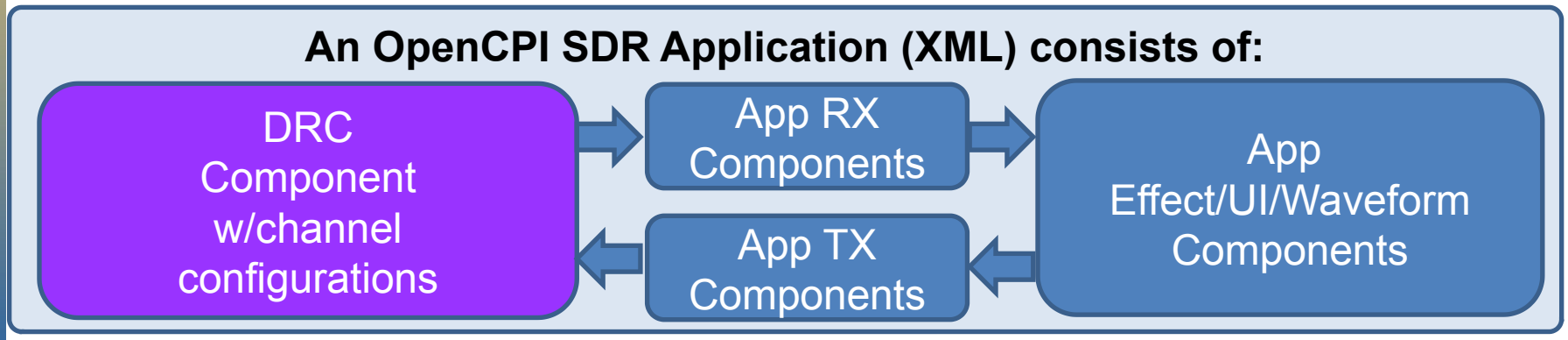

# OpenCPI - Open Component Portability Infrastructure

## An Introduction to the Digital Radio Controller (DRC) model and APIs, for Controlling and Configuring RF I/O in OpenCPI Systems that are "radios" (SDRs)

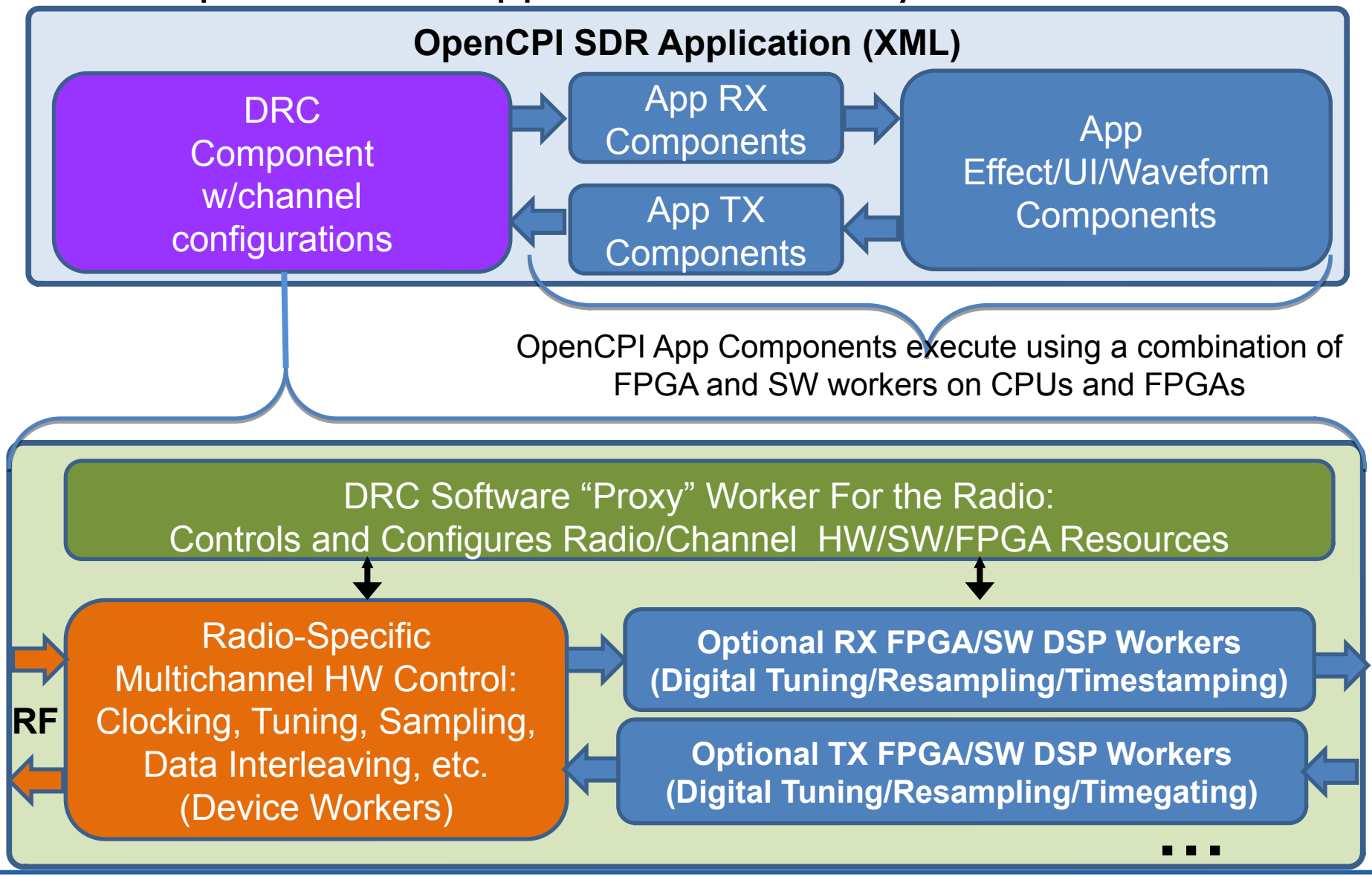
# Digital Radio Controller (DRC) Software

