How to Choose a Software Update Mechanism for Embedded Linux Devices

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Konsulko Group

- Services company specializing in Embedded Linux and Open Source Software
- Hardware/software build, design, development, and training services
- Based in San Jose, CA with an engineering presence worldwide
- http://konsulko.com/

Agenda

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- Things to consider
- Common embedded Linux update strategies
- Open source solutions
- Practical examples with Yocto/OpenEmbedded
- Conclusions

Things to Consider: Update Size

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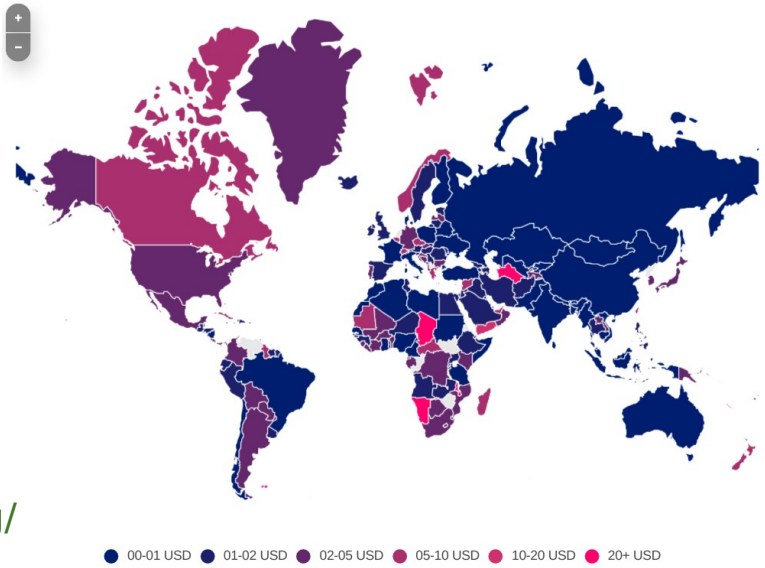
- Are there any limitations of the disk space?
- Are there any limitations of the network bandwidth for the data transfer?



- According to cable.co.uk in the US the average cost of mobile data is $3.33 per 1GB

  https://www.cable.co.uk/mobiles/worldwide-data-pricing/

Things to Consider: Data Transfer

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What are the different ways of transferring data for the updates?

- Over the air using WiFi or cellular data
- Ethernet cable
- USB stick
- Something else

Things to Consider: Managing Devices

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- Do you need to update a single device or multiple devices?
- Are all of devices using the same software stack?
- Are all devices online and do you need to monitor the update of the devices?
- Do you need to update different devices at different times?
- How to update fleet of devices?

Things to Consider: Building Images

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- What distribution and build system do you use?
- Is there a BSP for the hardware you use?
- Is the software update technology compatible with the build system and the BSP?

yocto PROJECT · openembedded

OpenWrt WIRELESS FREEDOM

PTX DIST

debian

Core

Build Frameworks for Embedded Linux Distro

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Popular open source build systems fro custom embedded Linux distributions:

- Yocto/OpenEmbedded
- Buildroot
- PTXdist
- OpenWRT
- Other

Can I just use Debian?

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- Debian is a stable full distribution with tens of thousands of packages available as binary files for installation without the need to cross-compile from source
- Numerous Debian derivatives exist for embedded devices

debian

- Debian or Yocto Project? Which is the Best for your Embedded Linux Project? Chris Simmonds, Embedded Linux Conference Europe 2019 https://www.youtube.com/watch?v=iDllXa8SzUgr

The Yocto Project

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- Open source collaborative project of the Linux foundation for creating custom Linux-based systems for embedded devices using the OpenEmbedded Build System
- OpenEmbedded Build System includes BitBake and OpenEmbedded Core
- Poky is a reference distribution of the Yocto Project provided as metadata, without binary files, to bootstrap your own distribution for embedded devices
- Bi-annual release cycle
- Long term support (LTS) release covering two-year period

Common Embedded Linux Update Strategies

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- A/B updates (dual redundant scheme)
- Delta updates
- Container-based updates
- Combined strategies

A/B Upgrades

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- Dual A/B identical rootfs partitions
- Data partition for storing any persistent data which is left unchanged during the update process
- Typically a client application runs on the embedded device and periodically connects to a server to check for updates
- If a new software update is available, the client downloads and installs it on the other partition
- Fallback in case of update failure

