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Synchronization and NGFI

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IEEE 1914.1 TF

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Synchronization and NGFI			
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Agenda

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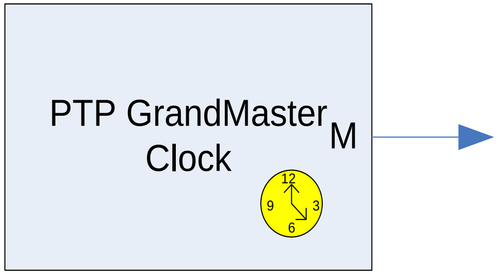
Synchronization Mechanisms

IEEE 1588v2

- Also known as Precision Timing Protocol (PTP)
- PTP sends time-of-day (ToD) information over packets and enables endpoints to align in ToD and/or frequency
- Uses master/slave hierarchy for timing distribution
- Immune to packet delay variation if all nodes support PTP
- Sensitive to delay symmetry of physical links

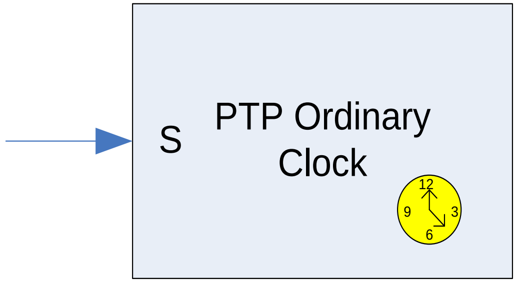
IEEE 1588 Ordinary Clock, Master

- A PTP instance that:
  - Has a single port
  - Is a source for the PTP domain’s timescale
- Could be a Grandmaster Clock, which is a clock of the highest quality in the PTP domain
- Could be a PTP instance that has a clock of superior quality than all other nodes that it has a connection to
- Periodically announces itself and its qualities to other connected PTP ports



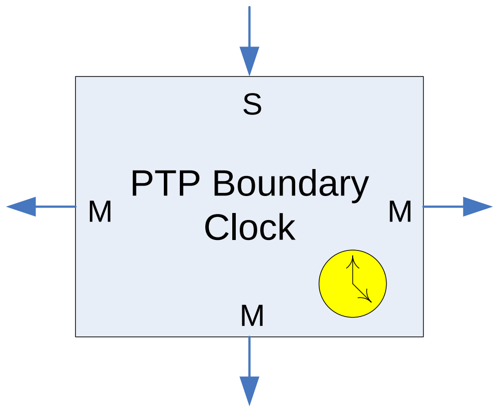
IEEE 1588 Ordinary Clock, Slave

- A PTP instance that:
  - Has a single port
  - Maintains a local copy of the PTP domain’s timescale
- Contains a local clock of inferior quality to at least one other node that it has a connection to
- Selects the best master timing reference from all sources that it is connected to



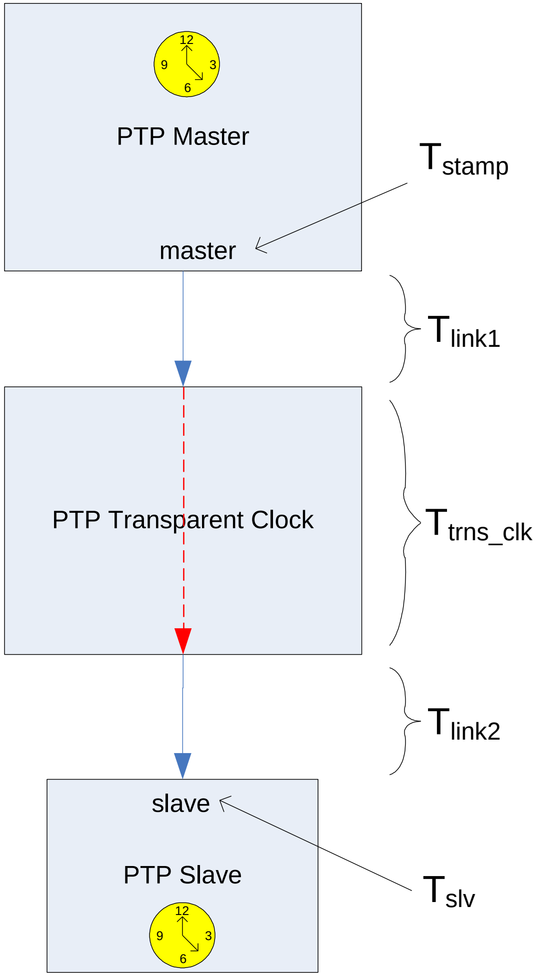
IEEE 1588 Boundary Clock

- A PTP instance that:
  - Has more than one port
  - Maintains a local copy of the PTP domain’s timescale
- One port may be a PTP slave port and other ports may be PTP master ports
- Terminates all incoming timing (i.e. non-management) PTP messages
- Could be used as a bridge between different PTP domains