- OpenCPI runs component-based apps on embedded ***systems***
- Some ***systems*** supported by OpenCPI are "radios"
- Radio systems (Software Defined Radios – SDRs) have ***channels*** with:
  - RF Antennas at one end and digital samples on the other
- DRC is how OpenCPI applications ***control/configure radio channels***
  - E.g. specifying tuning frequency and sampling rates
  - One DRC interface, common across radios.
- Application developers ***use*** DRC to configure/use RF I/O hardware.
- Platform developers ***implement*** a DRC for a radio (part of an OSP)



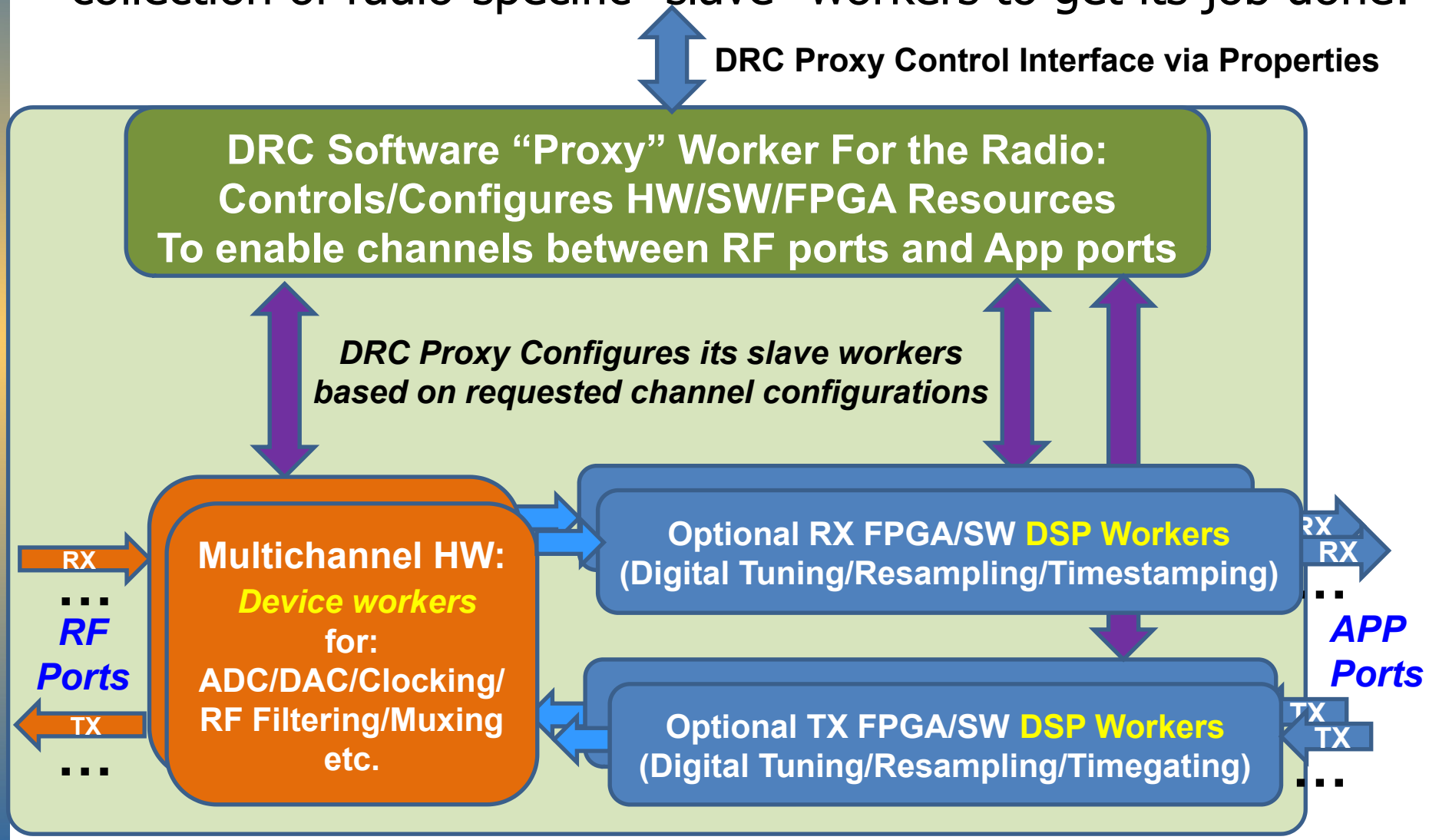
# Digital Radio Controller (DRC) Model

- How OpenCPI SDR Apps run on Radio Systems



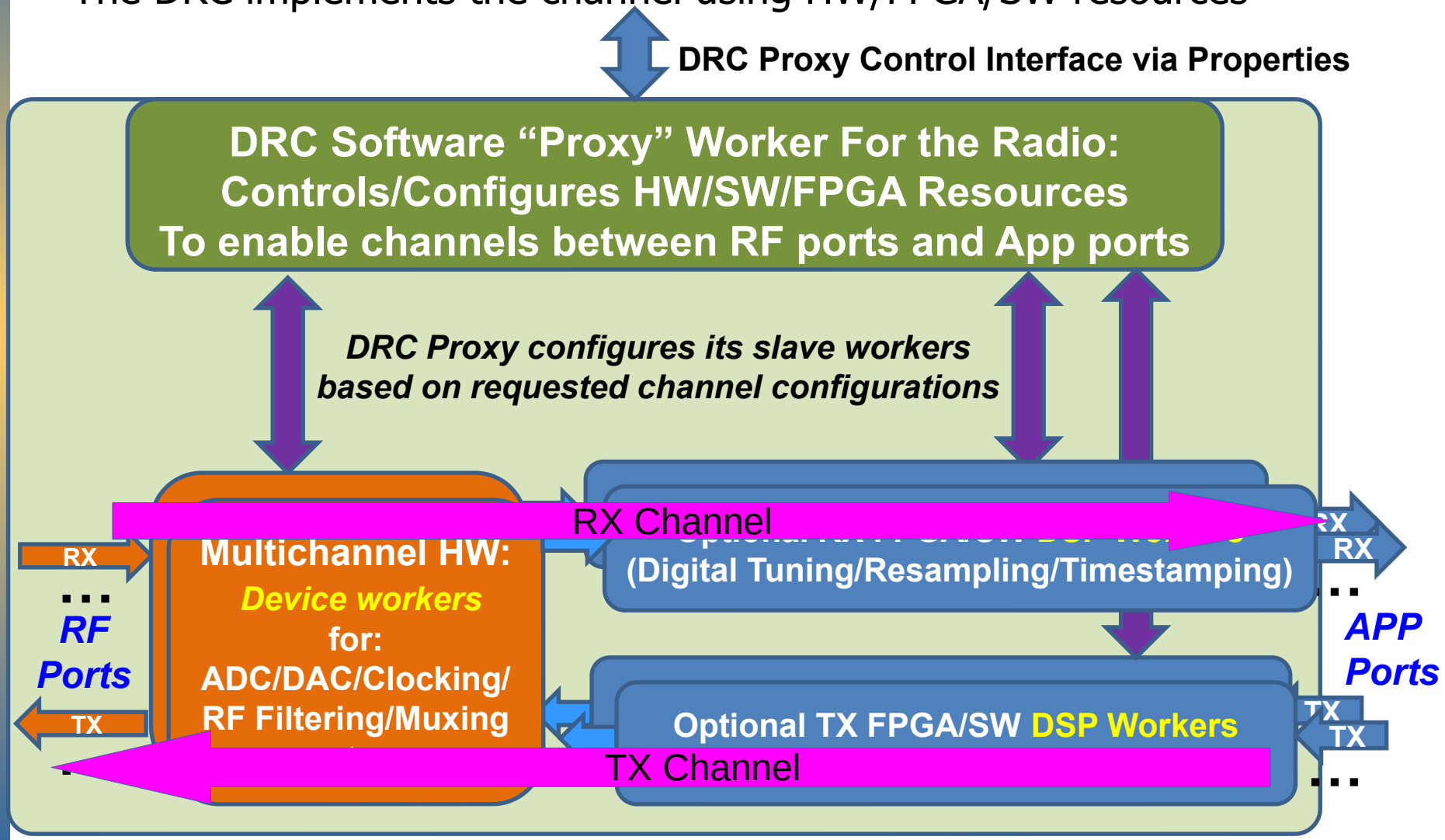
# Digital Radio Controller (Proxy) Worker

