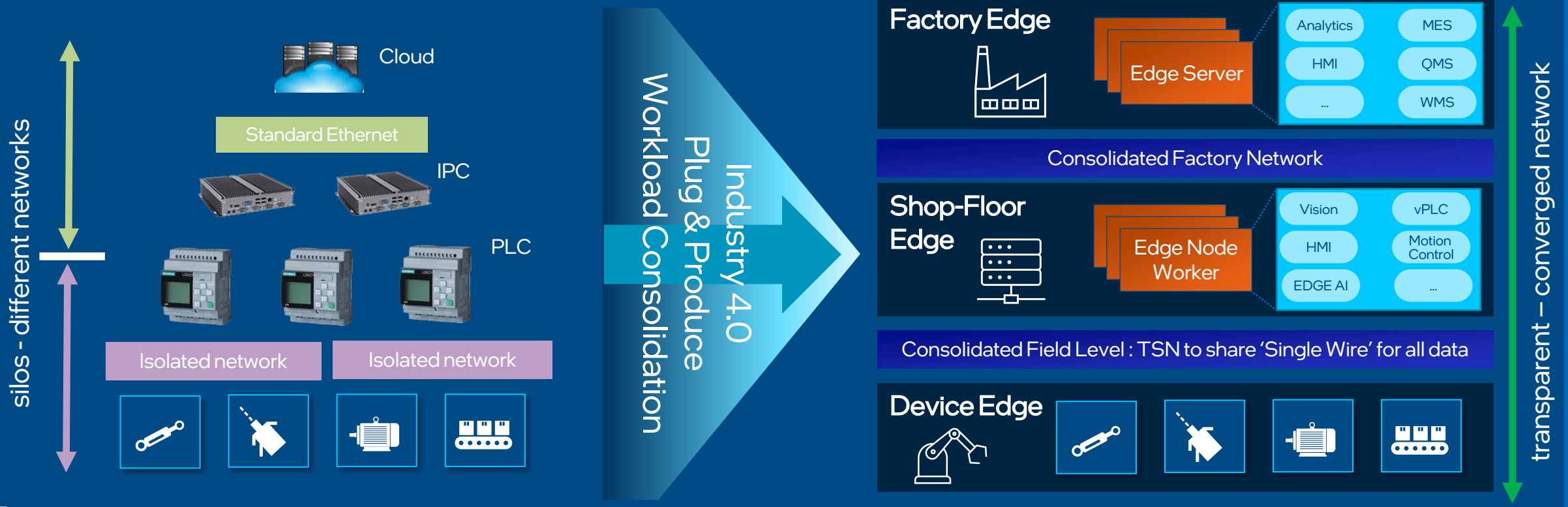
Portability and Agility

De-coupling software from hardware avoids vendor lock-in and lowers switching costs.

Data Analysis at the Edge

Convergence of real-time workloads with edge inference brings intelligence closer to the process resulting in faster time to insights & action

Industry Transformation to Software Defined and Autonomous Systems



- ❑ Fixed-function automation for mass production. Complex setup. Manual maintenance. Operate >20y as built, no change, extend, scale.
- ❑ Specific systems with dedicated busses. Closed ecosystems. Limited access to production data

- ❑ Customizable small-series production ('lot size one')
- ❑ Interoperable and standards-based: re-configure and scale
- ❑ Access to data for AI → flexible / react to specific situation

Real-time needs for SW-defined industrial control

customizable

scalable

Factory Edge

Factory Apps & Edge Management

Shop-Floor Edge

Virtualized Control Applications: vPLC, Motion etc..

Platform Requirements → Determinism + High Performance
- Determinism in real-time data processing (compute)
- High performance with best-effort / AI workloads

→ General Purpose Processor (GPP) for Workload Consolidation

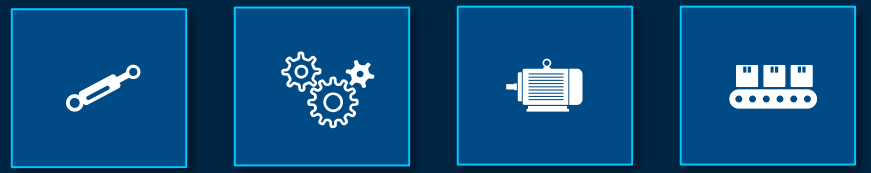
OS & Hypervisors → Cloud-Native Technologies
- Co-existence of mixed-criticality workloads on system - isolation
- Best use of compute resources for the different workloads

→ Real-time capable OS/Hypervisor/Container Orchestration System

Standardized Industrial Communication → Converged Networking
- Mixed-criticality communication at high throughput over single network
- Time Sensitive Networking (TSN) with multi-middleware

→ Industrial Network Interface Controller (NIC) with TSN Support

Device Edge



interoperable

flexible

Needs to process mixed-criticality workloads

Accurate time synchronization is fundamental to manage, orchestrate and communicate mixed-criticality workloads

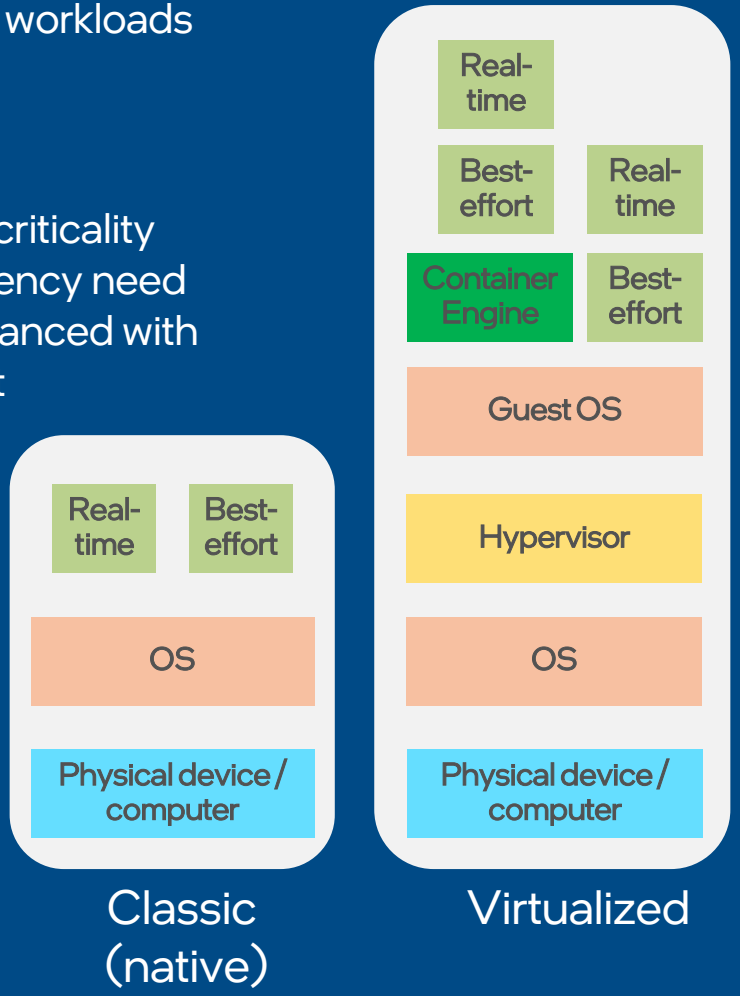
Different levels of isolation between real-time and best-effort workloads can be achieved

Determinism in time to meet latency and cycle time requirements of different types of workloads

Orchestration of mixed-criticality workload is complex: latency need per workload is to be balanced with available latency budget

Network convergence with TSN as key enabler of mixed-criticality communication on the network/connectivity side

→ Meet cycle time needs for real-time workloads
→ High-performance with best-effort workloads



Intel’s real-time offering

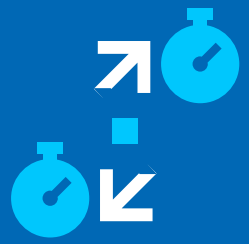
Real-time System Concepts

Timeliness

Ability to produce the expected result within a defined deadline

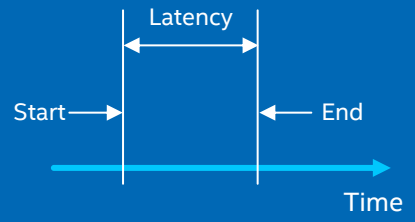
Time Synchronization

Ability of agents to operate together in unison by correlating independent clocks