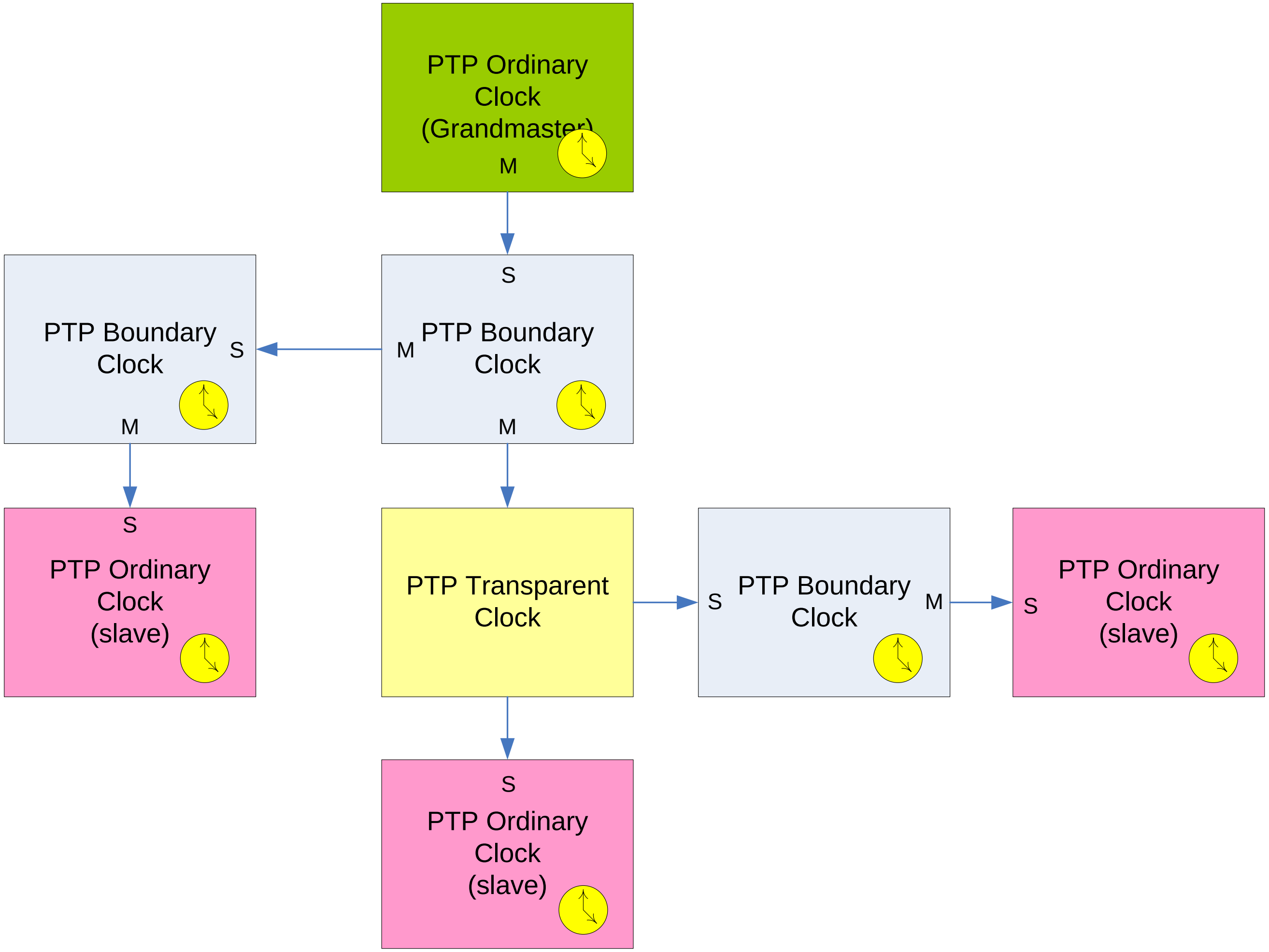


IEEE 1588 Transparent Clock

- A PTP instance that:
  - measures and records the time that a PTP message resides in it during transit
- The residence time (Ttrns_clk) is added to the correctionField in the PTP message
- PTP Slaves use the correctionField to compensate for the TC residence times when recovering the ToD