- The DRC device proxy worker (software) *for a radio* uses a collection of radio-specific "slave" workers to get its job done:



# Digital Radio Controller *Channels*

- A channel is between an RF port and an App port
- The DRC implements the channel using HW/FPGA/SW resources



# Digtal Radio Controller (DRC) History

- A Previous OpenCPI (pre 1.5) project had a framework group and an SDR applications group
- The apps group identified OpenCPI weaknesses for SDR app portability
- DRC was specified as the solution for portability of SDR apps.
  - *Interface between app developers and platform developers*
- A DRC prototype was developed (~2018/1.5) as a "technology-preview"
  - Only for FMCOMMS3 daughter card with ADI 9361 Xcvr
- Code was modified recently to run on other 9361-based SDRs:
  - E310 and Pluto
- This experience exposed the required work to finish DRC
  - To make DRC supported and suitable for new OSPs, etc.
  - Released and supported, as part of 2.1

# The DRC Application Interface: XML and ACI

- A DRC is a *component*, so it has properties and ports
  - DRC ***Properties*** used to configure channels (between RF ports and App ports)
  - DRC ***Ports*** (the App ports) convey baseband sample data to/from application components.

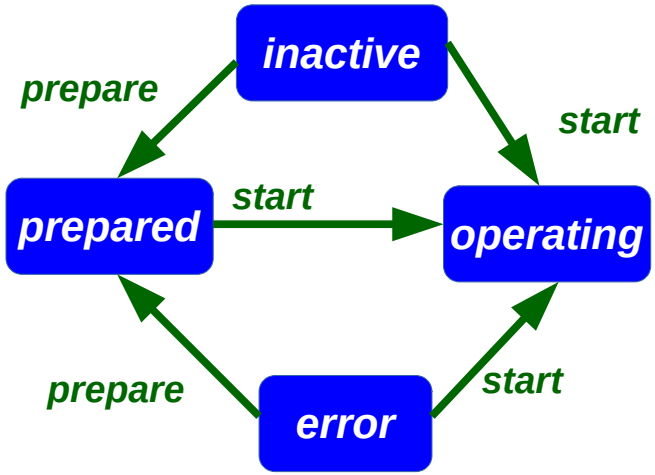
- Application XML specifies a DRC instance, e.g.:
  - `<instance component='ocpi.platform.drc'……/>`

