OpenAMP Framework

Ed Mooring, Felix Rubinstein, Tomas Evenson
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Zynq® UltraScale+™ MPSoC

Fixed Platform
- ARM Cortex™-A53
- NEON™
- Floating Point Unit
- Memory Management Unit
- DDR Controller
- DDR3/3L LPDDR4/3
- ECC Support
- 256 KB OCM with ECC
- 64 KB L2 Cache
- Security
- Configuration
- Encryption
- Authentication
- Secure Boot
- TrustZone
- Voltage/Temperature Monitor

Real-Time Processing Unit
- ARM Cortex™-R5
- Vector Floating Point Unit
- Memory Protection Unit
- 128 KB TCM w/ECC
- 32 KB I-Cache w/Parity
- 32 KB D-Cache w/ECC

Programmable Logic

AXI interfaces
- DSP
- Block RAM
- UltraRAM
- System Monitors

Variable Platform

High-Speed Connectivity
- DisplayPort
- USB 3.0
- SATA 3.0
- PCIe Gen2
- PS-GTR
- General I/O
- GPIO
- UART
- SPI
- Quad SPI NOR
- NAND
- SD/eMMC

Fixed Standard I/O

Variable I/O

High Density I/O / High Performance I/O / General Purpose GPIO
Execution Environments within Zync US+ MPSoC

- Multiple core clusters
  - A53, R5, MicroBlaze
- Multiple Execution Levels (EL)
  - EL0 – User space – Linux apps, Containers, RTOS apps
  - EL1 – OS space – Linux kernel, RTOS + RTOS apps
  - EL2 – Hypervisor – Xen, Jailhouse, ...
  - EL3 – Firmware – ARM Trusted Firmware
- Multiple Security Environments
  - TrustZone (TZ) – HW protecting resources (e.g. memory)
  - Trusted Execution Environment (TEE) – SEL1
- Multiple Operating systems
  - Linux (including Android) is used in majority of use cases
  - Most free and commercial RTOS’s are being used
    - FreeRTOS, Zephyr, VxWorks, Integrity, Nucleus, uC/OS, OSE, ThreadX
    - QNX/Neutrino, Sciopt, eT-kernel, Lynx, PikeOS, ...
  - Bare metal (no OS) is common on smaller cores
  - OS often pinned to specific core for embedded applications
Can We Simplify SW for Heterogenous Environments?

- Today, most heterogeneous environments are clobbered together ad-hoc
  - Everybody coming up with their own shared memory scheme
- Can we standardize how environments interact?
  - How to configure the environments?
  - How to manage (lifecycle) the environments?
  - How to pass messages between environments?
  - How to share resources between environments?
  - How to port any OS on top of a standardized abstraction layer?
- Can we have an open source implementation solving these problems?
  - Based on already existing open source projects?

*These are the questions OpenAMP tries to answer*
Executive Summary

- OpenAMP is an open-source framework to interact with heterogeneous SoCs
  - Facilitates use of processing resources for complex designs
- Standardization effort and open-source project
- Evolving AMP/OpenAMP Roll-out
  - From foundation to advanced capabilities
    - APU as master
    - RPU as master
    - Authentication, Decryption of executables
    - Multiple memory types and coherency, zero copy, etc.
  - Arbitrary executable management
  - OpenAMP executable management
Glossary

- SMP: Symmetric Multi-Processing
- AMP: Asymmetric Multi-Processing
- APU: Application Processor Unit
- RPU: Realtime Processor Unit
- LCM: Life Cycle Management
- IPI: Inter-Processor Interrupt
- IPC: Inter Process Communication
- HSA: Heterogeneous Software Architecture
Heterogeneous Software Architecture forced by ZynqUS+ MPSoC

- Not possible to run Linux across Cortex-A and Cortex-R
- AMP implied by differing PUs: APU and RPU
- GPU still abstracted through Libraries/API
- APU a good candidate for Linux
- RPU a good candidate for an RTOS
- Heterogeneous OSes are also needed for homogenous cores
- This can be solved either with unsupervised AMP or a hypervisor
AMP on Heterogeneous SoC

- Interface between APU and RPU will be device-specific
- Abstraction becomes more complicated
- Openly documented framework that different vendors could leverage to abstract device-specific interfaces would be ideal...
Heterogeneous SoCs are by no means a “new” concept
  - But we’re seeing more that give developers access to “raw” firmware and that deploy multiple ARM architectures

A Linux framework called rpmsg and remoteproc is proof of this
  - Introduced into the Linux kernel around 2011

remoteproc – Remote Processor
  - Framework that allows a Linux master to control/manage remote processors (power on/off, reset, load firmware)

rpmsg – Remote Processor Messaging
  - Messaging framework that provides inter-processor communication (IPC) between kernel drivers and remote processors
Linux Remoteproc

- The AMP framework was introduced to Linux due to an increasing number of heterogeneous hardware platforms
  - Introduced in 2011
  - Available as of Linux 3.4.1
- The key components of the framework are based on two responsibilities
  - **Management**
    - The `remoteproc` component is a mechanism that allows the Linux master to start software on a remote processor
  - **Messaging**
    - The `rpmmsg` component is remote processor messaging that provides inter-processor communication (IPC)
- Linux AMP framework was limited in scope
  - Masters expected to be Linux
  - No framework provided for firmware on remote processors
OpenAMP Framework

- The OpenAMP framework was introduced to expand the scope of the original Linux AMP framework
  - Provides a software framework for remote processors (for example, RTOS or bare-metal)
  - Adopts the same conventions as with Linux (remoteproc and rpmsg)
  - Master no longer needs to be Linux-based
- Introduced by Mentor Graphics in collaboration with Xilinx in 2014
- Clean-room implementation (BSD license)
What is OpenAMP?

