



System updates and rollback

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68	This document focuses on the system update mechanism, but also partly ad-	
69	dresses applications and how they interact with it.	
70	<b>Definitions</b>	
71	<b>Base OS</b>	
72	The core components of the operating system that are used by almost all Apertis	
73	users. Hardware control, resource management, service life cycle monitoring,	
74	networking	
75	<b>Applications</b>	
76	Components that work on top of the base OS and are specific to certain usages.	

## 77 **Use cases**

78 A variety of use cases for system updates and rollback are given below.

### 79 **Embedded device on the field**

80 An Apertis device is shipped to a location that cannot be easily accessed by a  
81 technician. The device should not require any intervention in the case of errors  
82 during the update process and should automatically go back to a know-good  
83 state if needed.

84 The update process should be robust against power losses and low voltage situ-  
85 ations, loss of connectivity, storage exhaustion, etc.

### 86 **Typical system update**

87 The user can update his system to run the latest published version of the soft-  
88 ware. This can be triggered either via periodic polling, upon user request, or  
89 any other suitable mean.

### 90 **Critical security update**

91 In the case of a critical security issue, the OEM could push an “update avail-  
92 able”message to some component in the device that would in turn trigger the  
93 update. This requires an infrastructure to reference all devices on the OEM side.  
94 The benefit compared to periodic polling is that the delay between the update  
95 publication and the update trigger is shortened.

### 96 **Applications and base OS with different release cadence**

97 Base OS releases involve many moving parts while application releases are sim-  
98 pler, so application authors want a faster release cadence decoupled from the  
99 base OS one.

### 100 **Shared base OS**

101 Multiple teams using the same hardware platform want to use the same base  
102 OS and differentiate their product purely with applications on top of it.

### 103 **Reselling a device**

104 Under specific circumstances, the user might want to reset his device to a clean  
105 state with no device-specific or personal data. This can happen before reselling  
106 the device or the user encountered an unexpected failure.

## 107 **Non use cases**

### 108 **User modified device**

109 The user has modified his device. For example, they mounted the file system  
110 read write, and tweaked some configuration files to customize some features. As  
111 a result, the system update mechanism may no longer be functional.

112 It might still be possible to restore the operating system to a factory state but  
113 the system update mechanism cannot guarantee it.

### 114 **Unrecoverable hardware failure**

115 An hardware failure has damaged the flash storage or another core hardware  
116 component and the system is no longer able to boot. Compensating for hardware  
117 failures is not part of the system update mechanism.

### 118 **Unrecoverable file system corruption**

119 The file system became corrupted due to a software bug or other failure and is  
120 not able to automatically correct the error. How to recover from that situation  
121 is not part of the system update and rollback mechanism.

## 122 **Development**

123 Developers need to modify and customize their environment in a way that often  
124 conflicts with the requirements for devices on the field.

## 125 **Requirements**

### 126 **Minimal resource consumption**

127 Some devices only have a very limited amount of available storage, the system  
128 update mechanism must keep the impact storage requirement as low as possible  
129 and have a negligible impact at runtime.

### 130 **Work on different hardware platforms**

131 Different devices may use different CPU architectures, bootloaders, storage tech-  
132 nologies, partitioning schemas and file system formats.

133 The system update mechanism must be able to work across them with mini-  
134 mal changes, ranging from single-partition systems running UBIFS on NAND  
135 devices to more common storage devices using traditional file systems over mul-  
136 tiple partitions.

## 137 **Every updated system should be identical to the reference**

138 The file system contents of the base OS on the updated devices must match  
139 exactly the file system used during testing to ensure that its behavior can be  
140 relied upon.

141 This also means that applications must be kept separate from the base OS to  
142 be able to update them while keeping the base OS immutable.

## 143 **Atomic update**

144 To guarantee robustness in case of errors, every update to the system must be  
145 atomic.

146 This means that if an update is not successful, it must not be partially installed.  
147 The failure must leave the device in the same state as if the update did not start  
148 and no intermediate state must exist.

## 149 **Rolling back to the last known good state**

150 If the system cannot boot correctly after an update has been installed success-  
151 fully it must automatically roll back to a known working version.

152 Applications must be kept separated to be able to roll back the base OS while  
153 preserving them or to roll them back while keeping the base OS unchanged.

154 The policy deciding what to roll back and when is product-specific and must  
155 be customizable. For instance, some products may chose to only roll back the  
156 base OS and keep applications untouched, some other products may choose to  
157 roll applications back as well.

158 Rollbacks can be misused to perform [downgrade attacks](#)<sup>1</sup> where the attacker  
159 purposefully initiates a rollback to an older version to leverage vulnerabilities  
160 fixed in the currently deployed version.

161 For this reason care need to be taken about the conditions on which a rollback  
162 is to be initiated. For instance, if the system is not explicitly in the process of  
163 performing an upgrade, rollback should never be initiated even in case of boot  
164 failure as those are likely due to external reasons and rolling back to a previous  
165 version would not produce any benefit. Relatedly, once a specific version has  
166 been booted successfully, the system should never roll back to earlier versions.  
167 This also simplifies how applications have to deal with base OS updates: since  
168 the version of the successfully booted deployment can only monotonically in-  
169 crease, user applications that get launched after the successful system boot has  
170 been confirmed will never have to deal with downgrades.

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<sup>1</sup>[https://en.wikipedia.org/wiki/Downgrade\\_attack](https://en.wikipedia.org/wiki/Downgrade_attack)

## 171 **Reset to clean state**

172 The user must be able to restore his device to a clean state, destroying all user  
173 data and all device-specific system configuration.

## 174 **Update control interface**

175 An interface must be provided by the updates and rollback mechanism to allow  
176 HMI to query the current update status, and trigger updates and rollback.

## 177 **Handling settings and data**

178 System upgrades should keep both settings and data safe and intact as this  
179 process should be as transparent as possible to the end user. As described in  
180 [preferences and persistence](#)<sup>2</sup> settings have a default value, which can change on  
181 upgrade, this results in the required solution being more complex than it might  
182 initially seem.

## 183 **Existing system update mechanisms**

### 184 **Debian tools**

185 The Debian package management binds all the software in the system. This can  
186 be very convenient and powerful for administration and development, but this  
187 level of management is not required for final users of Apertis. For example:

- 188 • Package administration command line tools are not required for final users.
- 189 • No support for update roll back. If there is some package breakage, or  
190 broken upgrade, the only way to solve the issue is manually tracking the  
191 broken package and downgrading to a previous version, solving dependen-  
192 cies along the way. This can be an error prone manual process and might  
193 not be accomplished cleanly.

194 In relation to system settings as defined in [preferences and persistence](#)<sup>3</sup>, Debian  
195 tools use a very simple approach. On package upgrades the `dpkg` will perform a  
196 check taking into account

- 197 • current version default configuration file
- 198 • new version default configuration file
- 199 • current configuration file

200 Different scenarios arise depending on whether user has applied changes to the  
201 configuration file. If current default configuration file is the same as current,

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<sup>2</sup>[https://www.apertis.org/concepts/archive/application\\_customization/preferences-and-persistence/](https://www.apertis.org/concepts/archive/application_customization/preferences-and-persistence/)

<sup>3</sup>[https://www.apertis.org/concepts/archive/application\\_customization/preferences-and-persistence/](https://www.apertis.org/concepts/archive/application_customization/preferences-and-persistence/)

202 then the user hadn't change it, which implies that it can be safely upgraded (if  
203 it is required).

204 However, if the current default configuration file is different from current the  
205 user had applied some changes, so it can't be upgraded silently. In this case  
206 `dpkg` asks the user to choose the version to use. This approach is not suitable  
207 for automated upgrades where there is no user interaction.