- The Application XML connects to the DRC's app ports (`rx` or `tx`), e.g.:
  - ```
    <connection>
      <port='rx' instance='drc'/>
      <port='in' instance='appcomp1'/>
    </connection>
    ```
  - *These app ports are actually directly connected to lower level hardware/FPGA workers*

- One DRC property (`configurations`) specifies one or more *radio* configurations
  - A radio configuration specifies a set of *channel* configurations (to be used together)
  - A radio configuration, when specified in app XML:
    - Is sufficient for static channel configurations
    - Allows the application to be pure XML using `ocpirun`
  - Configurations can also be specified/enabled/disabled at *runtime*
    - Using the normal property access methods in the OpenCPI ACI
    ```

# DRC "Channels"

- A channel is RX or TX, and is between two endpoints:
  1. A physical RF (antenna) connector, a.k.a. an ***RF Port***
  2. A digital sample "base band" port connected to the app (an ***App Port***)

- ***RF Ports*** are identified by ordinals (of Rx or Tx), but can be named.
  - (RF) connector names are system-specific (labels on connector panel)

- Digital sample ***app ports*** are numbered (rx[n] or tx[n])
  - A given DRC has enough of these app ports for what is possible.

- A ***channel*** is a path between an RF connector and the application port
  - But transceivers and radios have RF switching and multiplexing
  - A DRC can "retune" with DSP (soft) workers to get certain results.
  - Thus a DRC ***channel*** may be virtualized (HW+FPGA+SW)
    - RF switching, digital resampling/tuning etc.
    - Timestamping (rx) or timegating (tx)

# DRC App Interface: Static XML Example

```
<Application>
  <Instance component='drc'>
    <property name='configurations'  define one configuration with two channels
              value='{description My static radio channels,
                      channels {  define two channels, one rx, one tx
                       {rx true,
                        tuning_freq_mhz 2450,
                        bandwidth_3db_mhz 0.24,
                        sampling_rate_Msps 0.25,
                        samples_are_complex true,
                        gain_db -25,
                        tolerance_tuning_freq_mhz 0.01,
                        tolerance_sampling_rate_msps 0.01,
                        tolerance_gain_db 1},
                       {rx false,
                        tuning_freq_mhz 2450,
                        bandwidth_3db_mhz 0.24,
                        sampling_rate_Msps 0.25,
                        samples_are_complex true,
                        gain_db -25,
                        tolerance_tuning_freq_mhz 0.01,
                        tolerance_sampling_rate_msps 0.01,
                        tolerance_gain_db 1}}}'/>
     <property name='start' value='0'/>    start first radio config when app starts
   </Instance>
   ... other component instances in the app and connections to app ports ...
</Application>
```

# DRC App Interface: App Port Connections