Delta Updates

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- Only the binary delta between the difference is sent to the embedded device
- Works in a Git-like model for filesystem trees
- Saves storage space and connection bandwidth
- Rollback of the system to a previous state

A/B vs Delta Updates

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Update Strategy	Storage Space	Update Size	Rollback to a Previous Stage	Fallback to a Back-up Image on separate partition
A/B Updates	Large	Large	Yes	Yes
Delta Updates	Small	Small	Yes	No

Container-based Updates

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- Container technology has changed the way application developers interact with the cloud and some of the good practices are nowadays applied to the development workflow for embedded Linux devices and Internet of Things
- Containers make applications faster to deploy, easier to update and more secure through isolation
- Yocto/OE layer meta-virtualization provides support for building Xen, KVM, Libvirt, docker and associated packages necessary for constructing OE-based virtualized solutions

Combined Strategies

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Multiple combinations exist for more complicated use cases, for example:

- A/B updates with delta updates
- Containers with A/B updates of the base custom embedded Linux distribution

Popular open source solution for updates

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- Mender
- RAUC
- SWUpdate
- Swupd
- UpdateHub
- Balena
- Snap
- libostree (OSTree)
- Aktualizr
- Aktualizr-lite
- QtOTA
- Torizon
- FullMetalUpdate
- Rpm-ostree (used in Project Atomic)

Mender

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- Available as a free open source or paid commercial/enterprise plans
- **A/B** update scheme for open source and all plans as well as **delta** updates for professional and enterprise plans
- Back-end services (Hosted Mender)
- Written in Go, Python, JavaScript
- Yocto/OE integration through meta-mender and extra BSP layers: https://github.com/mendersoftware/meta-mender
- Source code in GitHub under Apache 2.0

MENDER

Mender Supported Devices

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The following hardware platforms and development boards are supported:

- Raspberry Pi
- BeagleBone
- Intel x86-64
- Rockchip
- Allwinner
- NXP
- And more in: https://github.com/mendersoftware/meta-mender-community

meta-mender-community

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dunfell | 8 branches | 0 tags | Go to file | Add file | Code

TheYoctoJester Merge pull request #270 from OE4T/dunfell-l4t-r32.7.2 ... f1f4089 10 days ago 514 commits

.github	Added a configuration file for stalebot	2 years ago
meta-mender-amlogic	Change repo sync manifest form git protocol to https	last month
meta-mender-atmel	Change repo sync manifest form ssh to https	2 months ago
meta-mender-beaglebone	Remove maintainer from readme	11 months ago
meta-mender-clearfog	clearfog: fix missing $ in local.append template	3 years ago
meta-mender-coral	Remove maintainer from readme	11 months ago
meta-mender-intel	meta-mender-intel: change README.md to dunfell	6 months ago
meta-mender-nxp	Remove maintainer from readme	11 months ago
meta-mender-odroid	Remove maintainer from readme	11 months ago
meta-mender-qemu	Remove maintainer from readme	11 months ago
meta-mender-raspberrypi	Remove maintainer from readme	11 months ago
meta-mender-rockchip	rockchip: update manifest file to point to thud branches	4 years ago
meta-mender-sunxi	Remove maintainer from readme	11 months ago
meta-mender-tegra	tegra: add flash layout, u-boot symlinks for L4T R32.7.2	11 days ago
meta-mender-toradex-nxp	toradex: Refresh u-boot patches and add BSP 5.6.0 support.	23 days ago
meta-mender-up	add support for UP2 board	4 years ago

About

Community supported integration layers for Mender on various boards

- Readme
- Apache-2.0 license
- 36 stars
- 19 watching
- 94 forks

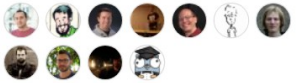
Releases

No releases published

Packages

No packages published

Contributors 25



+ 14 contributors

RAUC

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- A lightweight update client that runs on an Embedded Linux device and reliably controls the procedure of updating the device with a new firmware revision
- Supports multiple update scenarios
- Provides tool for the build system to create, inspect and modify update bundles
- Uses X.509 cryptography to sign update bundles
- Compatible with the Yocto Project, PTXdist and Buildroot