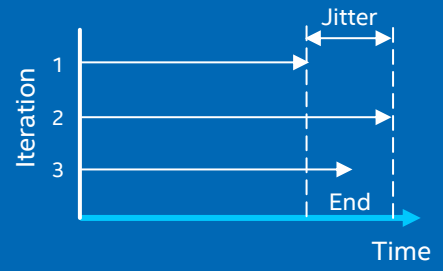
Latency

Measure of time to complete task



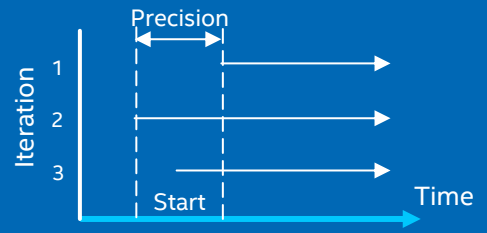
Jitter

Measure of time variation to complete task



Precision

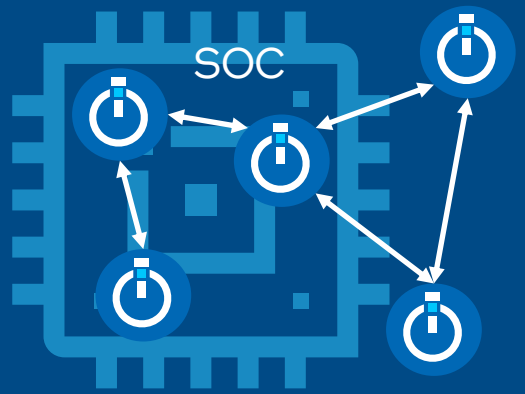
Measure of time variation coordinating tasks across multiple components



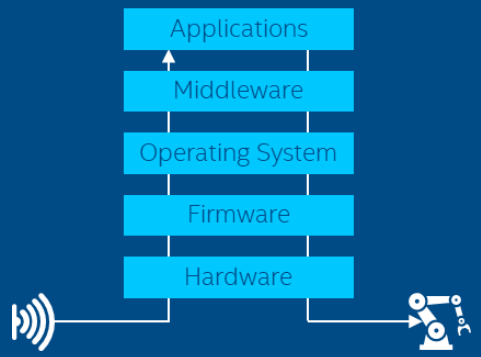
Emerging High-performance Real-time Solutions have unique Design Challenges

- Performance of real-time applications is a result of system level behavior
- Every element in the data path needs to be tightly synchronized
- Every element must perform in a reliable and predictable manner, within a specific time window
- In a SW defined environment real-time workloads exist in a mixed criticality environment

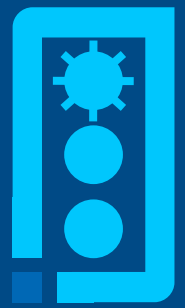
Unsynchronized clocks cause jitter and delays



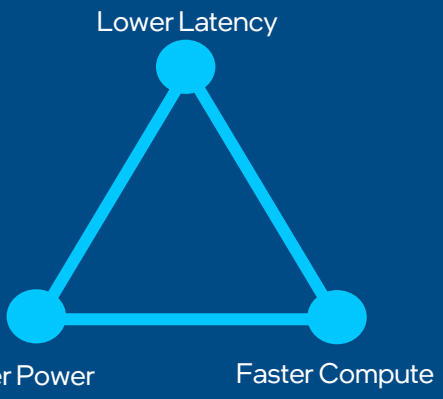
The most unpredictable element determines the worst-case execution time



Resource contention introduces interference and causes jitter



Configuration & tuning needed to balance performance vectors

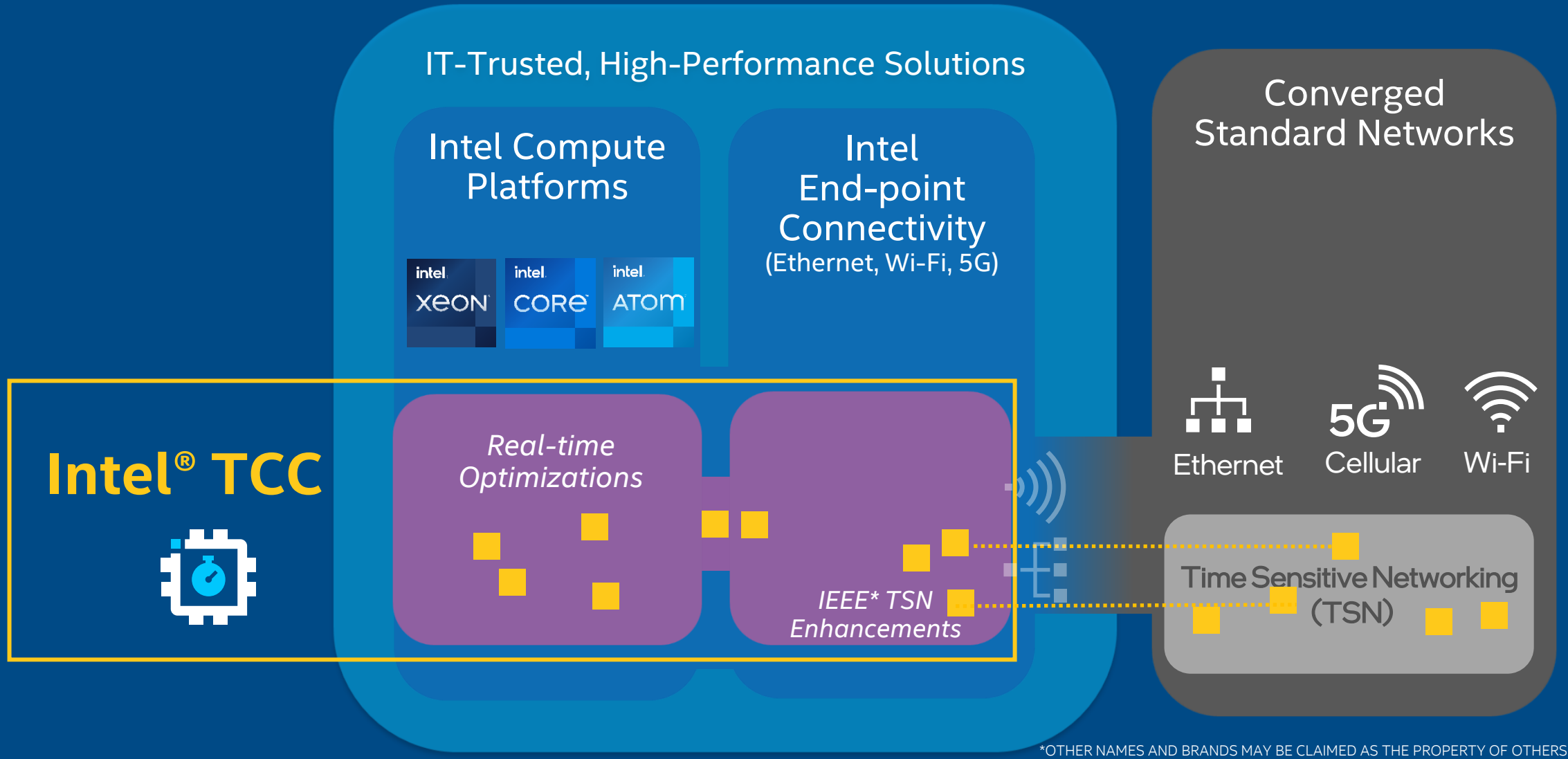


How Intel is enabling Time Coordinated Computing

1. Ecosystem engagements to support the transformations to a SW defined environment across industries.

2. Intel platform enhancements to enable workloads and workflows for the transformation

Intel® Time Coordinated Computing (Intel® TCC)



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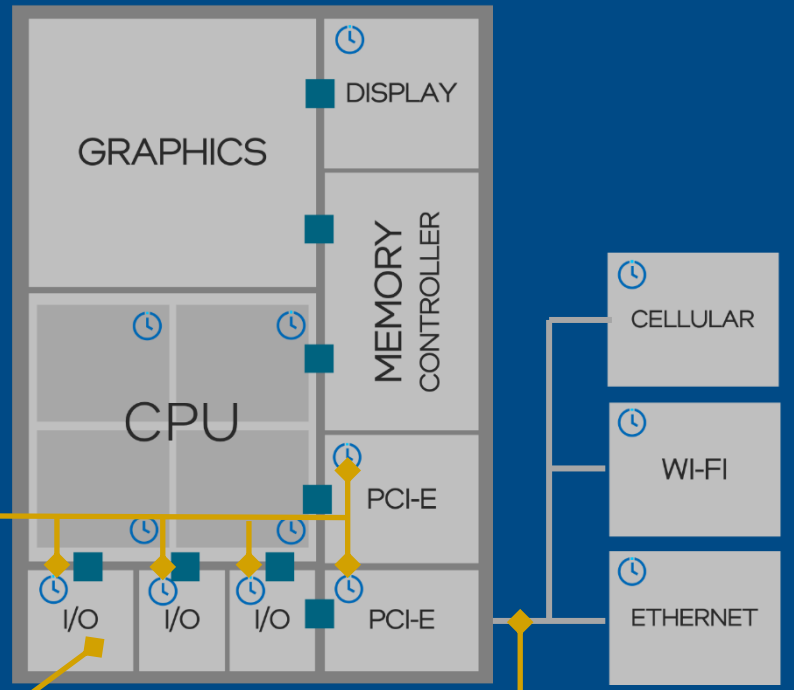
Intel Platform Enhancements
Silicon Platforms Examples