208 To overcome some of these limitations modern systems tend to use overlays to  
209 have a read-only partition with default values and an upper layer with custom  
210 values.

## 211 **ChromeOS**

212 ChromeOS uses an A/B parallel partition approach. Instead of upgrading the  
213 system directly, it installs a fresh image into B partition for kernel and rootfs,  
214 then flag those to be booted next time.

215 The partition metadata contains boot fields for the boot attempts (successful  
216 boots) and these are updated for every boot. If a predetermined number of  
217 unsuccessful boots is reached, the bootloader falls back to the other partition,  
218 and it will continue booting from there until the next upgrade is available. When  
219 the next upgrade becomes available it will replace the failing installation and  
220 will attempt booting from there again.

221 There are some drawbacks to this approach when compared to OSTree:

- 222 • The OS installations are not deduplicated, the system stores the entire  
223 contents of the A and B installations separately, where as OSTree based  
224 systems only store the base system plus a delta between this and any  
225 update using Unix hard links. This means an update to the system only  
226 requires disk space proportional to the changed files.
- 227 • The A/B approach can be less efficient since it will need to add extra  
228 layers to work with different partitions, for example, using a specific layer  
229 to verify integrity of the block devices, where OSTree directly handles  
230 operating system views and a content addressable data store (file system  
231 user space) avoiding the need of having different layers.
- 232 • Several partitions are usually required to implement this model, reducing  
233 the flexibility with which the storage space in the device can be utilized.

## 234 **Approach**

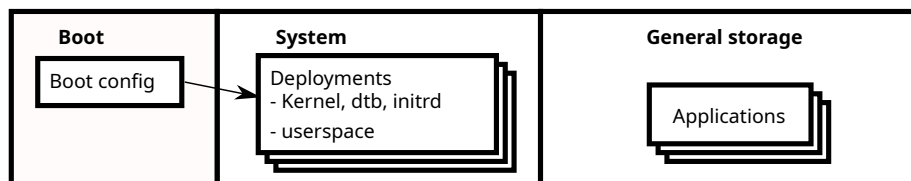
235 Package-based solutions fail to meet the robustness requirements, while dual  
236 partitioning schemes have storage requirements that are not viable for smaller  
237 devices.



238 OSTree<sup>4</sup> provides atomic updates on top of any POSIX-compatible file system  
239 including UBIFS on NAND devices, is not tied to a specific partitioning scheme  
240 efficiently handles the available storage.

241 No specific requirements are imposed on the partitioning schema. Use of  
242 the GUID Partition Table (GPT<sup>5</sup>) system for partition management is  
243 recommended for being flexible while having fail-safe measures, like keeping  
244 checksums of the partition layout and providing some redundancy in case  
245 errors are detected.

246 Separating the system volume from the general storage volume, where applica-  
247 tions and user data are stored, is also recommended.



## GPT Partitions

248

249 More complex schemas can be used for instance by combining OSTree with read-  
250 only fallback partitions to handle file system corruption on the main system  
251 partition, but this document focuses on a OSTree-only setup that provides a  
252 good balance between complexity and robustness.

## Advantages of using OSTree

253

- 254 • OSTree operates at the Unix file system layer and thus on top of any  
255 file system or block storage layout, including NAND flash setups, and in  
256 containers.
- 257 • OSTree does not impose strict requirements on the partitioning scheme  
258 and can scale down to a single partition while fully preserving its resiliency  
259 guarantees, saving space on the device and avoiding extra layers of com-  
260 plexity (for example, to verify partition blocks). Depending on the setup,  
261 multiple partitions can still be used effectively to separate contents with  
262 different life cycles, for instance by storing user data on a different parti-  
263 tion than the system files managed by OSTree.
- 264 • OSTree commits are centrally created offline (server side), and then they  
265 are deployed by the client. This gives much more control over what the  
266 devices actually run.
- 267 • It can store multiple file systems trees in a single repository.
- 268 • It is designed to implement fully atomic and resilient upgrades. If the  
269 system crashes or power is lost at any point during the update process,

<sup>4</sup><https://ostreedev.github.io/ostree/>

<sup>5</sup>[http://en.wikipedia.org/wiki/GUID\\_Partition\\_Table](http://en.wikipedia.org/wiki/GUID_Partition_Table)

270 you will have either the old system, or the new one.

- 271 • It clearly separate the OS from the device configuration and user data,
- 272 so resetting the system to a clean state simply involves deleting some
- 273 directories and their contents.
- 274 • OSTree is implemented as a shared library, making it very easy to build
- 275 higher level projects or tools on top of it.
- 276 • The files in `/usr` contents are mounted read-only from subfolders of `/os-`
- 277 `tree/deploy`, minimizing the chance of accidental deletions or changes.
- 278 • OSTree has no impact on startup performance, nor does increase resource
- 279 usage during runtime: since OSTree is just a different way to build the
- 280 rootfs once it is built it will behave like a normal rootfs, making it very
- 281 suitable for setups with limited storage.
- 282 • OSTree already offers a mechanism suitable for offline updates using static
- 283 deltas, which can be used for updates via a mass-storage device.
- 284 • Security is at the core of OSTree, offering content replication incrementally
- 285 over HTTPS via cryptographic signatures (using the ED25519 algorithm
- 286 on Apertis) and SHA256 hash checksums.
- 287 • The mechanism to apply partial updates or full updates is exactly the
- 288 same, the only difference is how the updates are generated on the server
- 289 side.
- 290 • OSTree can be used for both the base OS and applications, and its built-in
- 291 hard link-based deduplication mechanism allow to share identical contents
- 292 between the two, to keep them independent while having minimal impact
- 293 on the needed storage. The Flatpak application framework is already
- 294 based on OSTree.

## 295 **The OSTree model**

296 The conceptual model behind OSTree repositories is very similar to the one used  
297 by `git`, to the point that the [introduction in the OSTree manual](#)<sup>6</sup> refers to it as  
298 “git for operating system binaries”.

299 Albeit they take different tradeoffs to address different use-cases they both have:

- 300 • file contents stored as blobs addressable by their hash, deduplicating them
- 301 • file trees linking filenames to the blobs
- 302 • commits adding metadata such as dates and comments on top of file trees
- 303 • commits linked in a history tree
- 304 • branches pointing to the most recent commit in a history tree, so that
- 305 clients can find them

306 Where `git` focuses on small text files, OSTree focuses on large trees of binary  
307 files.

308 On top of that OSTree adds other layers which go beyond storing and distribut-  
309 ing file contents to fully handle operating system upgrades:

---

<sup>6</sup><https://ostreedev.github.io/ostree/introduction/>

- 310 • repositories - store one or more versions of the file system contents as
- 311 described above
- 312 • deployments - specific file system versions checked-out from the repository
- 313 • stateroots - the combination of immutable deployments and writable di-
- 314 rectories

315 Each device hosts a local OSTree repository with one or more deployments  
316 checked out.

317 Checked out deployments look like traditional root file systems. The bootloader  
318 points to the kernel and initramfs carried by the deployment which, after setting  
319 up the writable directories from the stateroot, are responsible for booting the  
320 system. The bootloader is not part of the updates and remains unchanged for  
321 the whole lifetime of the device as any changes has a high chance to make the  
322 system unbootable.