```
<Application>
  <Instance component='drc' connect='my_rx_processing'>
    <property name='configurations'  define one configuration with two channels
              value='{description My static radio channels,
                      channels {
                       {rx true,
                        ...
                        tolerance_gain_db 1},
                       {rx false,
                        ...
                        tolerance_gain_db 1}}'/>
     <property name='start' value='0'/>    start first radio config when app starts
   </Instance>
   <Instance component='my_tx_processing' connect='drc'/>
   <Instance component='my_rx_processing'/>
---OR---
   <connection>
      <port name='rx' instance='drc'/>
      <port name='in' instance='my_rx_processing/>
   </connection>
   <connection>
      <port name='tx' instance='drc'/>
      <port name='out' instance='my_tx_processing'/>
   </connection>
</Application>
```

# DRC Static and Dynamic Configurations

- Static XML Radio Configuration
  - The application's radio configuration is in the Application XML
  - One XML-based configuration can be enabled at app startup
  - This does not preclude dynamic changes later via ACI.

- Dynamic Configurations (possibly more than one)
  - May still be specified in application XML
    - But are not initially enabled
    - Are allowed to conflict since they are enabled separately
  - May also be entirely dynamically specified in ACI/C++ code
  - Enabled/disabled dynamically ACI/C++ code.

- An app may configure some channels statically (on one configuration) and others dynamically (in other configurations)

# DRC Application Interface – Dynamic/ACI

- ACI is based on reading and writing properties.
  - Set **`configurations`** (when not already specified in app XML)
  - Enable/disable configurations
  - Check status of configurations (enabled, disabled, error)

- ACI can query the DRC for constraints and request configurations that may determined based on what is possible/available.

- ACI may change channel configurations during execution
  - Change frequency/bandwidth/sampling rate/gain etc.

- ACI may change which channels are doing what

# DRC Component Specification: Properties

1. ***Configurations:*** a sequence of radio configurations
   - Each *radio* configuration is a sequence of *channel* configurations:
     - Which RF Port? Which App Port? RX or TX?
     - Channel attributes: freq/bw/sample rate/gain/real-or-IQ
     - Attribute tolerances

2. ***Status:*** dynamic/volatile information about configurations
   - A sequence of configuration status records
     - State: inactive, prepared, operating, error
     - Error: description of why it could not be prepared or started
     - Actual channel attributes/status, within tolerance etc.

3. ***Constraints:*** ranges of attribute values
   - A sequence of records, per RF port and direction

# DRC Component Specification: Actions

- *Separate properties for each action on a configuration*
- Actions (and thus properties) are:
  - **`Prepare`** – validate/preprocess configuration
    - Perhaps allocating resources
    - Minimizing "start" latency when started/switched later
  - **`Start`** – make operational
  - **`Stop`** – suspend operation of the configuration
  - **`Release`** — release any resources, make "inactive".
- Action properties are set with the configuration ordinal as value
- Static starting in app XML is just (for starting configuration 0):
  - `<property name='start' value='0'/>`
- Dynamic code example:
  - ```
    OA::Property start(app, "drc", "start");
    …
    start.setValue(1); // start configuration 1
    ```
    ```

# DRC Radio Configuration Lifecycle: States

- Initial `configurations` value is a sequence of zero or more configurations
- Configurations can be modified in any state; changes do not take immediate effect.
- Initial state is ***inactive***, allowed operations are:
  - ***prepare***: verify configuration, allocate resources, get ready to start
  - ***start***: (implies ***prepare*** when state is ***inactive***) make the configuration operational
- Next state is ***prepared:*** ready to be (quickly) ***started***, allowed operations are:
  - ***start***: make the configuration operational, ***operating***
  - ***release***: revert to ***inactive***, releasing any resources
- Next state is ***operating***: channels are active as requested, allowed operations are:
  - ***stop***: revert to ***prepared*** state
  - ***release***: revert to ***inactive***, releasing any resources
- Error state is ***error***: ***prepare*** or ***start*** failed, allowed operations are:
  - ***prepare, start*** or ***release***
- Configurations are independent
  - ***prepare*** or ***start*** will fail if other ***operating*** configurations cannot be maintained