Time Synchronization



Precision Time Coordination
Clocks from SOC subsystem can be more precisely correlated in software via hardware time stamping

Time-Aware GPIO
GPIO input and output that can be precisely coordinated in software (via Precision Time Coordination)

IEEE* 1588 (PTP) support in all Intel end point connectivity solutions
IEEE* 802.1AS TSN profile of IEEE* 1588 supported in many Intel end point connectivity solutions

PCI Express* Precision Time Measurement (PTM)

Intel Platform Enhancements
Silicon Platforms Examples

Timeliness

Power State Transition Optimizations

Enable CPU to keep executing instructions while its frequency is increasing/decreasing

Memory/Cache Allocation Optimizations

- Partitioning of shared caches at the way level between classes of service (L2 & L3 Cache) - Cache Allocation Technology (CAT)
- Limit amount of cache available to GPU

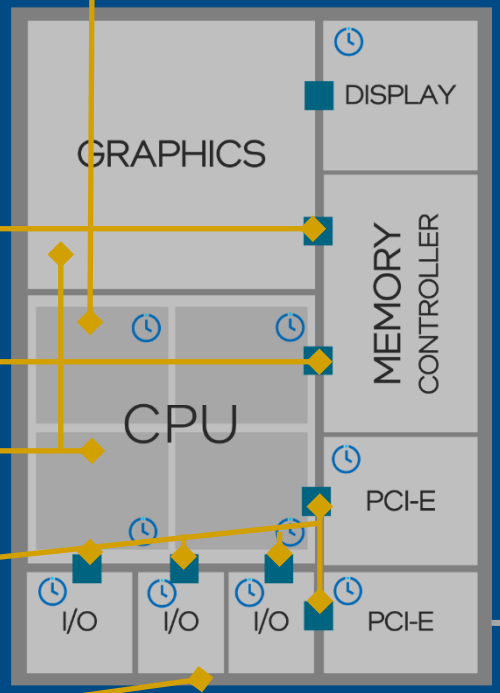
Intel® Speed Shift Technology for Edge Compute Applications

- Specific assignment of processor performance to where it is most needed

- **Fabric Virtual Channels**
- Virtual channels on Fabric available to high priority workloads.

Interrupt Request (IRQ) Optimizations

- Optimize processor microcode & other overhead in the critical path for interrupts in the CPU core
- Allow devices to deliver interrupts directly to the guest OS without requiring preprocessing by the hypervisor



Time Sensitive Networking

Support in all end-point connectivity solutions to take advantage of TSN features becoming common in edge networks

PCI Express* Virtual Channels

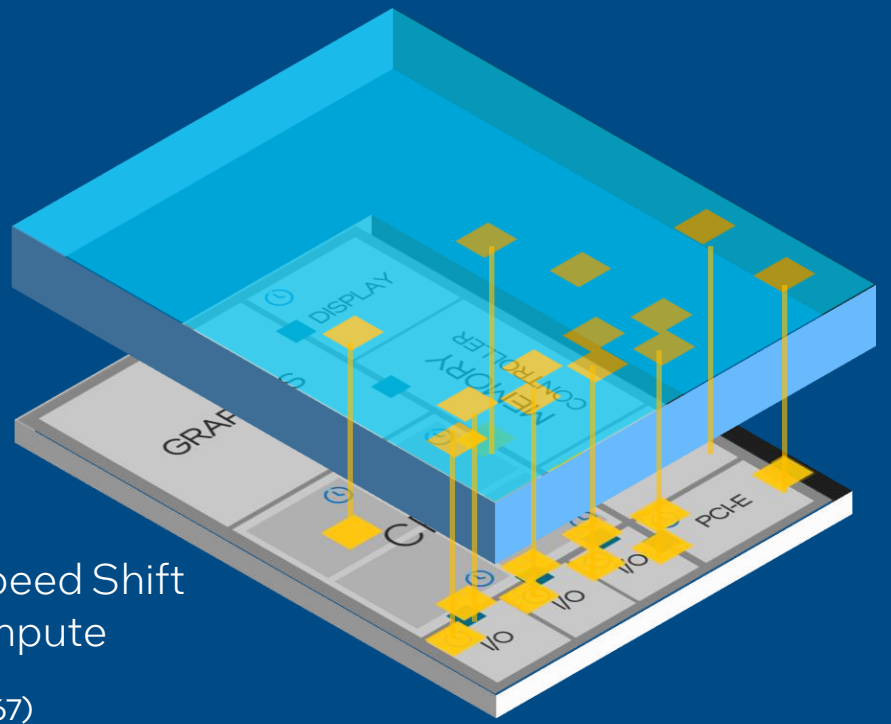
Virtual channels on PCIe available to high priority workloads.

Intel Platform Enhancements
BIOS/Firmware Examples

TCC BIOS options
- Power states and frequency transition optimizations
- Configuration of Intel® TCC features
  - Enable robust platform partitioning features
  - Limit amount of cache available to GPU
  - Optimize IO device utilization of Cache
  - Reduce number of interrupts impacting RT workloads
  - Prioritize processing of deterministic workloads
  - Set up RT Virtual Channels for VC-capable end-points

BIOS configuration Guidance
Intel TCC User Guide (RDC #786715)*

Model Specific Registers (MSR)
Programming of cache partitioning and Intel® Speed Shift Technology settings for Time Coordinated Compute



BIOS / Firmware

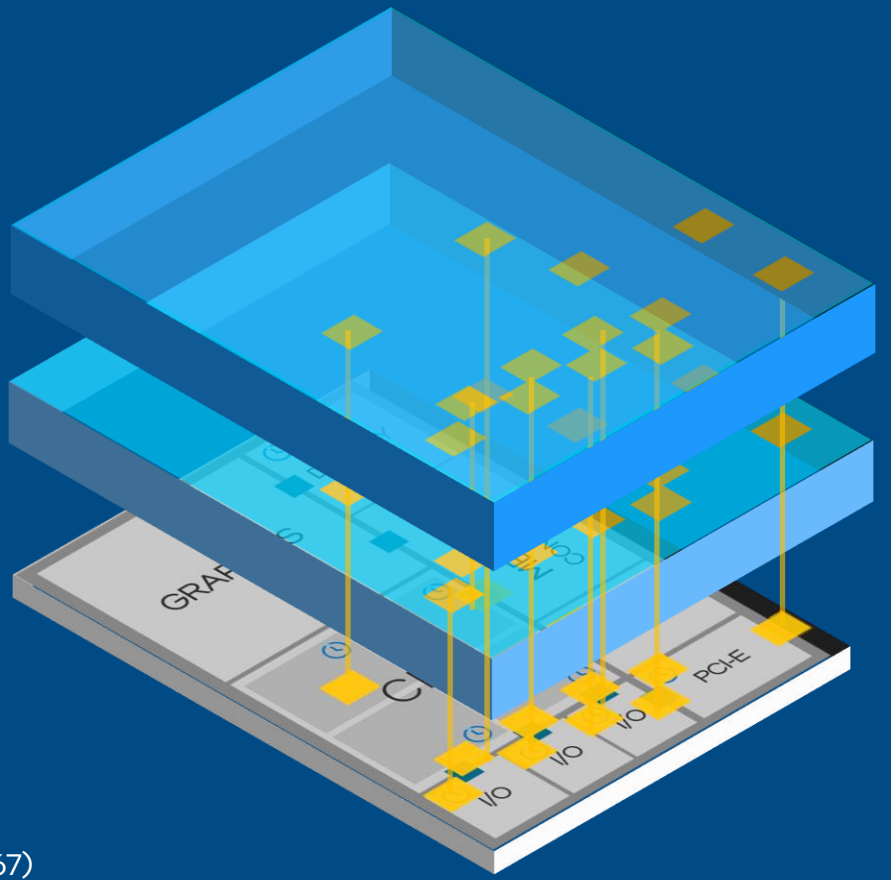
Silicon platforms

*A public version of the Intel TCC User guide is also available (RDC#831067)

Intel Platform Enhancements
Operating System and Hypervisor Examples

Features enabled/available in standard Linux

- Use of Linux Preempt RT
- TSN drivers and user space applications
- Ubuntu Real-time* available preconfigured
- Enabling of 3rd party & opensource RTOS & HV solutions



OS/ Hypervisor

BIOS / Firmware

Silicon platforms

Linux Kernel configuration guidance

- Intel TCC User Guide (RDC #786715)*

*A public version of the Intel TCC User guide is also available (RDC#831067)

