Deterministic Processing and Ethernet for Industry 4.0

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Agenda

• Industrial Application Requirements
• Deterministic Computing
• Protecting Industrial Devices
• Time Synchronization
• Deterministic Networking
Industrial Applications for Layerscape Solutions

- **Factory and Infrastructure**
  - Production and Facility Monitoring
  - Manufacturing Control
  - Process Control
  - Water Treatment, Oil & Gas
  - Energy Generation, Transmission & Distribution

- **Military and Aerospace**
  - Drones
  - Avionics Control
  - Military Vehicles

- **Transport**
  - Rail Systems
  - Mobility and Logistics
  - Industrial Vehicles

- **Buildings**
  - Control
  - Automation

- **Industrial Networking**
  - IoT Gateways
  - Industrial Gateways
  - Industrial Switches
  - Routers
  - Access Points
Manufacturing Automation/Smart Grid Requirements

Control Processor (LS1)

Processor Requires Real-Time Performance
Traditionally supported via RTOS

PCle or 16 bit parallel bus
Depends on data sizes and system architecture

Control loops run every 25-150 usecs
Requires low, deterministic latency
All elements must be synchronized
Control loop period determines how fast and how smoothly a mechanical system can run

Communications IC
Will be replaced by TSN

Communications IC

Motors, Drives
(LPC15xxx, Kinetis)
## Layerscape - A Broad and Scalable Edge Computing Portfolio

**Video/image processing, large-scale analytics, TSN ethernet, Gateway applications**

<table>
<thead>
<tr>
<th>Processor</th>
<th>Features</th>
</tr>
</thead>
</table>
| LS1028A   | - Cortex-A72  
- 2 cores  
- 1.6GHz  
- 4-9W  
- **Integrated TSN switch** |
| LS1043A   | - Cortex-A53  
- 2-4 cores  
- 1.6GHz  
- 1/10G Ethernet, USB, PCI  
- 5-10W |
| LS1046A   | - Cortex-A72  
- 2-4 cores  
- 1.8GHz  
- 1/10 G Ethernet, USB, PCI  
- 10-12W |
| LS1088A   | - Cortex-A53  
- 4-8 cores  
- 1.6GHz  
- 1/10 G Ethernet, USB, PCI  
- 8-16W |

**Data acquisition, analytics, monitoring, remote control**

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<thead>
<tr>
<th>Processor</th>
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| LS1012A   | - Cortex-A53  
- 1 core  
- 1GHz  
- 1-2W  
- **Ethernet, USB, PCI** |
| LS1021A   | - Cortex-A7  
- 2 cores  
- 1GHz  
- 2W  
- **Ethernet, USB, PCI** |
| LS2088A   | - Cortex-A72  
- 4-8 cores  
- 2.0GHz  
- 8 x 10GE  
- 20-35W |
| LX2160A   | - Cortex-A72  
- 8-16 cores  
- 2.2GHz  
- 10/25/40/100 GE  
- 31W |

- All LS-series processors have rich set of IO – USB, PCIE, SATA, GPIO, I2C, SPI, UART
- All support Trust Architecture for platform security
- Support both embedded and PC Linux distros
- Support industrial temperature ranges
- Support long lifecycles
OpenIL.org

- **A**: Built-in TSN and IEEE1588 Support
- **B**: Built-in industrial-grade security
- **C**: Support for various industrial networking protocols
- **D**: Manageable via industrial control and networking protocols
- **E**: Built-in graphic display support for HMI Applications
- **F**: Open Software Repository and Community
- **G**: Hard real-time applications support

Open Industrial Linux™
OpenIL for Industrial Automation

Scalable Hardware

Open Industrial Linux SDK

- ARM CPUs up to 100K Coremark Available
- PCIe
- Packet Engine 2-20Gbps
- Security Engine
- Ethernet Controllers 2x 1GE -> 2x 10GE

Customer Applications
- Networking, Security drivers
- Xenomai
- Bare Metal Framework
- SE Linux
- Trust Architecture

Determinism
Xenomai Linux, Bare Metal Framework
IEEE 1588, TSN

Security
SE Linux
OP-TEE

4G
802.11ac/n
BLE/Zigbee/Thread
NFC

LS1046
LS1043
LS1021
LS1012

COMPANY PUBLIC | 6
### OpenIL Running on Scalable Portfolio of Devices

#### Currently Supported Devices
- Single to Quad Core
- 32 and 64 bit Arm

<table>
<thead>
<tr>
<th>LS1043A</th>
<th>LS1046A</th>
<th>LS1012A</th>
<th>LS1021A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex-A53</td>
<td>Cortex-A72</td>
<td>Cortex-A53</td>
<td>Cortex-A7</td>
</tr>
<tr>
<td>2-4 cores</td>
<td>2-4 cores</td>
<td>1 core</td>
<td>2 cores</td>
</tr>
<tr>
<td>1.6GHz</td>
<td>1.8GHz</td>
<td>1GHz</td>
<td>1.2GHz</td>
</tr>
<tr>
<td>1/10G Ethernet, USB, PCI</td>
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<td>Ethernet, USB, PCI</td>
</tr>
<tr>
<td>5-10W</td>
<td>10-12W</td>
<td>1-2W</td>
<td>2W</td>
</tr>
</tbody>
</table>