- 323 • Each deployment is grouped in exactly one `stateroot`, and in normal cir-
- 324 cumstances Apertis devices only have a single `apertis` stateroot.
- 325 • A `stateroot` is physically represented in the `/ostree/deploy/$stateroot` di-
- 326 rectory, `/ostree/deploy/apertis` in this case.
- 327 • Each `stateroot` has exactly one copy of the traditional Unix `/var` directory,
- 328 stored physically in `/ostree/deploy/$stateroot/var`. The `/var` directory is
- 329 persisted during updates, when moving from one deployment to another
- 330 and it is up to each operating system to manage this directory.
- 331 • On each device there is an OSTree repository stored in `/ostree/repo`, and
- 332 a set of deployments stored in `/ostree/deploy/$stateroot/$checksum`.
- 333 • A deployment begins with a specific `commit` (represented by a SHA256
- 334 hash) in the OSTree repository in `/ostree/repo`. This `commit` refers to a file
- 335 system tree that represents the underlying basis of a deployment.
- 336 • Each deployment is primarily composed of a set of hard links into the
- 337 repository. This means each version is deduplicated; an upgrade process
- 338 only costs disk space proportional to the new files, plus some constant
- 339 overhead.
- 340 • The read-only base OS contents are checked out in the `/usr` directory of
- 341 the deployment.
- 342 • Each deployment has its own writable copy of the configuration store `/etc`.
- 343 • Deployments don't have a traditional UNIX `/etc` but ship it instead as
- 344 `/usr/etc`. When OSTree checks out a deployment it performs a 3-way
- 345 merge using the old default configuration, the active system's `/etc`, and
- 346 the new default configuration.
- 347 • Besides the exceptions of `/var` and `/etc` directories, the rest of the contents
- 348 of the tree are checked out as hard links into the repository.
- 349 • Both `/etc` and `/var` are persistent writable directories that get preserved
- 350 across upgrades. Additionally since `/home` is used to store user specific
- 351 data it is also writable and preseved across updates.

## 352 Resilient upgrade workflow

353 The following steps are performed to upgrade a system using OSTree:

- 354 • The system boots using the existing deployment
- 355 • A new version is made available as a new OSTree commit in the local  
356 repository, either downloading it from the network or by unpacking a  
357 static delta shipped on a mass storage device.
- 358 • The data is validated for integrity and appropriateness.
- 359 • The new version is deployed.
- 360 • The system reboots into the new deployment.
- 361 • If the system fails to boot properly (which should be determined by the  
362 system boot logic), the system can roll back to the previous deployment.

363 During the upgrade process, OSTree will take care of many important details,  
364 like for example, managing the bootloader configuration and correctly merging  
365 the `/etc` directory.

366 Each `commit` can be delivered to the target system over the air or by attaching a  
367 mass storage device. Network upgrades and mass storage upgrades only differ  
368 in the mechanism used by `ostree` to detect and obtain the update. In both cases  
369 the `commit` is first stored in a temporary directory, validated and only then it  
370 becomes part of the local OSTree repository before the real upgrade process  
371 starts by rebooting in the new deployment.

372 Metadata such as EdDSA or GPG signatures can be attached to each `commit` to  
373 validate it, ensuring it is appropriate for the current system and it has not been  
374 corrupted or tampered. The update process must be interrupted at any point  
375 during the update process should any check yield an invalid result; the [atomic  
376 upgrades mechanism in OSTree<sup>7</sup>](#) ensures that it is safe to stop the process at  
377 any point and no change is applied to the system up to the last step in the  
378 process.

379 The atomic upgrades mechanism in OSTree ensures that any power failure dur-  
380 ing the update process leaves the current system state unchanged and the up-  
381 date process can be resumed re-using all the data that has already been already  
382 validated and included in the local repository.

## 383 Online web-based OTA updates

384 OSTree supports bandwidth-efficient retrieval of updates over the network.

385 The basic workflow involves the actors below:

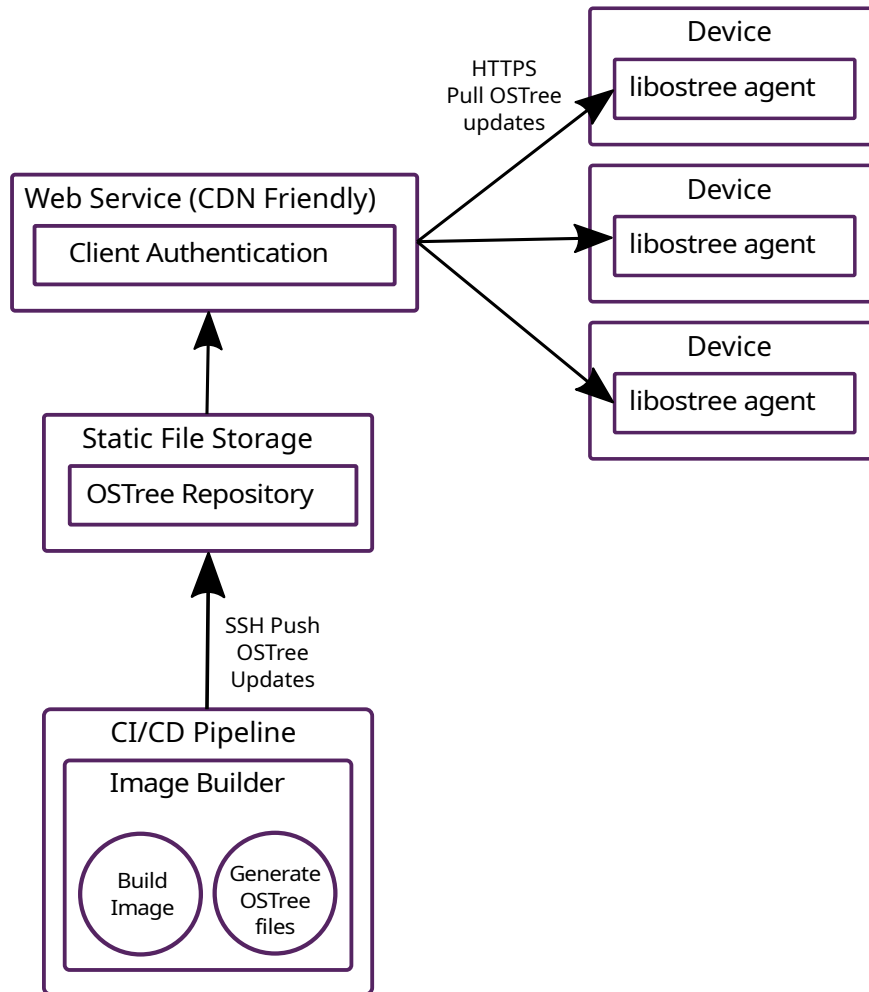
- 386 • the image building pipelines pushes commits to an OSTree repository on  
387 each build;

---

<sup>7</sup><https://ostreedev.github.io/ostree/atomic-upgrades/>

- a standard web server provides access over HTTPS to the OSTree repository handling it as a plain hierarchy of static files, with no special knowledge of OSTree;
- the client devices poll the web server and retrieve updates when they get published.

The following diagram shows how the data flows across services when using the web based OSTree upgrade mechanism.



Thanks to its repository format, OSTree client devices can efficiently query the repository status and retrieve only the changed contents without any OSTree-specific support in the web server, with the repository files being served as plain static files.