Intel Platform Supporting Development of Mixed Criticality Applications

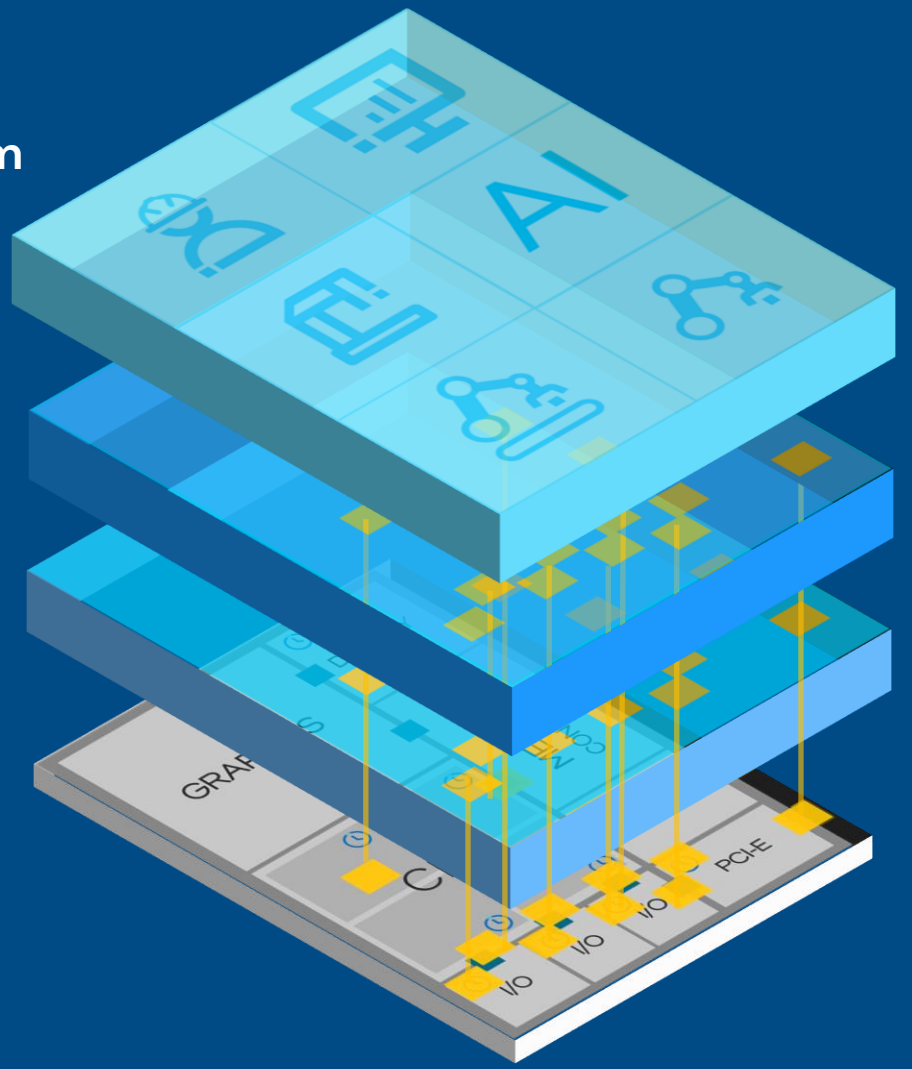
Variety of mixed-criticality customer applications running on Intel's platform deliver a SW-defined implementation:

Real-time Applications:

- vPLC
- PLC
- Industrial Computer Vision
- Motion control
- AV applications
- etc.

Best-effort Applications:

- HMI
- Data Analytics
- Security
- Manageability
- AI
- etc.

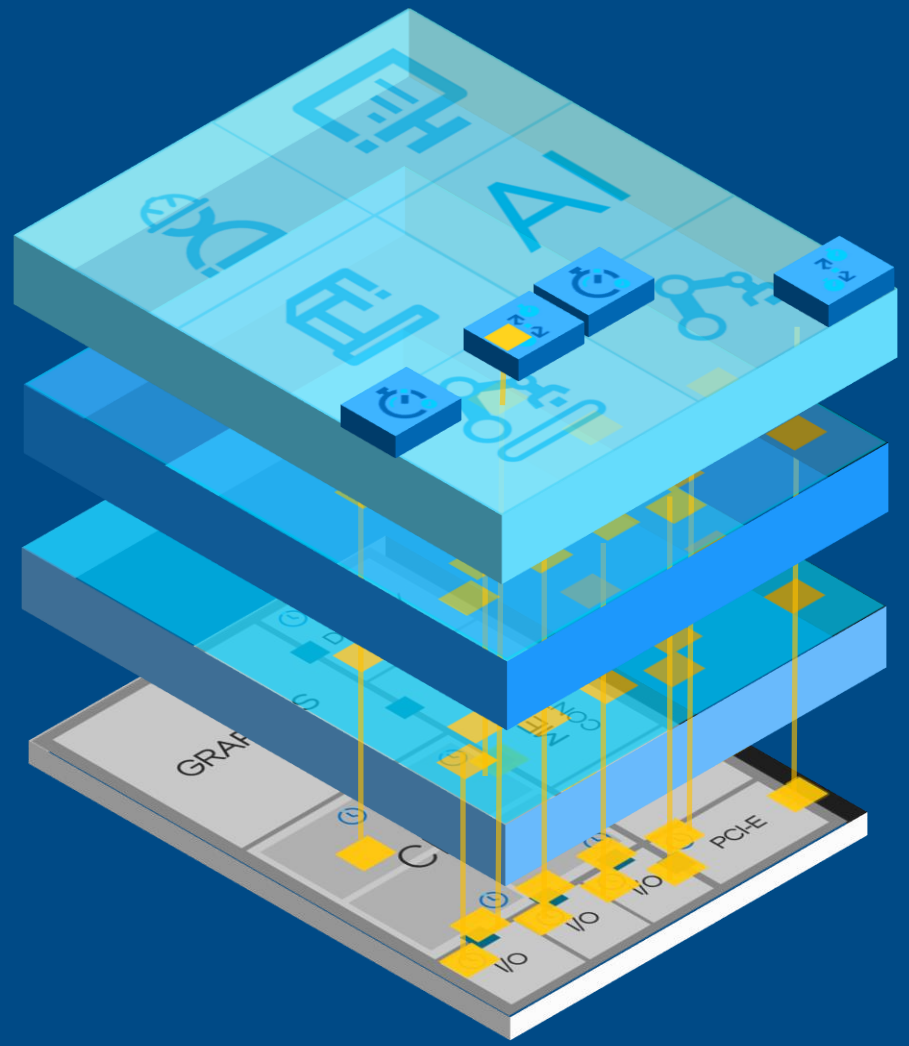


Mixed-criticality Applications

Application focused Reference Software Examples

Reference software & libraries for implementing applications for different markets & usages including

- TSN Reference Software
- Real-time Compute Performance KPI application
- Enabling of 3rd party SW partners