#### New Device Support in 2H 2018
- Adding 3D GPU
- Adding Integrated TSN

<table>
<thead>
<tr>
<th>i.MX 6Dual/6Quad</th>
<th>LS1028A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cortex-A9</td>
<td>Cortex-A72</td>
</tr>
<tr>
<td>2-4 cores</td>
<td>2 cores</td>
</tr>
<tr>
<td>800 MHz (Industrial)</td>
<td>1.3GHz</td>
</tr>
<tr>
<td>2D/3D GPU</td>
<td>4-9W</td>
</tr>
<tr>
<td>Integrated TSN switch</td>
<td>2D/3D GPU</td>
</tr>
</tbody>
</table>
One Package - Four SoC Options

4x A53 1.6 GHz
4.2 W Typical
26,650 Coremark
Per core SpecINT
Per core SpecFP

2x A53 1.0 GHz
2.5 W Typical
8,360 Coremark
Per core SpecINT
Per core SpecFP

23mm x 23mm
780 pin
FC-PBGA Package

4x A72 1.8 GHz
8.5 W Typical
45,330 Coremark
Per core SpecINT
Per core SpecFP

2x A72 1.2 GHz
5.6 W Typical
15,000 Coremark
Per core SpecINT
Per core SpecFP
Deterministic Computing
Deterministic Computing for Industrial Workloads

3 Levels of Real-Time Performance:

- Xenomai Mercury (PREEMPT-RT Patches)
  - LS10XX (Q1 2017)
- Xenomai Cobalt (Real-Time Co-Kernel)
  - LS10XX (Q2 2017)
- Bare-Metal Framework
  - LS10XX (Available Now!)

- Run management, communication software in Linux on 1 core
- Real-time applications running with RTOS (Xenomai) or Bare-Metal on other cores
Xenomai Latency Distribution on LS1043A

- Xenomai Cobalt 64-bit mode on LS1043A @ 1.6 GHz
- Measured using Xenomai latency tool
- Jitter < 450 ns
- Max latency of 680 ns
Protecting Industrial Devices

Root of Trust
Trust Architecture Provides a Trusted Platform

Hardware based security features to ease the development of trustworthy systems

All QorIQ SoCs support Trust Architecture

1. Secure Boot
2. Secure Storage
3. Key Protection
4. Key Revocation
5. Secure Debug
6. Tamper Detection
7. Strong Partitioning
8. Manufacturing Protection
Runtime Access Control with SELinux

- Improved access control

- Policies control file access, network resources, and IPC
  - Finer grain access control

- Use cases:
  - Prevent remote login for certain types of users
  - Restrict access to files from the web
Time Synchronization

linuxptp
### Layerscape Arm® MPUs With IEEE 1588 Hardware

**LS1046A**
- Cortex-A72
- 2-4 cores
- 1.8GHz
- 1/10 G Ethernet, USB, PCI
- 10-12W

**LS1028A**
- Cortex-A72
- 2 cores
- 1.3GHz
- 4-9W
- **Integrated TSN switch**

**LS1043A**
- Cortex-A53
- 2-4 cores
- 1.6GHz
- 1/10G Ethernet, USB, PCI
- 5-10W

**LS1021A**
- Cortex-A7
- 2 cores
- 1.2GHz
- 2W
- Ethernet, USB, PCI

- **Scalable family of ARM SoCs**
- **IEEE 1588 Hardware Time Stamping**
  - Hardware 2-Step supported in all devices
  - 1-Step supported in LS1028 Family
- **IEEE 1588 Timing Logic**
  - Use internal or external clock source
  - Generate periodic phase aligned pulse signals for external devices
1588 Clock Circuits Available in Layerscape SoCs

Use either internal or external clock to generate 1588 nominal frequency

Timestamping value used for Tx and Rx packets

Generate phase aligned periodic pulses
IEEE 1588 for Timing Synchronization

linuxptp support:
- LS1021A
- LS1043A
- LS1046A

Master/Slave
Boundary Clock Mode
802.1AS End Station

Synchronization within +/- 23 nsec for back to back boards

Example configurations and test results
1588 Performance

Timing settles within 5 seconds

Accuracy within ±23 nsec
Deterministic Networking
Embedded Time-Sensitive Networking (TSN)

- Converge OT and IT traffic in a single network
- Determinist Ethernet at gigabit speeds
- Reduce network delays, improve robustness
- Embedded in Multi-processor SoCs
802.1.Qbv – Time Aware Shaping

- Different priority traffic allocated for each queue
- Queue gate schedule synchronized to global time
- 8 Queues available

O – Gate open

**Schedule when queues open to send traffic, synchronized with 802.1AS**

**Talker**
802.1CB – Frame Replication and Elimination for Reliability

Talker replicates Ethernet frames and sends over multiple paths to Listener

- TSN hardware performs replication/elimination
- Zero time failover if 1 path fails
- No need for upper level retry mechanisms
- Simpler code base with reliability