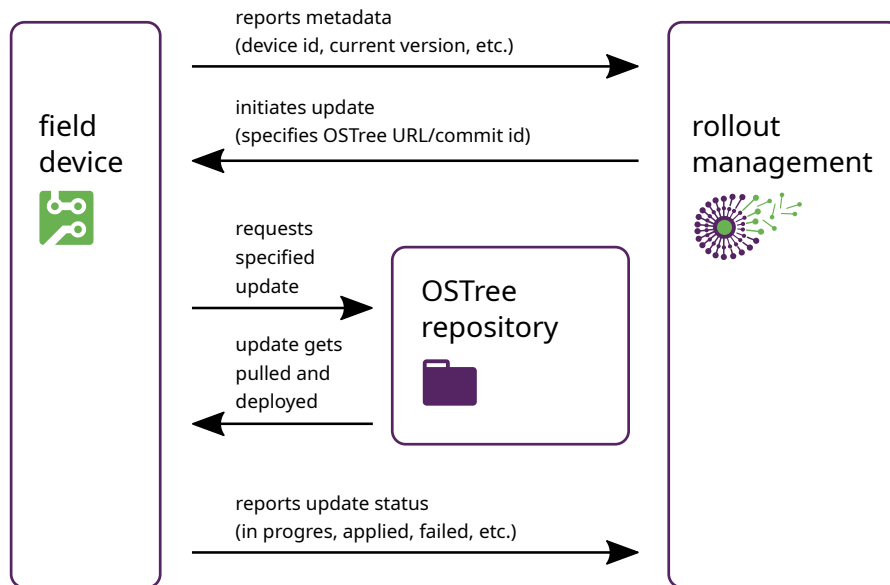
400 This means that any web hosting provider can be used without any loss of  
401 efficiency.

402 By only requiring static files, the web service can easily take advantage of CDN  
403 services to offer a cost efficient solution to get the data out to the devices in a  
404 way that is globally scalable.

405 The authentication to the web service can be done via HTTP Basic authentica-  
406 tion, SSL/TLS client certificates, or any cookie-based mechanism that is most  
407 suitable for the chosen web service, as OSTree does not impose any constraint  
408 over plain HTTPS. OSTree separately checks the chain of trust linking the down-  
409 loaded updates to the keys trusted by the system update manager. See also the  
410 [Controlling access to the updates repository](#) and [Verified updates](#) sections in  
411 this regard.

412 Monitoring and management of devices can be built using the same HTTPS  
413 access as used by OSTree or using completely separated mechanisms, enabling  
414 the integration of OSTree updates into existing setups.

415 For instance, integration with roll out management suites like [Eclipse hawkBit](#)<sup>8</sup>  
416 can happen by disabling the polling in the OSTree updater and letting the man-  
417 agement suite tell OSTree which commit to download and from where through  
418 a dedicated agent running on the devices.



419

420 This has the advantage that the roll out management suite would be in complete  
421 control of which updates should be applied to which devices, implementing

<sup>8</sup><https://www.eclipse.org/hawkbit/>

422 any kind of policies like progressive staged roll outs with monitoring from the  
423 backend with minimal integration.

424 Only the retrieval and application of the actual update data on the device  
425 would be offloaded to the OSTree-based update system, preserving its network  
426 and storage efficiency and the atomicity guarantees.

## 427 **Offline updates**

428 Some devices may not have any connectivity, or bandwidth requirements may  
429 make full system updates prohibitive. In these cases updates can be made  
430 available offline by providing OSTree “static delta”files on external media devices  
431 like USB mass storage devices.

432 The deltas are simple static files that contains all the differences between two  
433 specific OSTree commits. The user would download the delta file from a web  
434 site and put it in the root of an external drive. After the drive is mounted, the  
435 update management system would look for files with a specific name pattern in  
436 the root of the drive. If an appropriate file is found, it is checked to be a valid  
437 OSTree static bundle with the right metadata and, if that verification passes,  
438 the user would get a notification saying that updates are available from the drive.  
439 If the update file is corrupted, is targeted to other platforms or devices, or is  
440 otherwise invalid, the upgrade process must stop, leaving the system unchanged  
441 and a notification may be reported to the user about the identified issues.

442 Static deltas can be partial if the devices are known beforehand to have a specific  
443 OSTree commit already available locally, or they can be full by providing the  
444 delta from the `NULL` empty commit, thus ensuring that the update can be applied  
445 without any assumption on the version running on the devices at the expense  
446 of a potential increase of the requirements on the mass storage device used to  
447 ship them. Both partial and full deltas leading to the same OSTree commit will  
448 produce identical results on the devices.

## 449 **Switching to the new branch**

450 The branches naming schema used in Apertis contains the major version, for  
451 instance: `apertis/v2022/armhf-uboot/fixedfunction`. So for Apertis the “major  
452 upgrade”is technically considered as switching to another branch with a more re-  
453 cent Apertis version, for example `apertis/v2023/armhf-uboot/fixedfunction`. By  
454 default such kinds of offline upgrade with switching to another branch is re-  
455 stricted by the update manager.

456 Offline upgrades between branches (including “major updates”) consists of 2  
457 steps which should be a part of offline upgrade:

- 458 1. Prepare the proper commit at build time

459 This step is pretty simple –while preparing the relevant commit we just  
460 need to add the branch name(s) from which we are supposed to be able

461 to upgrade to the current version. For example, while preparing commit  
462 for v2021 version just add following into `ostree-commit` action:

```
463 ref-binding:  
464 - apertis/v2021/{{$architecture}}-{{$board}}/{{$type}}  
465 - apertis/v2020/{{$architecture}}-{{$board}}/{{$type}}
```

466 this produce the commit compatible with version v2020 allowing to install  
467 the new OS version v2021 onto the board.

## 468 2. Set correct refs in repository

469 After successful boot of the updated version all refs in `libostree` repository  
470 are still pointing to the previous branch due the nature of offline upgrade.

471 This needs to be fixed for proper detection of further upgrades, including  
472 updates over the air. It is the responsibility of the update manager to  
473 update the refs once the update has been determined to be successful.

474 This functionality requires no changes to be made to previously released OSTree  
475 versions. The configuration that determines upgrade paths is held in the newer  
476 OSTree commit.

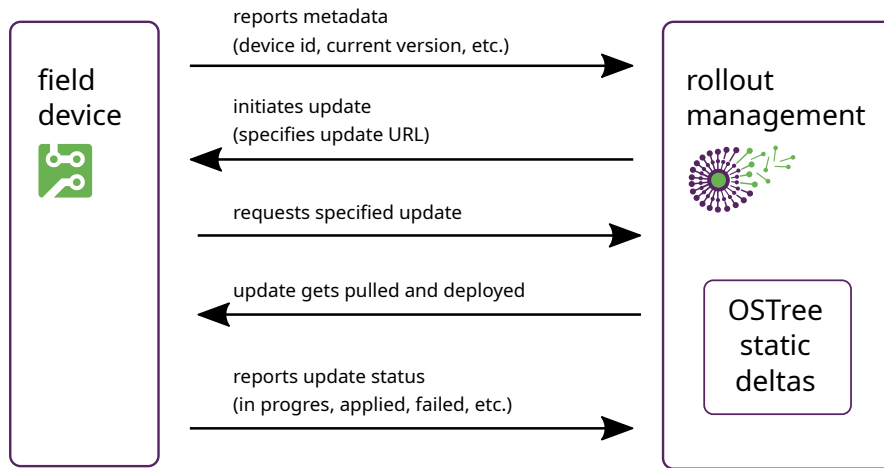
477 Apertis currently only supports upgrades to newer versions, downgrades to older  
478 versions of Apertis are not supported.

## 479 **Online web-based OTA updates using OSTree Static Deltas**

480 The OSTree based OTA update mechanism described above, whilst taking full  
481 advantage of OSTree's repositories, may not suit all users of Apertis. Where  
482 existing deployment services such as hawkBit are already deployed, a need to  
483 expose and maintain an extra service, the OSTree repository, may not be  
484 welcome.

485 The ability of OSTree to perform updates using static deltas provides us with  
486 the option to serve these via the deployment infrastructure instead of serving  
487 updates from the OSTree repository.