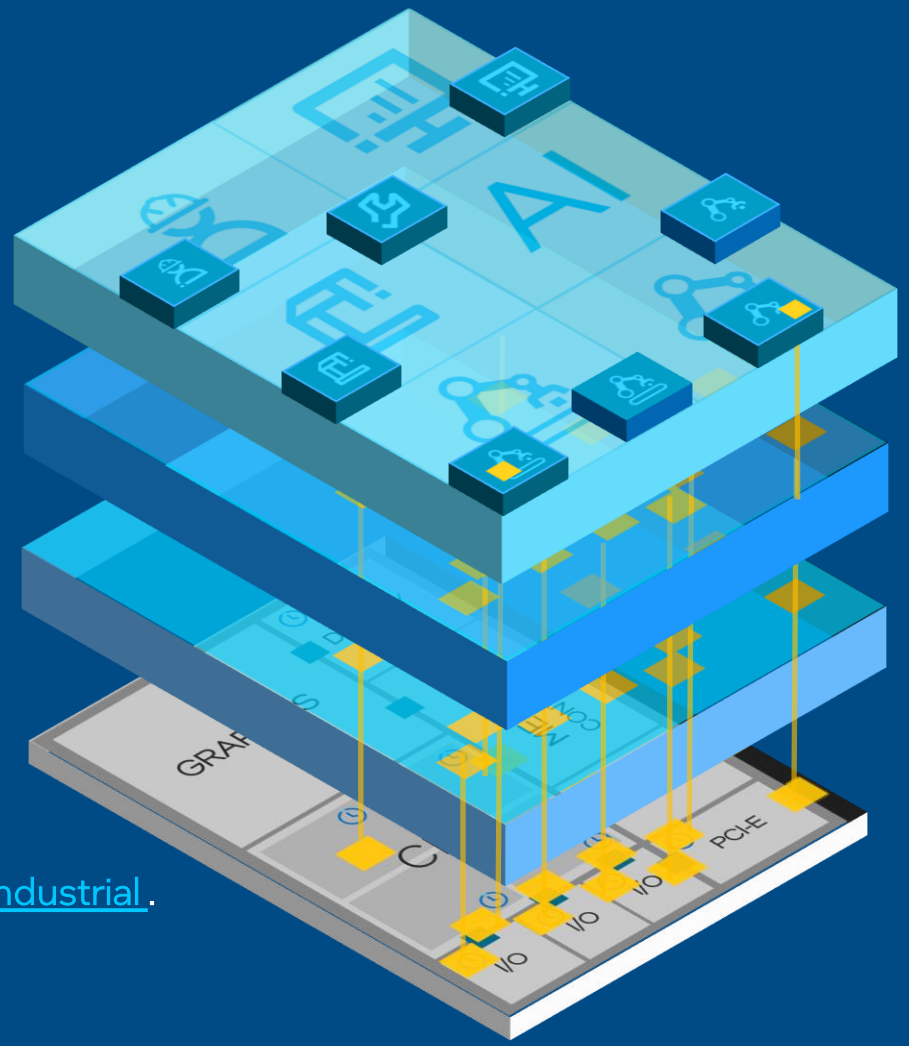
Intel® Edge Controls for Industrial

Real-time Linux* Framework & Microservice-based Software for Control Consolidation

- Helps to accelerate and simplify the development of control solutions.
- Modular approach allows customers to take the ingredients they need
- Focused on solving key customer challenges in select market segments:

Machine Builders	Discrete Automation	Process Automation	Industrial Robotics
Integrated Motion Controller, Logic Control, HMI, Vision	(Automotive) Cell Controllers, PLC	(Oil & Gas, Grid Substations) DCS Controllers	Controller & MVAI Controller for Robots

For more information, visit: Intel® Edge Controls for Industrial .



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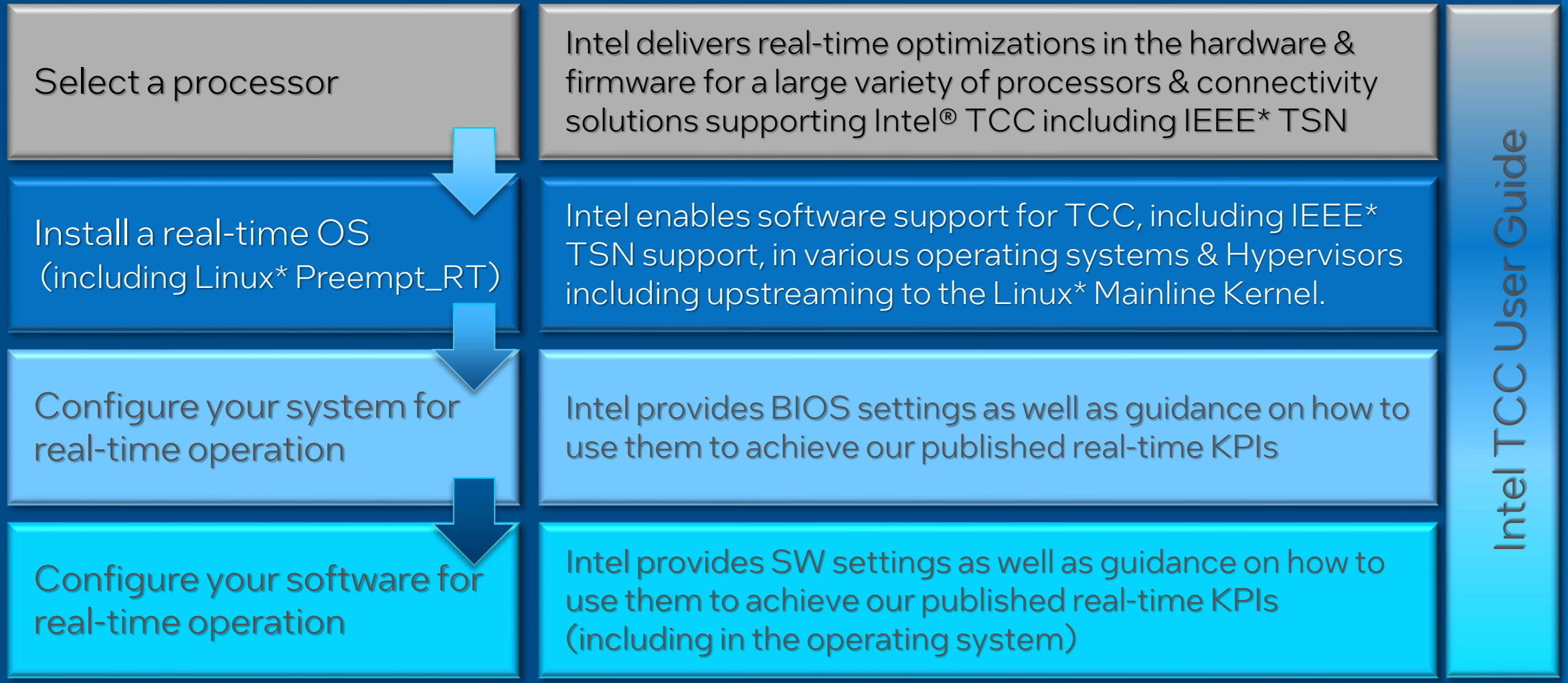
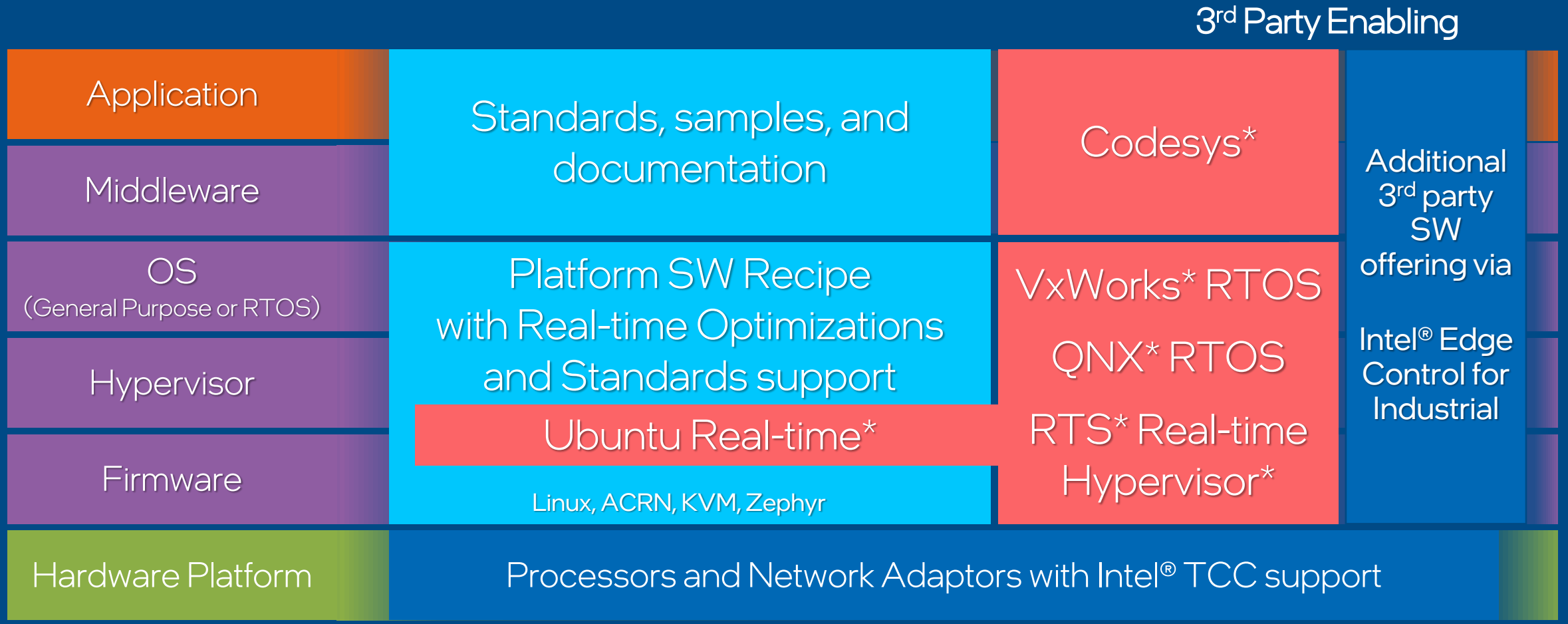
Designing a System for Mixed Criticality