RAUC Licenses

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- RAUC – LGPLv2.1
  https://github.com/rauc/rauc
- meta-rauc - MIT
  https://github.com/rauc/meta-rauc
- rauc-hawkbit – LGPLv2.1
  https://github.com/rauc/rauc-hawkbit
- rauc-hawkbit-updater – LGPLv2.1
  https://github.com/rauc/rauc-hawkbit-updater

RAUC Integration Steps

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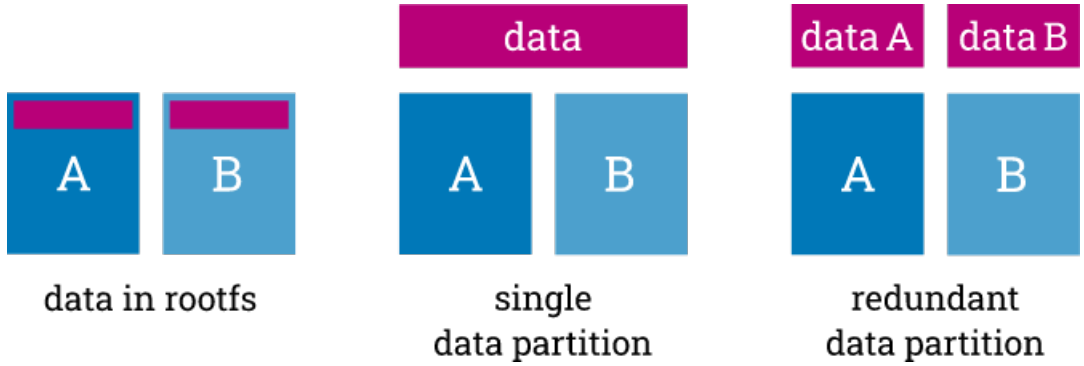
- Select an appropriate bootloader
- Enable **SquashFS** in the Linux kernel configurations
- **ext4** root file system (RAUC does not have an ext2 / ext3 file type)
- Create specific partitions that matches the RAUC slots
- Configure Bootloader environment and create a script to switch RAUC slots
- Create a certificate and a keyring to RAUC’s **system.conf**

RAUC Data Partition

- Supports single and redundant data partitions
- For redundant data partitions the active rootfs slot has to mount the correct data partition dynamically, for example with a udev rule



meta-rauc-community

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- Yocto/OE layer with examples how to integrate RAUC on various machines
- Started in 2020
- Moved to the RAUC organization in GitHub in 2021
- Currently supports x86-64, QEMU, Raspberry Pi through **meta-raspberrypi**, Sunxi (Allwinner) devices through **meta-sunxi**, NVIDIA Jetson TX2 through **meta-tegra**
- https://github.com/rauc/meta-rauc-community/

Contributions are always welcome as GitHub pull requests!

RAUC Example with Raspberry Pi 4

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- Integration layer (branch **Dunfell**):
  https://github.com/rauc/meta-rauc-community/tree/master/meta-rauc-raspberrypi
- Add layers to **bblayers.conf** and add the following configuration to **local.conf**:

```
MACHINE = "raspberrypi4"
DISTRO_FEATURES_append = " systemd"
VIRTUAL-RUNTIME_init_manager = "systemd"
DISTRO_FEATURES_BACKFILL_CONSIDERED = "sysvinit"
VIRTUAL-RUNTIME_initscripts = ""
IMAGE_INSTALL_append = " rauc"
IMAGE_FSTYPES="tar.bz2 ext4 wic.bz2 wic.bmap"
SDIMG_ROOTFS_TYPE="ext4"
ENABLE_UART = "1"
RPI_USE_U_BOOT = "1"
PREFERRED_PROVIDER_virtual/bootloader = "u-boot"
WKS_FILE = "sdimage-dual-raspberrypi.wks.in"
```