488

489 Such an approach would likely need to utilize full OSTree deltas in order to  
 490 ensure updates were viable on target devices regardless of how frequently they  
 491 had previously been updated. As a result this approach does not take advantage  
 492 of the bandwidth efficiency that would be presented by **Online web-based OTA**  
 493 **updates** as previously discussed, however it does enable updates to be performed  
 494 via existing installed deployment infrastructure.

495 This is the approach currently used by the Apertis example implementation.

## 496 OSTree security

497 OSTree is a distribution method. It can secure the downloading of the update  
 498 by verifying that it is properly signed using public key cryptography (EdDSA  
 499 or GPG). It is largely orthogonal to verified boot, that is ensuring that only  
 500 signed data is executed by the system from the bootloader, to the kernel and  
 501 user space. The only interaction is that since OSTree is a file-based distribution  
 502 mechanism, block-based verification mechanism like `dm-verity` cannot be used.  
 503 OSTree can be used in conjunction with signed bootloader, signed kernel, and  
 504 IMA (Integrity Measurement Architecture) to provide protection from offline  
 505 attacks.

## 506 Verified boot

507 Verified boot is the process which ensures a device is only runs signed code. This  
 508 is a layered process where each layer verifies signature of its upper layer.

509 The bottom layer is the hardware, which contains a data area reserved to certifi-  
 510 cates. The first step is thus to provide a signed bootloader. The processor can  
 511 verify the signature of the bootloader before starting it. The bootloader then  
 512 reads the boot configuration file. It can then run a signed kernel and initramfs.  
 513 Once the kernel has started, the initramfs mounts the root file system.

514 At the time of writing, the boot configuration file is not signed. It is read and  
515 verified by signed code, and can only point to signed components.

516 Protecting bootloader, kernel and initramfs already guarantees that policies  
517 baked in those components cannot be subverted through offline attacks. By  
518 verifying the content of the rootfs the protection can be extended to user space  
519 components, albeit such protection can only be partial since device-local data  
520 can't be signed on the server-side like the rest of the rootfs.

521 To protect the rootfs different mechanisms are available: the block-based ones  
522 like `dm-verity` are fundamentally incompatible with file-based distribution meth-  
523 ods like OSTree, since they rely on the kernel to verify the signature on each  
524 read at the block level, guaranteeing that the whole block device has not been  
525 changed compared to the version signed at deployment time. Due to working  
526 on raw block devices, `dm-verity` is also incompatible with UBIFS and thus it is  
527 unsuitable for NAND devices.

528 Other mechanisms like IMA (Integrity Measurement Architecture) work instead  
529 at the file level, and thus can be used in conjunction with UBIFS and OSTree  
530 on NAND devices.

531 It is also possible to check that the deployed OSTree rootfs matches the server-  
532 provided signature without using any other mechanism, but unlike IMA and  
533 `dm-verity` such check would be too expensive to be done during file access.

### 534 **Verified updates**

535 Once a verified system is running, an OSTree update can be triggered. Apertis is  
536 using [ed25519](https://ed25519.cr.yp.to/)<sup>9</sup> variant of EdDSA signature. Ed25519 ensures that the commit  
537 was not modified, damaged, or corrupted.

538 On the server, OSTree commits must be signed using ed25519 secret key. This  
539 occurs via the `ostree sign --sign-type=ed25519 <COMMIT_ID>` command line. The  
540 secret key could be provided via additional CLI parameter or file by using option  
541 `--keys-file=<path_to_file>`.

542 OSTree expect what secret key consists of 64 bytes (32b seed + 32b public)  
543 encoded with base64 format. The ed25519 secret and public parts could be  
544 generated by numerous utilities including `openssl`, for instance:

```
545 openssl genpkey -algorithm ed25519 -outform PEM -out ed25519.pem
```

546 Since OSTree is not capable to use PEM format directly, it is needed to [extract](#)  
547 [the secret and public keys](#)<sup>10</sup> from PEM file, for example:

```
548 PUBLIC="$(openssl pkey -outform DER -pubout -in ${PEMFILE} | tail -  
549 c 32 | base64) "
```

```
550 SEED="$(openssl pkey -outform DER -in ${PEMFILE} | tail -c 32 | base64) "
```

---

<sup>9</sup><https://ed25519.cr.yp.to/>

<sup>10</sup><http://openssl.6102.n7.nabble.com/ed25519-key-generation-td73907.html>

551 As mentioned above, the secret key is concatenation of SEED and PUBLIC  
552 parts:

```
553 SECRET="$(echo ${SEED}${PUBLIC} | base64 -d | base64 -w 0)"
```

554 On the client, ed25519 is also used to ensure that the commit comes from a  
555 trusted provider since updates could be acquired through different methods like  
556 OTA over a network connection, offline updates on plug-in mass storage devices,  
557 or even mesh-based distribution mechanism. To enable the signature check,  
558 repository on the client must be configured by adding option `sign-verify=true`  
559 into the `core` or `per-remote` section, for instance:

```
560 ostree config set 'remote "origin".sign-verify' "true"
```

561 OSTree searches for files with valid public signatures in directories  
562 `/usr/share/ostree/trusted.ed25519.d` and `/etc/ostree/trusted.ed25519.d`. Any  
563 public key in a file in these directories will be trusted by the client. Each  
564 file may contain multiple keys, one base64-encoded public key per string. No  
565 private keys should be present in these directories.

566 In addition it is possible to provide the trusted public key per-remote by  
567 adding into remote's configuration path to the file with trusted public keys (via  
568 `verification-file` option) or even single key itself (via `verification-key`).

569 In the OSTree configuration, the default is to require commits to be signed.  
570 However, if no public key is available, no any commit can be trusted.

### 571 **Offline update files with signed metadata**

572 Starting with version v2020.7 `libostree` supports delta bundles with [signed meta-](#)  
573 [data](#)<sup>11</sup>, which allows to ensure that the whole delta bundle comes from a trusted  
574 source. Previous versions only allowed to assert the provenance of the commits  
575 in the bundle, leaving the metadata unverified.

576 Support for delta bundles with signed metadata is available in the Apertis Up-  
577 date Manager since version 0.2020.20, which can also handle delta bundles with  
578 unsigned metadata. Previous versions of the Apertis Update Manager also  
579 supported an experimental format for signed metadata, which has now been  
580 dropped in favor of the format that has been landed upstream in `libostree`  
581 2020.7.

582 To improve the security on target devices the repository configuration must have  
583 additional option `core.sign-verify-deltas` set to `true`:

```
584 ostree config set core.sign-verify-deltas "true"
```

585 This is forcing AUM and `libostree` to accept only update bundles with signed  
586 metadata.

---

<sup>11</sup><https://github.com/ostreedev/ostree/pull/1985>

587 **Compatibility with upgrades** Until `v2021pre` there were no support of up-  
588 grade bundles with signed metadata in Apertis.

589 For upgrading from version `v2020` to `v2021` we have produced additional upgrade  
590 bundle. This additional bundle has unsigned metadata, allowing offline upgrades  
591 from the previous release. So for `v2021`, and only for `v2021` we have 3 update  
592 bundle types:

- 593 • `*.delta` –depending on CI it may have signed or unsigned metadata. This  
594 version is uploaded into hawkBit server and used for tests.
- 595 • `*.delta.enc` –encrypted bundle containing delta file above.
- 596 • `*.compat-v2020.delta` –bundle with unsigned metadata compatible with  
597 previous Apertis release. This file should be used for upgrading the Apertis  
598 version `v2020`.

### 599 **Securing OSTree updates download**

600 OSTree supports “pinned TLS”. Pinning consist of storing the public key of the  
601 trusted host on the client side, thus eliminating the need for a trust authority.