Intel® Real-time Partner and Opensource Enabling

Engaging with partners and the opensource community to drive ecosystem readiness



RTOS = REAL TIME OPERATING SYSTEM

Intel end point solution support for base TSN specifications

		Intel Endpoint Solutions (Intel® Ethernet Controller i226 & integrated 2.5 GbE)	Intel FPGAs with TSN support	
NETWORK MANAGEMENT	802.1Qat	✓	✓	Defined in Application-level Software
	802.1Qcc	✓	✓	
	802.1Qdd	✓≡	✓≡	
	802.1Qdj	✓≡	✓≡	
TIME SYNC	802.1AS	Avnu Component Certified Sep'24 ✓	✓	Defined in User-space Software & Hardware/Driver
LATENCY & BANDWIDTH	802.1Qav	✓	✓	Defined in Hardware/Driver (NICs & SOCs) or Field Programmable (FPGA)
	802.1Qbv	Avnu Component Certified Sep'24 ✓	✓	
	802.1Qbu/br	✓	✓	

✓ = Supported ✓≡ = Spec not complete, but expected to be supported

Intel® TCC Value Proposition

Improved performance for time-sensitive applications

Timely & reliable data processing

Better out-of-box real-time performance for deterministic workloads

Timeliness & Time-Sync

Doing more with the same system

Maximum efficiencies by aggregating real-time and best-effort applications on a single system

Timely & reliable data delivery

Support for IEEE* Time Sensitive Networking (TSN) over converged network

Timeliness & Time-Sync

Future-proofing designs

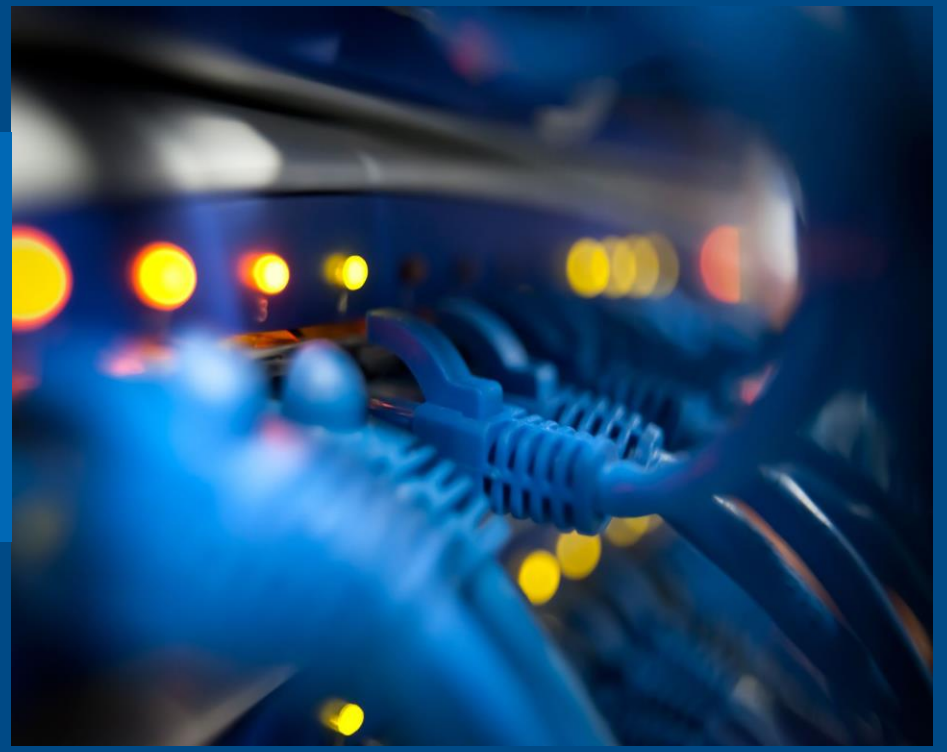
Scale between Intel Atom®, Intel® Core™ and Intel® Xeon® processors and across processor generations

Time Sensitive Networking (TSN)
Enabling Converged, Secure Networks

Needs for transformation across markets

Shift to portable, software defined workloads

Shift to secure, converged networks



To support the need for converged edge networks, industries are adding new network capabilities. One of the largest initiatives in this area is the field of *Time Sensitive Networking*

Time Sensitive Networking

PROFESSIONAL AV

AUTOMOTIVE

INDUSTRIAL

AEROSPACE

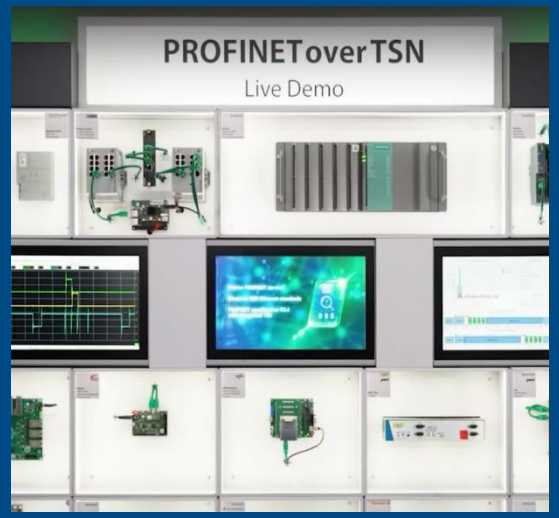
CELLULAR NETWORKS

STANDARD EDGE NETWORKS

- Time Synchronization
- Resource Management
- Latency
- Availability/ Reliability

Enhancements to ***standard networking*** enabling *simpler management, coexistence of protocols* and *convergence of networks* **supporting *mixed criticality* workloads**

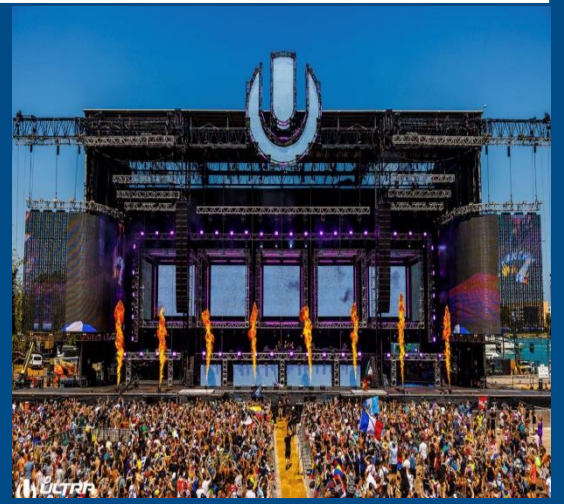
Example ecosystems building on standard TSN



https://www.profibus.com/technology/industrie-40/profinet-over-tsn

https://www.cc-link.org/en/cclink/cclinkie/cclinkie_tsn.html

https://opcfoundation.org/flc/



https://avnu.org/Milan/

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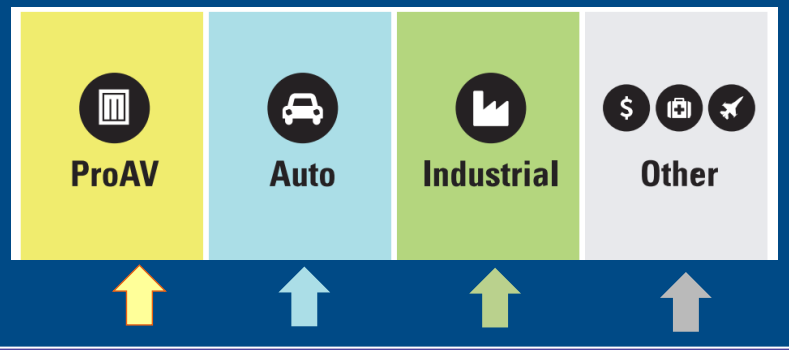
Key Ethernet TSN Standards

PROTOCOL	DESCRIPTION
IEEE* 802.1AS	IEEE Std 802.1AS specifies the generalized Precision Time Protocol (gPTP). It provides a Layer 2 time synchronizing service
IEEE* 802.1Qav	Forwarding and Queueing Enhancements for Time-Sensitive Streams, which specifies the Credit Based Shaper
IEEE* 802.1Qbv	Enhancements for Scheduled Traffic. It specifies time aware queue draining to schedule the transmission of frames relative to a known time scale
IEEE* 802.1Qbu	Frame Preemption. It allows a Bridge Port to suspend the transmission of non-time critical frames while one or more time-critical frames are transmitted
IEEE* 802.3br	Interspersed Express Traffic (IET)
IEEE* 802.1Qat/Qcc	Stream Reservation Protocol (SRP) - Gen2 Enhancements

Intel products align to all current TSN profiles including IEC*/IEEE* profile 60802 (Profile for Industrial Automation) and 802.1BA (Professional Audio Video)

Avnu* network component certification for TSN

Avnu Components: certified (profile-agnostic) TSN capabilities used in products (end stations, switches) across markets



Intel® Ethernet Controller i226 : First Certified endpoint device in the market!