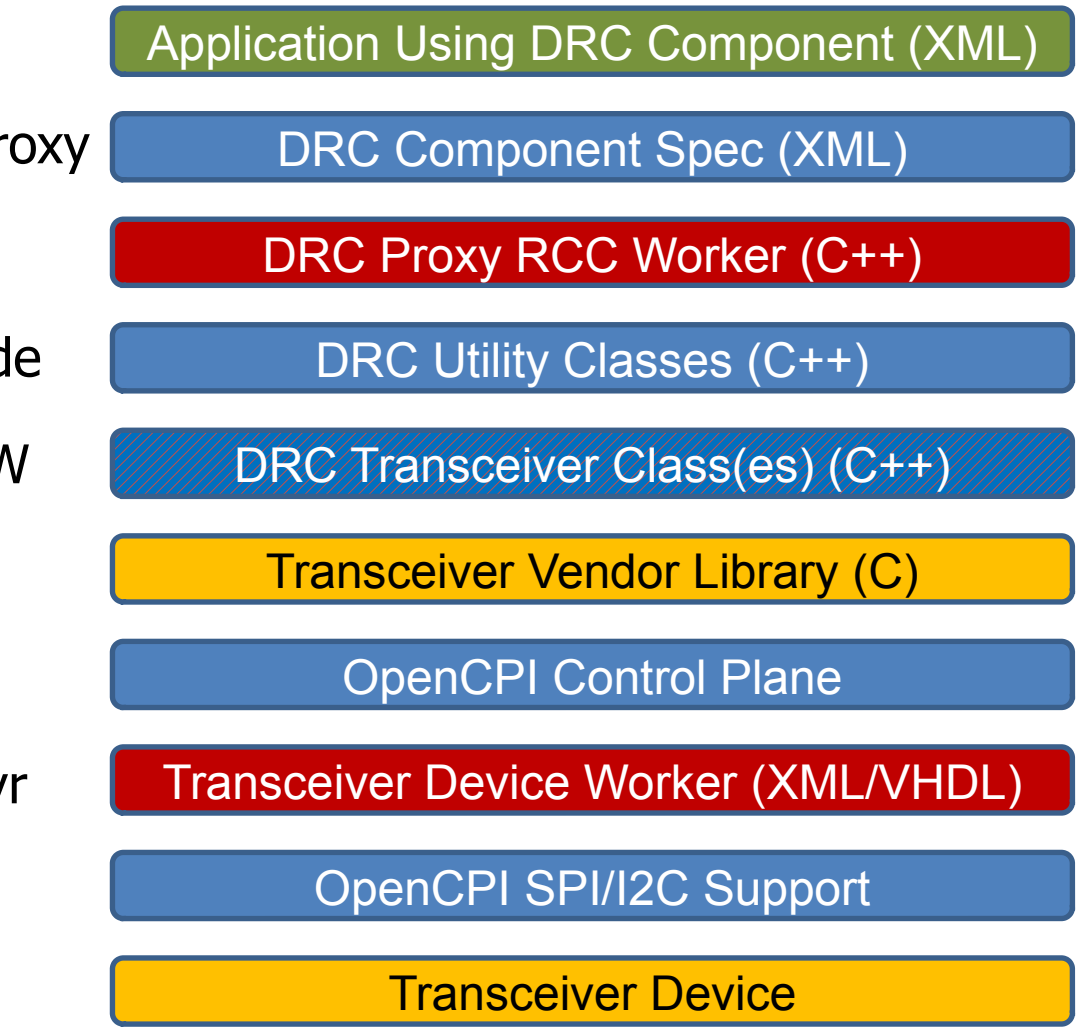

**release: from all states to inactive**
**failure of prepare or start goes to error**

# DRC For Platform Developers

- If the system is a "radio", the DRC proxy is part of the OSP
- The DRC proxy manages device workers related to RF I/O
- The DRC translates channel configurations into device-level settings
  - Clock generation
  - RF muxing and switching
  - Hardware-based RF filtering
  - Hardware-based tuning and resampling
- When possible, it manages and detects conflicts between settings
  - I.e. if channel 1 is programmed for X, channel 2 cannot be Y
- When needed, uses DSP workers for tuning/resampling
- See the section "Supporting the Digital Radio Controller (DRC) Component Specification" in the ***OpenCPI Platform Development Guide***

# DRC Layered Architecture (for developers)

- *How the DRC is implemented for a radio (notionally).*
- App XML has DRC instance
- App deployment finds DRC proxy
- DRC proxy written for radio
- DRC generic proxy helper code
- DRC proxy helper for Xcvr/HW
- E.g. AD9361 helper library
- Control plane to access HW
- Device worker written for Xcvr
- Generic SPI/I2C support
- Actual radio hardware