602 TLS can be configured in the `remote` configuration on the client using the follow-  
603 ing entries:

```
604 tls-ca-path  
605     Path to file containing trusted anchors instead of the system CA database.
```

606 Once a key is pinned, OSTree is ensured that any download is coming from a  
607 host which key is present in the image.

608 The pinned key can be provided in the disk image, ensuring every flashed device  
609 is able to authenticate updates.

### 610 **Controlling access to the updates repository**

611 TLS also permit the OSTree client to authenticate itself to the server before  
612 being allowed to download a commit. This can also be configured in the `remote`  
613 configuration on the client using the following entries:

```
614 tls-client-cert-path  
615     Path to file for client-side certificate, to present when making requests to  
616     this repository.  
617 tls-client-key-path  
618     Path to file containing client-side certificate key, to present when making  
619     requests to this repository.
```

620 Access to remote repositories can also be controlled via HTTP cookies. The  
621 `ostree remote add-cookie` and `ostree remote delete-cookie` commands will up-  
622 date a per-remote lookaside cookie jar, named `$remotename.cookies.txt`. In this  
623 model, the client first obtains an authentication cookie before communicating  
624 this cookie to the server along with its update request.

625 The choice between authentication via TLS client-side certificates or HTTP  
626 cookies can be done depending on the chosen server-side infrastructure.

627 Provisioning authentication keys on a per-device basis at the end of the deliv-  
628 ery chain is recommended so each device can be identified and access granted  
629 or denied at the device granularity. Alternatively it is possible to deploy au-  
630 thentication keys at coarser granularities, for instance one for each device class,  
631 depending on the specific use-case.

### 632 **Security concerns for offline updates over external media**

633 OSTree static deltas includes the detached metadata with signature for the  
634 contained commit to check if the commit is provided by a valid provider and its  
635 integrity.

636 The signed commit is unpacked to a temporary directory and verified by OSTree  
637 before being integrated in the OSTree repository on the device, from which it  
638 can be deployed at the next reboot.

639 This is the same mechanism used for commit verification when doing OTA  
640 upgrades from remote servers and provides the same features and guarantees.

641 Usage of inlined signed metadata ensures that the provided update file is aimed  
642 to the target platform or device.

643 Updates from external media present a security problem not present for directly  
644 downloaded updates. Simply verifying the signature of a file before decompress-  
645 ing is an incomplete solution since a user with sufficient skill and resources  
646 could create a malicious USB mass storage device that presents different data  
647 during the first and second read of a single file –passing the signature test, then  
648 presenting a different image for decompression.

649 The content of the update file is extracted into the temporary directory and the  
650 signature is checked for the extracted commit tree.

### 651 **Settings**

652 As described in [preferences and persistence](#)<sup>12</sup> there are different types of settings  
653 which should be preserved across updates. The setting should either be kept  
654 intact or updated to reflect new logic of the application.

655 When using OSTree, most of the file system is read-only. Since system settings  
656 need write support, the `/etc` and `/var` partitions are configured to be read-write.  
657 This also applies to the `/home` partition, with it being configured as read-write  
658 so user data and settings can be preserved.

659 During an OSTree upgrade, a new commit is applied on the OSTree repo, this  
660 provides the new content that will be used for the read-only portions of the

---

<sup>12</sup>[https://www.apertis.org/concepts/archive/application\\_customization/preferences-and-persistence/](https://www.apertis.org/concepts/archive/application_customization/preferences-and-persistence/)

661 rootfs, but does not modify the read-write parts. To handle the upgrade of  
662 system settings stored in `/etc`, a copy of its default values are kept in `/usr/etc`  
663 which is updated with the new commit. Thanks to this information `OSTree` can  
664 detect the files that have been changed and apply a 3-way merge, to update the  
665 `/etc`.

666 This process allows to update settings to new defaults for files that were not  
667 modified and keep intact those that were.

668 Applications are encouraged to handle settings adaptation to new version follow-  
669 ing the guidelines described in [user and user data management](#) and [preference](#)  
670 [and persistence](#)<sup>13</sup>.

## 671 **Error handling**

672 If for any reason the update process fails to complete, the update will be black-  
673 listed to avoid re-attempting it. Another update won't be automatically at-  
674 tempted until a newer update is made available.

675 The only exception from this rule is failure due incorrect signature check. The  
676 commit could be re-signed with the key not known for the client at this moment,  
677 and as soon as client acquire the new public key blacklist mechanism shouldn't  
678 prevent the update.

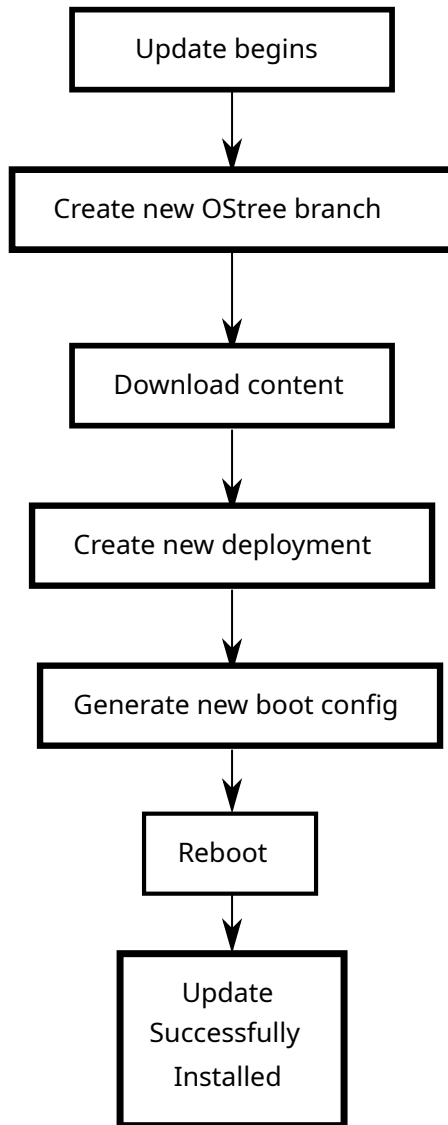
679 It is possible that an update is successfully installed yet fail to boot, resulting  
680 in a rollback. In the event of a rollback the update manager must detect that  
681 the new update has not been correctly booted, and blacklist the update so it  
682 is not attempted again. To detect a failed boot a watchdog mechanism can be  
683 used. The failed updates can then be blacklisted by appending their `OSTree`  
684 commit ids to a list.

685 This policy prevents a device from getting caught in a loop of rollbacks and  
686 failed updates at the expense of running an old version of the system until a  
687 newer update is pushed.

688 The most convenient storage location for the blacklist is the user storage area,  
689 since it can be written at runtime. As a side effect of storing the blacklist there,  
690 it will automatically be cleared if the system is reset to a clean state.