- Comp. Cert. Rel. 1: 802.1AS + 802.1Qbv (**certified September 2024**)
- Other TSN capabilities to follow (Qbu, ….)
- Avnu Certified Component Registry

Any hardware device using i226 can also list as certified and refer to the certification documentation on Avnu website
Intel will make available software configuration used for certification

Other Avnu Cert. Programs: Network devices/switches (profile-based: proAV and Automotive), wireless TSN (under development)

More resources/information on TSN:

- IEEE* TSN: https://1.ieee802.org/tsn/
- Avnu* Alliance: https://avnu.org (TSN Compliance organization)

NEX Edge products supporting Time Coordinated Computing

NEX offering supporting Time Coordinated Computing

Intel processors with support for Time Coordinated Computing usages, the combination of real-time workloads and best effort workloads on the same system, by leveraging many silicon and SW optimizations on our products.

Intel® Xeon® D-2800 and D-1800 processors

Intel® Xeon® D-2700 and D-1700 processors

14th Gen Intel® Core™ S-series processors

13th Gen Intel® Core™ P & S-series processors

12th Gen Intel® Core™ S-series processors

11th Gen Intel® Core™ UP3/H-series processors

Intel Atom® x7000E/x7000C/x7000RE Series processors

Intel Atom® x6000E Series processors

Ethernet controllers supporting Converge OT and IT traffic in a single IEEE Standard Network with IEEE TSN support

Intel® Ethernet Controller I225/I226

- 2.5GbE MAC/PHY, PCIe v3.1, gen2 x1
- I225/i226-IT/LM only: TSN (802.1AS, 802.1Qbu, 802.3br, 802.1Qbv), PCIe PTM
- Avnu Alliance Component Certified for compliance with the IEEE 802.1AS and IEEE 802.1Qbv

The information above is not an official POR document and may be different from other Intel divisions with similar products.
Select features, highlighted above, are not supported on all SKUs. Dates, details and information are subject to change without notice.
For the latest detailed schedule information, please refer to individual product gold decks, or contact your Intel representative.
For a complete list of all available SKUs, across current and prior product generations, please refer to the NEX Quick Reference Guide (QRG) available on rdc.intel.com.

ALL PRODUCT PLANS AND ROADMAPS ARE SUBJECT TO CHANGE WITHOUT NOTICE.

Time Coordinated Computing SKU Map*

Intel Atom® Processors

- Intel Atom® x6427FE Processor
- Intel Atom® x6425RE Processor
- Intel Atom® x6414RE Processor
- Intel Atom® x6212RE Processor
- Intel Atom® x6200FE Processor
- Intel Atom® x7211E Processor
- Intel Atom® x7425E Processor
- Intel Atom® x7213E Processor
- Intel Atom® x7211RE Processor
- Intel Atom® x7213RE Processor
- Intel Atom® x7433RE Processor
- Intel Atom® x7835RE Processor
- Intel Atom® x7203C Processor
- Intel Atom® x7405C Processor
- Intel Atom® x7809C Processor

11 Gen Intel® Core™ Processors (UP3-Series)

- Intel® Core™ i7-1185GRE Processor
- Intel® Core™ i5-1145GRE Processor
- Intel® Core™ i3-1115GRE Processor

12 Gen Intel® Core™ Processors (S-Series) **

- Intel® Core™ i9-12900E Processor
- Intel® Core™ i7-12700E Processor
- Intel® Core™ i5-12500E Processor
- Intel® Core™ i3-12100E Processor

Intel® Xeon® W Processors **

Intel® Xeon® W-11865MRE Processor
Intel® Xeon® W-11865MLE Processor
Intel® Xeon® W-11555MRE Processor
Intel® Xeon® W-11555MLE Processor
Intel® Xeon® W-11155MRE Processor
Intel® Xeon® W-11155MLE Processor

13 Gen Intel® Core™ Processors (U/P/H Series)

- Intel® Core™ i7-1365UE/1365URE/1366URE Processor
- Intel® Core™ i5-1345UE/1345URE Processor
- Intel® Core™ i3-1335UE Processor
- Intel® Core™ i3-1315UE/1315URE Processor
- Intel® Core™ i7-1375PRE Processor
- Intel® Core™ i7-1370PE/1370PRE Processor
- Intel® Core™ i5-1350PE/1350PRE Processor
- Intel® Core™ i3-1340PE Processor
- Intel® Core™ i3-1320PE/1320PRE Processor
- Intel® Core™ i7-13800HE/13800HRE Processor
- Intel® Core™ i5-13600HE/13600HRE Processor
- Intel® Core™ i3-13300HE/13300HRE Processor

13 Gen Intel® Core™ Processors (S-Series)**

- Intel® Core™ i9-13900E/13900TE Processor
- Intel® Core™ i7-13700E/13700TE Processor
- Intel® Core™ i5-13500E/13500TE Processor
- Intel® Core™ i5-13400E Processor
- Intel® Core™ i3-13100E/13100TE Processor

14 Gen Intel® Core™ Processors (S-Series)

- Intel® Core™ i9-14900/14900T/ 14901KE/14901E/ 14901TE Processor
- Intel® Core™ i7-14700/14700T/ 14701E/ 14701TE Processor
- Intel® Core™ i5-14500/14500T/ 14501E/ 14501TE Processor
- Intel® Core™ i5-14400/14400T/ 14401E/ 14401TE Processor
- Intel® Core™ i3-14100/14100T Processor

Intel® Xeon® D Processors

- Intel® Xeon® D-2752TER Processor
- Intel® Xeon® D-1746TER Processor
- Intel® Xeon® D-1735TR Processor
- Intel® Xeon® D-1715TER Processor
- Intel® Xeon® D-1712TR Processor

Discrete Ethernet Products

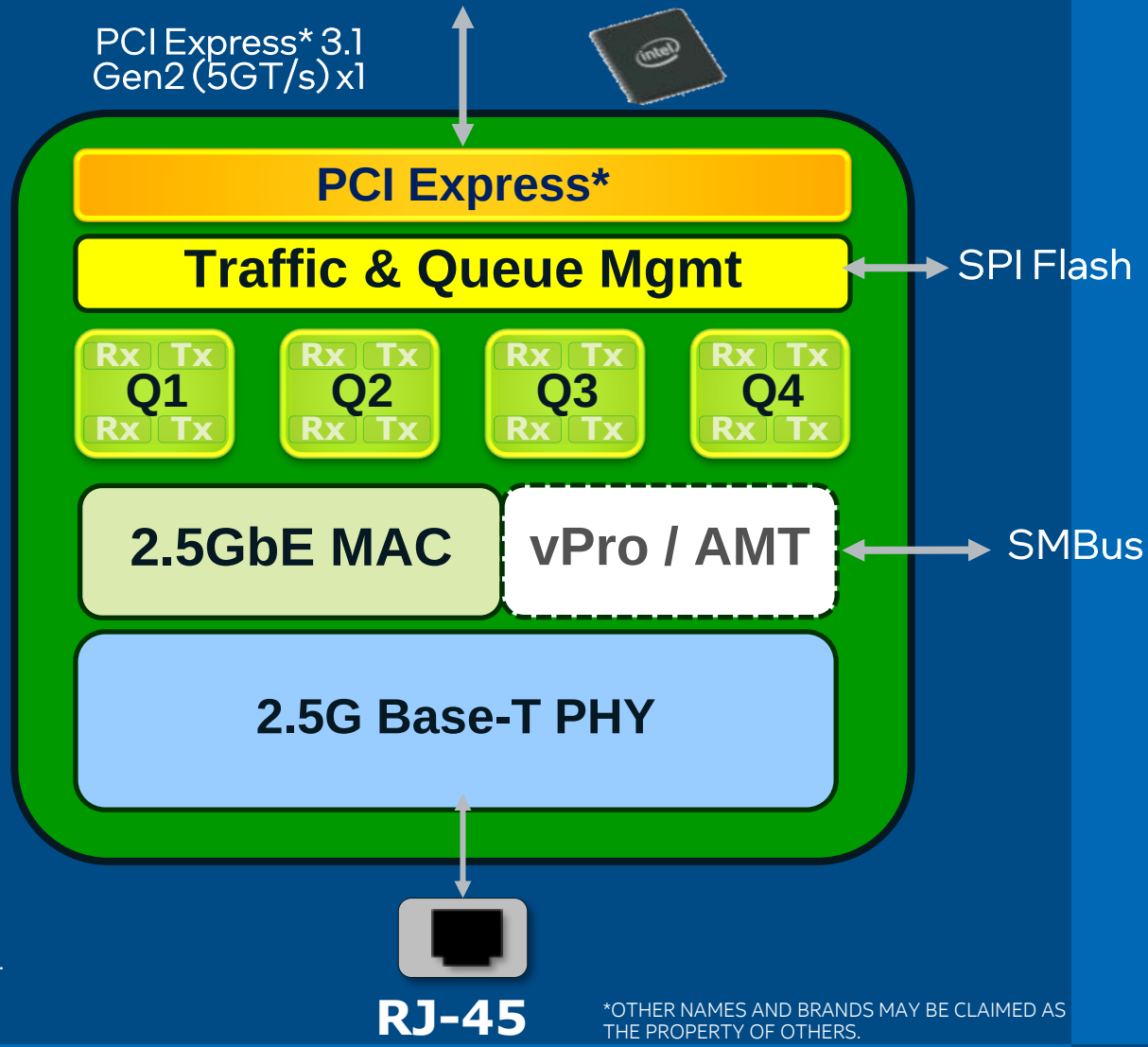
- Intel® I226-LM (Embedded use conditions, 2.5G TSN capable discrete ethernet)
- Intel® I226-IT (Extended temp, 2.5G TSN capable discrete ethernet)