- OpenAMP standardizes how Operating Systems interact:
  - Between Linux and RTOS/bare-metal
  - In multicore heterogenous systems
- Includes:
  - Lifecycle APIs to start/stop/restart other OSes (RemoteProc)
  - Inter-Process Communication APIs to share data (RPMsg)
  - Shared memory protocol for OS interactions (VirtIO)
- Guiding principles
  - open-source implementations for Linux and RTOSes
  - Prototype and prove in open-source before standardizing
  - Business friendly APIs and implementations to allow proprietary solutions
OpenAMP libraries

- Lifecycle Management (LCM) – allows a master to control/manage remote processors: power on/off, reset, load firmware
- Inter-Processor Communication (IPC) for shared memory management when sending/receiving data from/to master/remote
- Proxy operations – Remote access to systems services. A transparent interface to remote contexts from Linux user space applications running on the master processor
- **libmetal** provides an OS environment and hardware abstraction layer
  - Used by the other components of OpenAMP
- **Ongoing** work to decouple RemoteProc and RPMsg so that they can be used independently
From Linux AMP to OpenAMP

**Linux AMP**
- Kernel modules. No support for firmware on remote processors. Apps on a remote must understand rpmsg/remoteproc.
- Masters must run Linux
- Low level device-specific code is not supported

**OpenAMP**
- User libraries. Adds support for the RemoteProc and RPMsg to RTOS and bare metal
- Master no longer needs to be Linux-based
- Abstracts the device-specific behavior
Remote LCM with RemoteProc

- **RemoteProc** – **Remote Processor**, provides support for a master to run firmware on a remote processor.
- **RemoteProc** is a framework that allows a master to control/manage remote processors (power on/off, reset, and load firmware). A RemoteProc driver is used for lifecycle management of remote firmware.
- **RemoteProc**
  - Provides API to control remote processor
  - Abstracts hardware differences between involved processors
  - Establishes communication channels between master and remote processors using the RPMsg framework
  - Declares a minimal set of device-specific low-level handlers
Master/Remote IPC with RPMsg

- RPMsg (Remote Processor Messaging)
  - Provides inter-processor communication (IPC) between master and remote processors.
    - An RPMsg represents a communication channel between the master and a specific remote processor
  - Defines only vendor agnostic aspects of communication
    - E.g. API and the format of messages.
    - Relies on RemoteProc for device-specific handlers
VirtIO

- **VirtIO library**
  - An abstraction layer over devices in a para-virtualized hypervisor
  - Implements the [OASIS virtIO standard](https://www.oasis-open.org/standards/virtio/) for shared memory management
  - A virtualization standard for network, disk device (etc.) drivers
    - Applicable to OpenAMP configurations
Libmetal Overview

● libmetal
  ○ Provides common APIs for:
    ■ Device access
    ■ Interrupt handling
    ■ Memory management
    ■ Synchronization primitives
  ○ Across:
    ■ Linux user space (based on UIO and VFIO support in the kernel)
    ■ RTOS (with and without virtual memory)
    ■ Bare-metal environments
● Fundamental to OpenAMP architecture
  ○ RemoteProc, RPMsg and VirtIO use libmetal
OpenAMP Remote Startup Process

- **OpenAMP architecture**
  - Assumes the master is already running and remote processor is in standby or powered down

- **Remote Processor Firmware Loading**
  - OpenAMP master loads firmware into the memory location

- **Remote Processor Start**
  - OpenAMP master starts remote processor
    - Example: wake-up remote, release remote from reset, power-on remote, etc.
  - Master waits for remote
  - Master establishes a communication channel to the remote processor
SoC and OS Vendor Support

- Vendor handles the low-level porting for their specific platform(s)
- Vendor supplies example applications for their platform(s)
  - Application includes demonstration of resource table
  - Example application demonstrating basic IPC (e.g., echo)
  - Example application demonstrating master off-loading
- Vendor supplies Linux RPMsg driver for their platform(s)
- Vendor supplies example kernel module and user-space application for interacting with remote device
Status

● OpenAMP is an active, evolving community project
  ○ Project home: github.com/OpenAMP
  ○ Source structure is fluctuating and standardization is a work in progress
  ○ Roadmap for advanced use-cases and features
    ■ IPC performance needs improvement (WIP)

● Availability
  ○ Commercial
    ■ uC/OS, Thread-X, Enea OSE, Mentor Nucleus
  ○ Open Source
    ■ Zephyr
    ■ Linux
    ■ FreeRTOS
  ○ Porting of the framework still necessary for many commonly used platforms
What’s Supported Today

- Range of use cases:
  - Interfaces: message passing, file-system, block, graphics, network
- Provide consistent and portable application interfaces across:
  - Environments: Linux kernel and user-space, FreeRTOS, Zephyr, bare-metal
  - Processor architectures: Cortex-A53, Cortex-A72, Cortex-R5, MicroBlaze, x86, MIPS32
  - Secure and Non-Secure modes
  - Threads and Processes (on Linux and RTOSes)
  - Virtualized guests and containers (with hypervisors)
Conclusion

● OpenAMP provides a software framework for developers to
  ○ Enable MPSoC Life Cycle Management (LCM)
  ○ Load firmware across a multi-processor system
  ○ Establish communication between the processors
● OpenAMP provides these features in a platform agnostic manner
Thank you

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contactus@linaro.org