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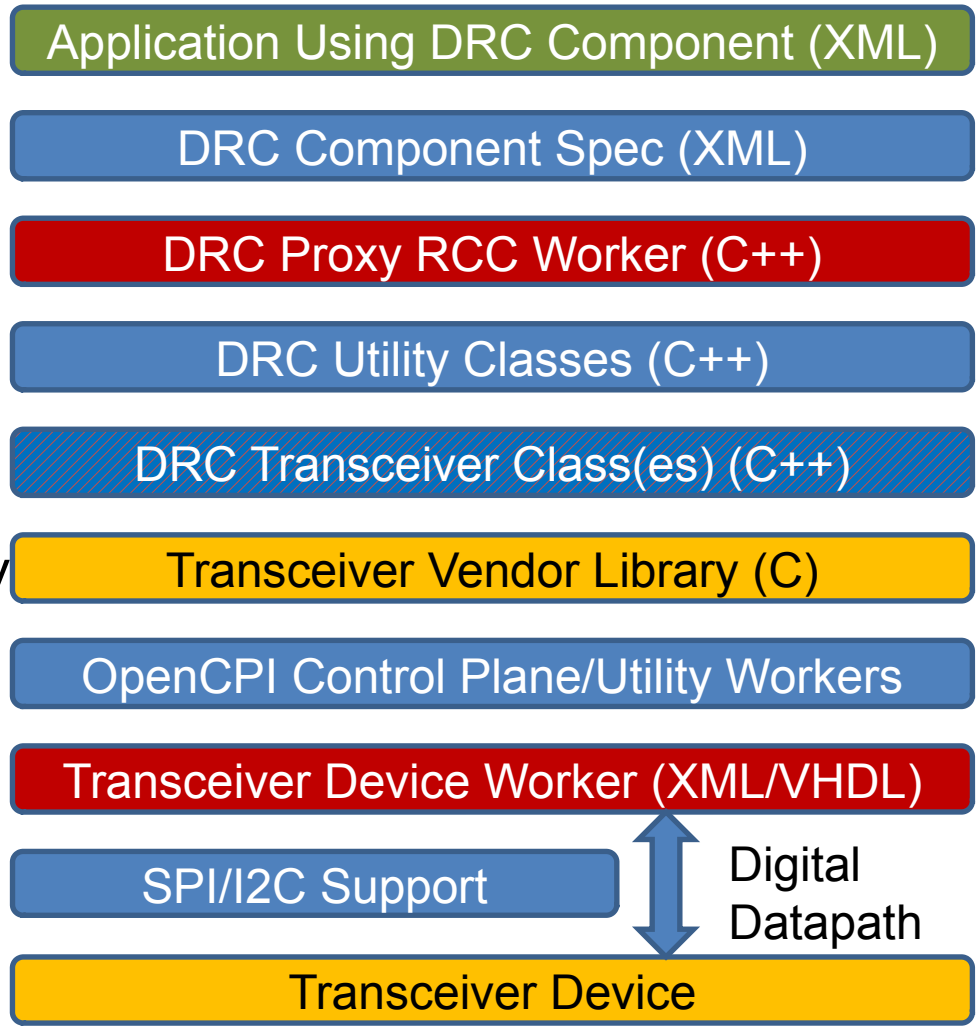
# DRC Platform Implementation for the OSP

- *How the DRC is implemented for a radio.*
- App XML has DRC instance
- App deployment finds DRC proxy
- **DRC proxy written for radio**
- DRC generic proxy helper code
- **DRC proxy helper: Xcvr/HW**
- E.g. AD9361 NO-OS helper library
- Control plane to access HW
- **Device worker for Xcvr**
- Generic SPI/I2C support
- Actual radio hardware

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# DRC Device Worker Dependencies

- Device workers developed and tested without/before DRC support
  - Using direct/explicit configuration properties
  - Should be developed and tested first
- Use OpenCPI Helper Device workers for digital data path
  - Attached to data_{src,sink}_{q}{adc,dac}
  - Timestamper, timegate
- Device workers for configuring transceivers (register access)
- Device workers for external clock generators etc.
- Then the DRC proxy XML specifies a slave assembly:
  - Which workers, which properties, how they are connected

# DRC Proxy Worker Code

- DRC Proxy Worker Implements the DRC Application Interface
  - Based on properties in the generic DRC component spec.
  - DRC is "just another component" in the App.

- There is a helper header file and class for all DRC proxies:
  - `#include "OcpiDrcProxy.hh"`
  - See drc_plutosdr.rcc as an example

- DRC Helper classes & proxies for transceivers/adc/dac etc.
  - Some generic helper classes to reduce copy/paste
  - Transceiver code for widely used transceivers, like ad9361

- DRC proxy worker is for the radio system as a whole
  - Multiple transceivers would be integrated in one proxy
  - Separate devices, clock generators, GPIO, etc.
  - Compensating for tuning limitations, per channel

# DRC Summary

- DRC is a component, with a component specification
- Provides applications access to radio hardware, with ports and properties.
- Implements channels between RF ports and App ports.
- DRC implementations are proxies that use underlying workers to access and control various hardware and DSP elements
- Platform developers create DRC proxies as part of OSPs for radios