---

<sup>13</sup>[https://www.apertis.org/concepts/archive/application\\_customization/preferences-and-persistence/](https://www.apertis.org/concepts/archive/application_customization/preferences-and-persistence/)



691

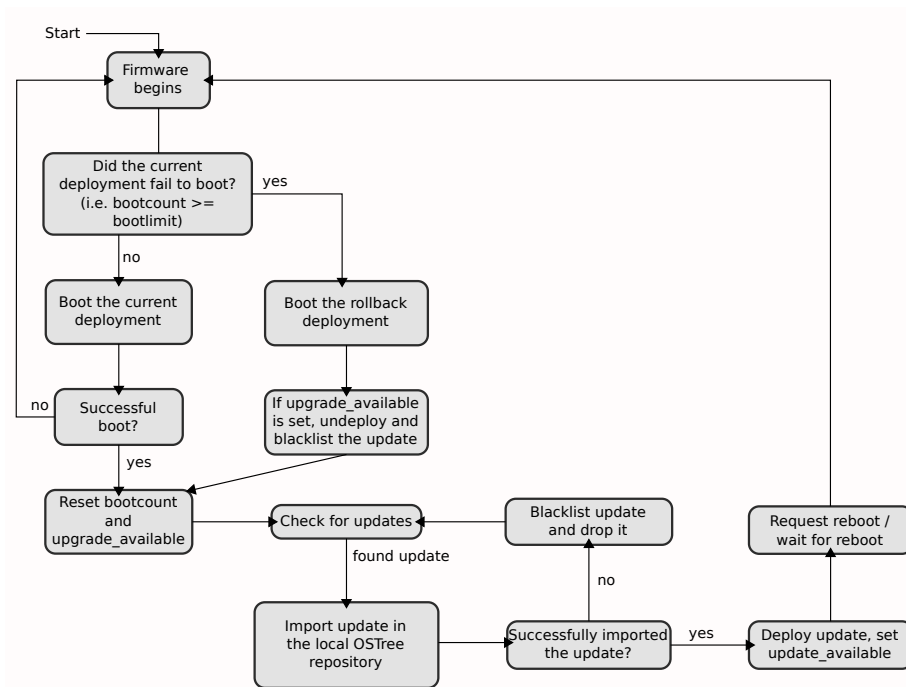
## 692 **Implementation**

693 This section provides some more details about the implementation of offline  
694 system updates and rollback in Apertis, which is split in three main components:

- 695 • the updater daemon
- 696 • the bootloader integration
- 697 • the command-line HMI

698 **The general flow**

699 The Apertis update process deals with selecting the OSTree deployment to boot,  
700 rolling back to known-good deployments in case of failure and preparing the new  
701 deployment on updates:



702

703 While the underlying approach differs due to the use of OSTree in Apertis over  
704 the dual-partition approach chosen by ChromeOS and the different bootloaders,  
705 the update/rollback process is largely the same as [the one in ChromeOS<sup>14</sup>](#).

706 **The boot count**

707 To keep track of failed updates the system maintains a persistent counter that  
708 it is increased every time a boot is attempted.

709 Once a boot is considered successful depending on project-specific policies (for  
710 instance, when a specific set of services has been started with no errors) the  
711 boot count is reset to zero.

712 This boot counter needs to be handled in two places:

- 713 • in the bootloader, which boots the current OSTree deployment if the  
714 counter is zero and initiates a rollback otherwise

<sup>14</sup><https://www.chromium.org/chromium-os/chromiumos-design-docs/filesystem-autoupdate#TOC-Diagram>



715     • in the updater, which needs to reset it to zero once the boot is considered  
716         successful

717 Using the main persistent storage to store the boot count is viable for most  
718 platform but would produce too much wear on platforms using NAND devices.  
719 In those cases the boot count should be stored on another platform-specific  
720 location which is persistent over warm reboots, there's no need for it to persist  
721 over power losses.

722 However, in the reference implementation the focus is on the most general solu-  
723 tion first, while being flexible enough to accommodate other solutions whenever  
724 needed.

## 725 **The bootloader integration**

726 Since bootloaders are largely platform-specific the integration needs to be done  
727 per-platform.

728 For the SabreLite ARM 32bit platform, integration with the [U-Boot](#)<sup>15</sup> boot-  
729 loader is needed.

730 OSTree already provides dedicated hooks to update the `u-boot` environment to  
731 point it to the latest deployment.

732 Two separate boot commands are used to start the system: the default one boots  
733 the latest deployment, while the alternate one boots the previous deployment.

734 Before rebooting to a new deployment the boot configuration file is switched  
735 and the one for the new deployment is made the default, while the older one is  
736 put into the location pointed by the alternate boot command.

737 When a failure is detected by checking the boot count while booting the latest  
738 deployment, the system reboots using the alternate boot command into the  
739 previous deployment where the rollback is completed.

740 Once the boot procedure completes successfully the boot count gets reset and  
741 stopped, so failures in subsequent boots won't cause rollbacks which may worsen  
742 the failure.

743 If the system detects that a rollback has been requested, it also need to make  
744 the rollback persistent and prevent the faulty updates to be tried again. To do  
745 so, it adds any deployment more recent than the current one to a local blacklist  
746 and then drops them.

## 747 **The updater daemon**

748 The updater daemon is responsible for most of the activities involved, such as  
749 detecting available updates, initiating the update process and managing the  
750 boot count.

---

<sup>15</sup><http://www.denx.de/wiki/U-Boot/WebHome>

751 It handles both online OTA updates and offline updates made available on  
752 locally mounted devices.

### 753 **Detecting new available updates**

754 For offline updates, the [GVolumeMonitor](#)<sup>16</sup> API provided by GLib/GIO is used  
755 to detect when a mass storage device is plugged into the device, and the [GFile](#)<sup>17</sup>  
756 GLib/GIO API is used to scan for the offline update stored as a plain file in the  
757 root of the plugged file system named `static-update.bundle`.

758 For online OTA updates, the [OstreeSysrootUpgrader](#)<sup>18</sup> is used to poll the remote  
759 repository for new commits in the configured branch.

760 When combined with roll out management systems like [Eclipse hawkBit](#)<sup>19</sup>, the  
761 roll out management agent on the device will initiate the upgrade process with-  
762 out the need for polling.

### 763 **Initiating the update process**

764 Once the update is detected, it is verified and compared against a local blacklist  
765 to skip updates that have already failed in the past (see [Update validation]).

766 In the offline case the static delta file is checked for consistency before being  
767 unpacked in the local OSTree repository.

768 During online updates, files are verified as they get downloaded.

769 In both cases the new update results in a commit in the local OSTree repository  
770 and from that point the process is identical: a new deployment is created from  
771 the new commit and the bootloader configuration is updated to point to the  
772 new deployment on the next boot.

### 773 **Reporting the status to interested clients**

774 The updater daemon exports a simple D-Bus interface which allows to check  
775 the state of the update process and to mark the current boot as successful.

### 776 **Resetting the boot count**

777 During the boot process the boot count is reset to zero using an interface that  
778 abstracts over the platform-specific approach.

779 While product-specific policies dictate when the boot should be considered  
780 successful, the reference images consider a boot to be successful if the `multi-`  
781 `user.target` target is reached.

---

<sup>16</sup><https://developer.gnome.org/gio/stable/GVolumeMonitor.html>

<sup>17</sup><https://developer.gnome.org/gio/stable/GFile.html>

<sup>18</sup><https://github.com/ostreedev/ostree/blob/master/src/libostree/ostree-sysroot-upgrader>

.c

<sup>19</sup><https://www.eclipse.org/hawkbit/>

## 782 **Marking deployments**

783 Rolled back deployments are added to a blacklist to avoid trying them again  
784 over and over.

785 Deployments that have booted successfully get marked as known good so that  
786 they are never rolled back, even if at a later point a failure in the boot process is  
787 detected. This is to avoid transient issues causing an unwanted rollback which  
788 may make the situation worse.

789 To do so, the boot counting is stopped once the current boot is considered  
790 successful, effectively marking the current boot as known-good without the need  
791 to maintain a whitelist and synchronize it with the bootloader.

792 As a part of marking the deployment as successful the updater daemon checks  
793 the target branches from the OSTree commit metadata. If the booted deploy-  
794 ment contains references to several branches, the updater daemon determines  
795 which branch has the highest version and resets all refs and the origin to that  
796 branch. Using the branches naming scheme used in Apertis, this could be con-  
797 sidered as “major upgrade” of the system. From this point on, the system is  
798 fully switched to the new branch and accepts only upgrades created in the new  
799 branch.