Manual RAUC Update of Raspberry Pi 4

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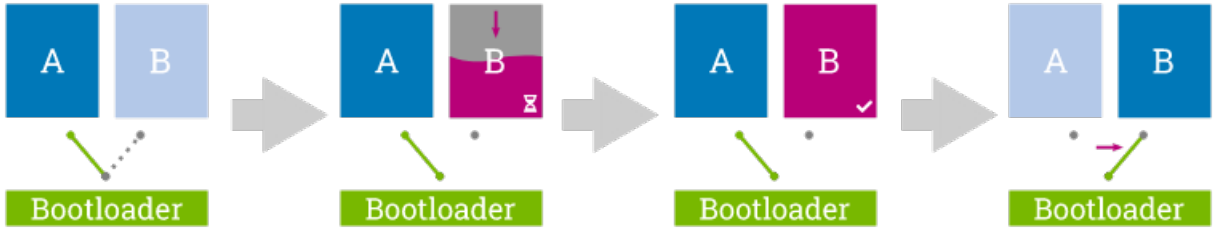
- On the build system:

```
cd tmp/deploy/images/raspberrypi4/
python3 -m http.server
```

- On the embedded device:

```
wget http://example.com:8000/update-bundle-raspberrypi4.raucb -P /tmp
rauc install /tmp/update-bundle-raspberrypi4.raucb
reboot
```



Eclipse hawkBit

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- Domain independent back-end framework for rolling out software updates to constrained edge devices as well as more powerful controllers and gateways connected to IP based networking infrastructure
- Written in Java
- Available in GitHub under EPL-1.0 License
- Compatible with RAUC and SWUpdate
- https://www.eclipse.org/hawkbit/

Mender

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Mender A/B updates supports two client modes:

- Managed (default) - client running as a daemon polls the server for updates
- Standalone - updates are triggered locally which is suitable for physical media or any network update in pull mode

```
SYSTEMD_AUTO_ENABLE_pn-mender = "disable"
```

```
$ cd tmp/deploy/images/raspberrypi4
$ python3 -m http.server
Serving HTTP on 0.0.0.0 port 8000 (http://0.0.0.0:8000/) ...
```

```
$ mender -install http://example.com:8000/core-image-base-raspberrypi4.mender
```

Mender Data Partition

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- Mender creates a **/data** partition to store persistent data, preserved during Mender updates. Supports ext4, Btrfs and F2FS file systems.
- The Mender client on the embedded devices uses **/data/mender** to preserve data and state across updates
- Variable **MENDER_DATA_PART_SIZE_MB** configures the size of the **/data** partition. By default it is 128 MB. If enabled, mender feature **mender-growfs-data** which relies on **systemd-growfs** tries to resize on first boot with the remaining free space
- It is possible to create an image for the data partition in advance with bitbake:

```
IMAGE_FSTYPES:append = " dataimg"
```

Mender

Steps to install Mender A/B update on embedded Device:

- Apply update
- Reboot
- On the first boot after a successful update, though the Mender client a commit must be performed to accept the update (otherwise the system will roll-back on next reboot)

Mender Single File Artifact

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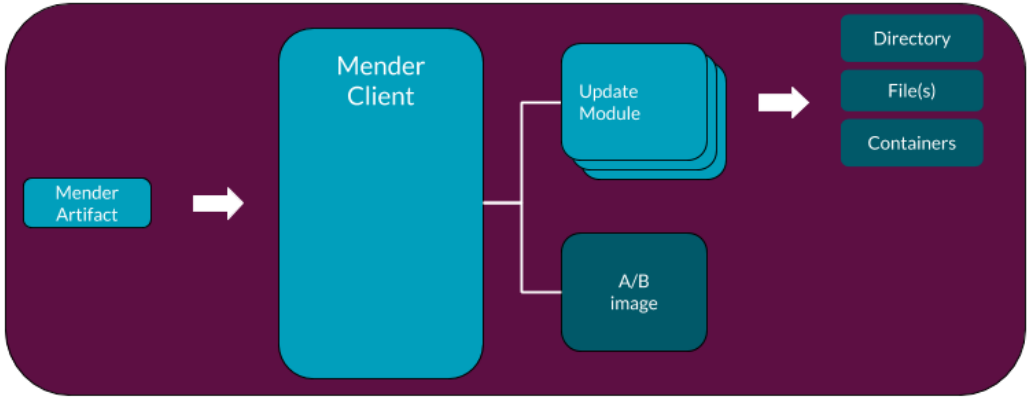
- Deployment of a single file, directory or even a container image is possible through “Application updates”