- Listener provides first Ethernet frame that arrives to application
- Listener removes duplicates
802.1Qbu – Frame Pre-emption

- Ensure zero delay for express traffic
- Efficient use of bandwidth for pre-emptable traffic
- Used with TAS, or stand-alone

Express Traffic

Pre-emptable Traffic

Start to transmit frame of pre-emptable traffic

Interrupt pre-emptable frame with express frame. Will transmit remaining pre-emptable frame once express frame complete
LS1021ATSN – TSN Solution Reference Design

- Synchronization with IEEE® 1588
- 4 Switched Gigabit Ethernet TSN interfaces
  - Time Aware Shaping
  - Per-Stream Filtering and Policing
- Arduino Shield for IoT Wireless Integration
- Expandable IO – mini PCIe, SATA, USB 3.0, SD Card, GPIO

Available Now – $829
Single Board TSN Demonstration

- 3 host Linux machines connected through a switch
- 2 TCP flows competing for bandwidth
- Flows bottlenecked because they are sharing the same link towards Host 2
- Combined throughput cannot exceed 1000Mbps
- Utilize TSN features to isolate flows
  - *Ingress Policing*: rate-limit traffic coming from Host 3
  - *Time Gating*: schedule the 2 flows on different time slots
Start TSN on LS1021A-TSN – Enhance with LS1028A

**LS1021A-TSN**

**TSN Features**
- Time Aware Shaper (802.1Qbv)
- Per-Stream Filtering & Policing (802.1Qci)
- Credit Based Shaper (802.1Qav)
- Time Synchronization (802.1AS)

**LS1028A**

**New TSN Features**
- Frame Pre-emption (802.1Qbu)
- Frame Replication and Elimination (802.1CB)
- Cut-through Switching
- Cyclic Queuing and Forwarding (802.1Qch)
- 802.1AS-Rev

Supported by one SDK – Open Industrial Linux
LS1028A Reference Design

Front Panel
- 2x CAN FD Interfaces
- 2x UART

Back Panel
- Full Size SD Card Slot
- Up to 4K Display via DisplayPort
- 2x mikroBUS™ sockets for Click Boards
- USB 3.0 Type C and Type A
- 1G/100M/10M TSN Ethernet Controller
- 4 Switched 1G/100M/10M TSN Ethernet Ports
- Internal M.2 PCIe, SATA slots

Compelling Combination of IO, Computing and TSN
**LS1028A: Dual ARM Cortex A72 Processor**

### Core Complex
- 2x 64-bit Cortex-A72 with Neon SIMD engine
- Speed up to 1300 MHz
- Parity and ECC protected 48 KB L1 instruction and 32 KB L1 data cache
- 1 MB L2 cache with ECC protection

### Basic peripheral and Interconnect
- 2x USB 3.0 OTG controllers with integrated PHY
- 2x eSDHC controllers supporting SD/SDIO 4.0
- 2x CAN-FD controllers
- 8x UART serial ports

### Networking elements
- Four Port TSN Ethernet Switch up to 2.5 Gbps on each port
- Up to four SGMIIs supporting 1 Gbps
- Up to one USXGMII supporting 2.5 Gbps
- Up to one QSGMII
- Up to one RGMII
- 2x PCI Express Gen 3 controllers
- 1x SATA Gen 3.0 controller

### Accelerators and Memory Control
- 1x 16/32-bit DDR3L/4 Controller with ECC support up to 1.6 GT/s
- Time Sensitive Networking (TSN) Ethernet Switch
- Security Engine (SEC)
- QorIQ Trust architecture: Secure boot, ARM Trust zone and security monitor

### Qualification
- Commercial and extended temperature (support for 125C Tj)

### Power
- 5W TDP

#### Target Applications:
- Industrial Control, PLCs, Gateways
- Automotive
- Professional Audio/Video
- IoT Gateways
- Human Machine Interface

#### Package
- 17x17mm, 0.75mm pitch FC-PBGA
OPC UA over TSN for Industry 4.0 Communications

• OpenIL integrates with Open62541
  - Open source C implementation of OPC UA
  - Mozilla Public License v2.0
  - server side capabilities

• LS1021A Running OPC UA Server
  - Providing switch statistics
  - Access via FreeOpcUa Client GUI
Layerscape for Industry 4.0

- Open Industrial Linux growing to support more SoCs
  - Coverage across Layerscape and i.MX

- Deterministic Processing
  - Xenomai Linux
  - Bare Metal Framework

- Secure industrial systems with root of trust and SELinux

- Synchronized and Deterministic Networking
  - 1588
  - TSN
References and Additional Information

- Open Industrial Linux User Guide
- Open Industrial Linux Bare Metal Framework Developer Guide
- Application Note: AN3423 – Support for IEEE™ 1588 Protocol in PowerQUICC and QorIQ Processors
- LS1046A Reference Design Board
- LS1043A Reference Design Board
- LS1012A Reference Design Board
- LS1021ATSN Reference Design Board
- LS1028A Layerscape SoC with integrated TSN