## 800 **Command line HMI**

801 A command line tool is provided to query the status using `the org.apertis.ApertisUpdateManager`  
802 `D-Bus API`<sup>20</sup>:

```
803 $ updatectl  
804 ** Message: Network connected: No  
805 ** Message: Upgrade status: Deploying
```

806 The current API exposes information about whether the updater is idle, an  
807 update is being checked, retrieved or deployed, or whether a reboot is pending  
808 to switch to the updated system.

809 It can also be used to mark the boot as successful:

```
810 $ updatectl --mark-update-successful
```

## 811 **Update validation**

812 Before installing updates the updater check their validity and appropriateness  
813 for the current system, using the metadata carried by the update itself as pro-  
814 duced by the build pipeline. It ensures that the update is appropriate for the  
815 system by verifying that the collection id in the update matches the one config-  
816 ured for the system. This prevents installing an update meant for a different

---

<sup>20</sup><https://gitlab.apertis.org/pkg/apertis-update-manager/-/blob/apertis/v2021/data/apertis-update-manager-dbus.xml>

817 kind of device, or mixing variants. The updater also checks that the update ver-  
818 sion is newer than the one on the system, to prevent downgrade attacks where  
819 a older update with known vulnerabilities is used to gain privileged access to a  
820 target.

## 821 **Testing**

822 Testing ensures that the following system properties for each image are main-  
823 tained:

- 824 • the image can be updated if a newer update bundle is plugged in
- 825 • the update process is robust in case of errors
- 826 • the image initiates a rollback to a previous deployment if an error is de-  
827 tected on boot
- 828 • the image can complete a rollback initiated from a later deployment

829 To do so, a few components are needed:

- 830 • system update bundles have to be built as part of the daily build pipeline
- 831 • a know-good test update bundle with a very large version number must  
832 be create to test that the system can update to it

833 At least initially, testing is done manually. Automation from LAVA will be  
834 researched later.

### 835 **Images can be updated**

836 Plugging a device with the known-good test update on it bundle the expectation  
837 is that the system detects it, initiates the update and on reboot the deployment  
838 from the known-good test bundle is used.

### 839 **The update process is robust in case of errors**

840 To test that errors during the update process don't affect the system, the device  
841 is unplugged while the update is in progress. Re-plugging it after that checks  
842 that updates are gracefully restarted after transient errors.

### 843 **Images roll back in case of error**

844 Injecting an error in the boot process checks that the image initiates the roll  
845 back to a previous deployment. Since a newly-flashed image doesn't have any  
846 previous deployment available, one needs to be manually set up beforehand by  
847 downloading an older OSTree commit.

### 848 **Images are a suitable rollback target**

849 A known-bad deployment similar to the known-good one can be used to ensure  
850 that the current image works as intended when it is the destination of a rollback  
851 initiated by another deployment.

852 After updating to the known-bad deployment the system should rollback to the  
853 version under test, which should then complete the rollback by cleaning the boot  
854 count, blacklisting the failed update and undeploy it.

## 855 **User and user data management**

856 As described in the [Multiuser<sup>21</sup>](#) design document, Apertis is meant to accom-  
857 modate multiple users on the same device, using existing concepts and features  
858 of the several open source components that are being adopted.

859 All user data should be kept in the general storage volume on setups where it is  
860 available, as it enables simpler separation of concerns, and a simpler implemen-  
861 tation of user data removal.

862 Rolling back user and application data cannot be generally applied and no  
863 existing general purpose system supports it. Applications must be prepared to  
864 handle configuration and data files coming from later versions and handle that  
865 gracefully, either ignoring unknown parameter or falling back to the default  
866 configuration if the provided one is not usable.

867 Specific products can choose to hook to the update system and manage their  
868 own data rollback policies.

## 869 **Application management**

870 Application management on Apertis has requirements that the main update  
871 management system does not:

- 872 • It is unreasonable to expect a system restart after an application update.
- 873 • Each application must be tracked independently for rollbacks. System  
874 updates only track one “stream” of rollbacks, where the application update  
875 framework must track many.

876 Flatpak matches the requirements and is also based on OSTree. The ability  
877 to deduplicate contents between the system repository and the applications  
878 decouples applications from the base OS yet keeping the impact on storage  
879 consumption minimal.

## 880 **Application storage**

881 Applications can be stored per-device or per-user depending on the needs of the  
882 product.

883 An application may require storage space for personal settings, license informa-  
884 tion, caches, and any manner of long term private storage. These files should

---

<sup>21</sup>[https://www.apertis.org/concepts/archive/application\\_security/multiuser/](https://www.apertis.org/concepts/archive/application_security/multiuser/)

885 generally not be easily accessible to the user as directly modifying them could  
886 have detrimental effects on the application.

887 Application storage requirements can be divided into broad groups:

- 888 • An area for application exports to integrate with the system. This is  
889 managed by the application manager and not directly by applications  
890 themselves.
- 891 • User specific application data –for settings and any other per-user files. In  
892 the event of an application rollback, depending on the product this data  
893 may get rolled back with the application or the application needs to deal  
894 with potentially mismatching versions.
- 895 • Application specific application data –for data that is rolled back with  
896 an application but isn't tied to a user account –such as voice samples or  
897 map data. This data should be handled in the same way as user specific  
898 application data.
- 899 • Cache –easily recreated data. To save space, this should not be stored for  
900 rollback purposes, and should be cleared on a rollback in case applications  
901 change their cache data formats between versions.
- 902 • Storage for files in standard formats that aren't tied to specific applications,  
903 as explained in the [Multiuser](#)<sup>22</sup> design, this storage is shared between all  
904 users. This data should be exempt from the rollback system.

## 905 Further developments

- 906 • Handling a larger threat model using [The Update Framework Specification](#)<sup>23</sup> / [Uptane](#)<sup>24</sup> with [Aktualizr](#)<sup>25</sup>
- 907
- 908 • Integrating with server side management services like [Eclipse hawkBit](#)<sup>26</sup>
- 909 • Hardware-assisted [verified boot](#)<sup>27</sup> with TPM/OP-TEE
- 910 • File system-level integrity checks [Integrity Measurement Architecture \(IMA\)/Extended Verification Module \(EVM\)](#)<sup>28</sup>
- 911
- 912 • Add fail safe partition to handle file system corruption

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<sup>22</sup>[https://www.apertis.org/concepts/archive/application\\_security/multiuser/](https://www.apertis.org/concepts/archive/application_security/multiuser/)

<sup>23</sup><https://github.com/theupdateframework/specification/blob/master/tuf-spec.md>

<sup>24</sup><https://uptane.github.io/>

<sup>25</sup><https://foundries.io/insights/2018/05/25/ota-part-1/>

<sup>26</sup><https://www.eclipse.org/hawkbit/>

<sup>27</sup><https://www.chromium.org/chromium-os/chromiumos-design-docs/verified-boot>

<sup>28</sup><https://sourceforge.net/p/linux-ima/wiki/Home/>

## 913 **Related Documents**

914 A survey of system update managers:

- 915 • [https://wiki.yoctoproject.org/wiki/System\\_Update](https://wiki.yoctoproject.org/wiki/System_Update)

916 The OSTree bootable file systems tree store:

- 917 • <https://ostreedev.github.io/ostree/>

918 The U-Boot Bootloader:

- 919 • <http://www.denx.de/wiki/U-Boot/WebHome>

920 The ChromeOS auto-update system:

- 921 • [https://www.chromium.org/chromium-os/chromiumos-design-docs/filesystem-](https://www.chromium.org/chromium-os/chromiumos-design-docs/filesystem-autoupdate)  
922 [autoupdate](https://www.chromium.org/chromium-os/chromiumos-design-docs/filesystem-autoupdate)