Mender add-ons

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Mender supports several add-ons:

- **Remote Terminal** - interactive shell sessions with full terminal emulation
- **File Transfer** - upload and download files to and from a device
- **Port Forward** - forward any local port to a port on a device without opening ports on the device
- **Configure** - apply configuration to your devices through a uniform interface

Mender with x86-64 support

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- Mender added support for x86-64 machines through GRUB in 2018
- Initial installation of the distribution is most commonly done using a live image on a USB stick

Mender Delta Updates

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- Mender offers robust delta update rootfs as a module for the **commercial** Mender plan (**closed source** implementation)
- Requires reboot to apply the update
- Supports rollback
- Tool mender-binary-delta create a binary delta by comparing 2 different Mender artifacts
- Mandatory requirement for the implementation is a **read-only** root file system

Read-only Root Filesystem

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Yocto and OpenEmbedded offer two options to create a read-only root filesystem:

- Thought the image's recipe file:

```
IMAGE_FEATURES += "read-only-rootfs"
```

- Alternatively, through **local.conf**:

```
EXTRA_IMAGE_FEATURES = "read-only-rootfs"
```

- Beware, there might be packages in the image that expect the root filesystem to be writable and might not function properly. A solution is to move these files and directories to the data partition.

Combined Strategies with Containers

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- Yocto/OE layer **meta-virtualization** provides support for building Xen, KVM, Libvirt, docker and associated packages necessary for constructing OE-based virtualized solutions
- **virtualization** has to be added to the **DISTRO_FEATURES**:

```
DISTRO_FEATURES:append = " virtualization"
```

- For example adding Docker to the embedded Linux distribution is easy:

```
IMAGE_INSTALL:append = " docker-ce"
```

- There are use cases on powerful embedded devices where containers are combined with A/B updates of the base Linux distribution built with Yocto/OE, for example with RAUC or Mender

libostree

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- Libostree (previously known as “OSTree”), is a shared library and tools for distributing and deploying file system images as atomic upgrades of the whole file system tree
- Provides a suite of command line tools that combines a “git-like” model for committing and downloading bootable filesystem trees, along with a layer for deploying them and managing the bootloader configuration.
- Effective with respect to disk space and connection bandwidth
- Supports rollback of the system to a previous state
- Used in many embedded Linux solutions: Fedora IoT, Torizon, Aktualizr, Aktualizr-lite and QtOTA

libostree

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- libostree encourages systems to implement UsrMove
  https://www.freedesktop.org/wiki/Software/systemd/TheCaseForTheUsrMerge/
- libostree comes with optional dracut+systemd integration:
  https://ostreedev.github.io/ostree/adapting-existing/
- libostree only preserves /var across upgrades
- /var is empty by default and the operating system needs to dynamically create the targets of these at boot, for example with systemd-tmpfiles (if using systemd)

Aktualizr and Aktualizr-lite with libostree

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- Aktualizr is a C++ application that implements the client-side functionality for OTA Connect according to the Uptane security framework
- libaktualizr provides API calls to perform the various steps that are necessary for checking for updates, validating the files downloaded, etc
  https://github.com/advancedtelematic/aktualizr
- Aktualizr-lite is a C++ implementation of TUF OTA update client based on aktualizr without the complexity of Uptane
  https://github.com/foundriesio/aktualizr-lite
- Yocto/OE integration:
  https://github.com/advancedtelematic/meta-updater
  https://github.com/foundriesio/meta-lmp

Conclusion

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- There are numerous things to consider when implementing an upgrade mechanism for an embedded Linux device
- There are many reliable open source software solutions to upgrade embedded Linux devices to use and worth developing another proprietary homegrown solution
- Combined update strategies such as A/B upgrades with containers for applications are increasingly popular nowadays
- The update process implementation depends on the build system and the bootloader
- Often real-world solutions require a persistent data partition which is left unchanged during the update process

Thank You!

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Useful links:

- https://www.yoctoproject.org/
- https://mender.io/
- https://rauc.io/
- https://ostreedev.github.io/ostree/
- https://www.konsulko.com/building-platforms-with-secure-over-the-air-updating/
- https://www.konsulko.com/how-mender-works/
- https://www.konsulko.com/getting-started-with-rauc-on-raspberry-pi-2/