*Not all real-time capabilities available on every sku
** See Integrated Ethernet with TSN page for integrated etherent PCH requirements

Real-time Supplemental Details and Slides

Intel® Discrete Ethernet Controller i226-V/-LM /-IT

- Schedule
  - i226 V, LM, and IT silicon are in production
  - Full IOTG platform support w/ 11th, 12th, and 13th Gen Intel® Core™, Intel Atom® x6000E & X700E, Intel Xeon D, and Intel Xeon W platforms
- Intel® 2.5G Base-T MAC/PHY LAN
  - Supported on IoTG roadmap, extended availability, EMB use[2]
  - I226: V/LM Sku @ 2.5G (0-70C), IT Sku @2.5G (-40 – 85C)
  - Support for 10M/100M/1000M/2.5G speeds
  - i226 LM/IT Skus: Enhanced AVB/TSN capabilities, and PCIe PTM (Linux only)
  - Support for AMT/Intel ® vPro™ Technology (Q1'21 launch, Windows Only)
- Why leverage i226?
  - Add 2.5G Ethernet, or TSN connectivity to a system w/o integrated Ethernet
  - Expand number of TSN capable ethernet ports beyond what is integrated into Intel® SoC
  - Add 2.5G LAN w/ vPro™ capability to a system
  - Avnu Component Certification for IEEE 802.1AS (Time synchronization) and IEEE 802.1Qbv (Enhancement for Scheduled Traffic) TSN components.
- Learn more here: link



I225 v3 / B3 stepping is supported on select IOT platforms.

[2] Support for embedded use / long life, For EMI CISPR requirements no supported up to 10V, see datasheet for exact details.

Intel reserves the right to change roadmaps or discontinue products, software and software support services through standard EOL/PDN processes. Please contact your Intel account rep for additional information."

*OTHER NAMES AND BRANDS MAY BE CLAIMED AS THE PROPERTY OF OTHERS.

Integrated Ethernet with TSN

KEY HARDWARE CAPABILITIES

Intel Number of Integrated Ethernet / MAC Controllers
- 1 to 3x 2.5GbE port with TSN support varying by processor family
- 1x 1GbE port on Intel® Core™ processors

Features :
- IEEE 802.1: AS, Qav, Qbv, Qbu
- IEEE 802.3: br
- Various HW-based Rx Filtering
- Time Base Scheduling (TBS)
- Perf Monitors

Interfaces per Controller (see diagram to the right)

KEY SOFTWARE CAPABILITIES

VxWorks*
Linux Yocto*, Ubuntu*
- Kernel Driver
  - PREEMPT_RT kernel patches, to complement TSN
  - Support for Standard Kernel TSN APIs
- Reference TSN middleware stacks
  - OPC-UA (Client/Server, open62541 PubSub)
  - Linuxptp (802.1AS)
  - OpenAvnu (802.1AS, 802.1Qav, ...)
  - Demo Application

1 - Can also be paired with discrete Ethernet TSN controller I225/i226 for more ports

Intel® TCC and TSN Documentation

Document	Scope	Distribution via Resource and Documentation Center	Availability
Documentation useful for both Intel® TCC and Time Sensitive Networking			
User Guides	Guidance on usage of TCC on Intel platforms and options available under the TCC umbrella.	• Public version of Intel TCC User Guide (RDC #831067)	Now available
Intel® Ethernet Controller I225/I226	Document library	Doc library	Now available

Ethernet PHY for integrated ethernet enabling specifications

Sub-system	Item	Vendor	Part number	Interface	Intel Product Supported	Note
LAN	10/100 Mb, 1 Gb Ethernet PHY	Marvell*	88E1512	SGMII, RGMII (Atom[1] only)	Atom[1], Core™[2], Xeon® W	RGMII supported only on 2 ports of Atom[1] SoC, all 3 ports support SGMII
LAN	10/100 Mb, 1/2.5 Gb Ethernet PHY	Marvell*	88E2110	SGMII	Atom[1], Core™[2], Xeon® W	
LAN	10/100 Mb, 1 Gb Ethernet PHY	MaxLinear*	GPY115	SGMII	Atom[1], Core™[2], Xeon® W	Industrial temperature range
LAN	10/100 Mb, 1/2.5 Gb Ethernet PHY	MaxLinear*	GPY211	SGMII	Atom[1], Core™[2], Xeon® W	Commercial temperature range
LAN	10/100 Mb, 1/2.5 Gb Ethernet PHY	MaxLinear*	GPY215	SGMII	Atom[1], Core™[2], Xeon® W	Industrial temperature range
LAN	10/100 Mb, 1 Gb Ethernet PHY	Ti*	DP83867	SMGII	Atom[1], Core™[2], Xeon® W	Industrial temperature range
LAN	10/100 Mb, 1 Gb Ethernet connection	Intel	i219-LM	PCIe	Core™[2], Xeon® W	This Ethernet port does not support TSN

All products, computer systems, dates and figures specified are preliminary based on current expectations and are subject to change without notice.

1 Atom = Select Intel Atom® x6000E & x7000E Processors
2 Core™ = Select 11th, 12th and 13th Gen Intel® Core™ Processors

TSN Feature Comparison

FEATURE	DESCRIPTION	i210	I225/i226	Integrated 2.5GbE MAC with TSN support on select Intel Atom® and Intel® Core™ Processors
IEEE 1588-2008 V2	Standard for a Precision Clock Synchronization Protocol for Networked measurements and Control Systems	Yes (v1 2002)	Yes	Yes
IEEE 802.1AS-REV 2011	A specific profile of IEEE* 1588-2008. IEEE* 802.1AS specifies the generalized Precision Time Protocol (gPTP). It provides a layer 2 time synchronization service.	Yes	Yes[2]	Yes
IEEE 802.1Qav-2009	Credit based shapers.	Yes	Yes[2]	Yes
Launch time	Per package Tx Time setting and prefetching.	Yes	Yes[2]	Yes
IEEE 802.1Qbv	Enhancement for Scheduled Traffic.	Yes (SW)	Yes[2] (HW[1])	Yes (HW)
IEEE 802.1Qbu-2016	Frame preemption.	No	Yes[2]	Yes
IEEE 802.3Qbr	Interspersed express traffic. Interrupts transmission of an ordinary frame to transmit an "express" frame.	No	Yes[2]	Yes

All products, computer systems, dates and figures specified are preliminary based on current expectations and are subject to change without notice.

1 Only one gate-open window per queue per Qbv cycle
2 On i225/i226-LM/IT only

Ethernet Feature Comparison

FEATURE	DESCRIPTION	i210	i225/i226	Integrated 2.5GbE MAC with TSN support on select Intel Atom® and Intel® Core™ Processors
Max Link speed	100Mbs up to 2.5Gbs.	1Gbps	2.5Gbps	2.5Gbps
External PHY	Ability to connect external components like different and PHYs and PHY less connection to a switch for port expansion	No	No	Yes
TX/RX queues	Number of queues to support IEEE* 802.1Q specified traffic.	4/4	4/4	4/6 (8/8 on Intel® Atom x6000E processors)
Multiple VC/TC	Ability to map multiple priority data traffic into different queues as specified in 802.1Q to achieve QoS.	No	No	Yes
Multiple DMA channels	To achieve low latency by mapping each queue to a separate DMA channel.	No	No	Yes
Multi MSI	To achieve low latency by mapping each queue to interrupt to a separate MSI.	No	Yes[2]	Yes
PTM	Precision Time Measurements for PCIe interface	No	Yes[2]	Yes
vPRO	vPRO compatible in Windows environment	No	Yes	No[1]

1 vPRO supported on select Intel® Core™ processors on separate integrated 1GbE MAC only (using Intel's i219 PHY)
2 On i225/i226-LM/IT only