Example IEEE 1588 network



Slave Calculations and Effects of Uplink/Downlink Delay Asymmetry

Slave Frequency offset is calculated as follows:

$$\text{master\_to\_slave\_freq\_ratio} = (t1_i - t1_{i-1}) / (t2_i - t2_{i-1})$$

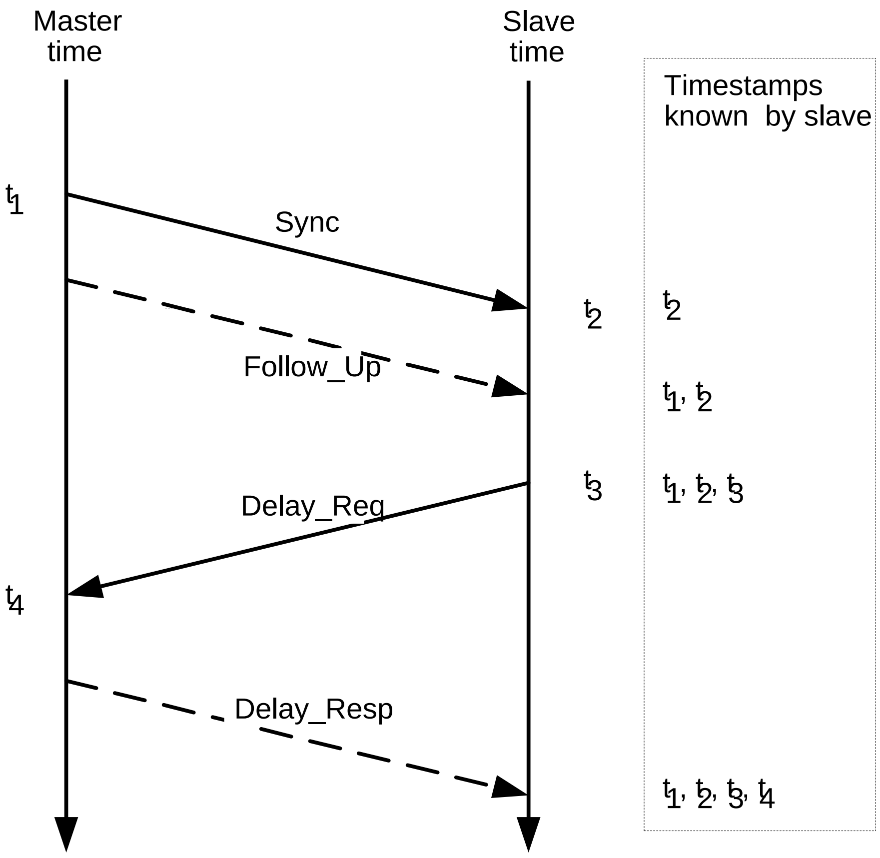
Slave ToD correction is derived as follows:

t2 + slave_ToD_correction = t1 + one-way link_delay

where: one-way link_delay = 0.5[(t4-t1)-(t3-t2)]

thus: slave_ToD_correction = 0.5(t1 – t2 – t3 + t4)

Link Delay Asymmetry creates error in Slave's ToD equal to (0.5 * asymmetry).



Effect of PTP-Unaware Nodes

- PTP-Unaware Nodes in a PTP Communication Path (e.g. a generic Ethernet switch) create asymmetry between master-to-slave and slave-to-master delays
- This results in a Slave ToD that is wrong by (0.5 * asymmetry).
- Asymmetry errors add linearly
- Proprietary filtering algorithms have been developed to improve performance, but fronthaul’s most stringent performance requirements may not be achievable with the presence of PTP-unaware nodes

IEEE 1588 High Accuracy Profile

- Under development for the upcoming version of IEEE 1588 (2017 or 2018)
- Enables timestamping accuracy better than ±1ns
- Requires assistance of a synchronous physical clock (e.g. SyncE) that is coherent with the PTP clock
- See "White Rabbit" implementation from CERN
  - Uses bidirectional fiber
  - Uses a "golden device" to calibrate out any static delay differences between devices
  - Compensates for semi-static delays (e.g. delays that may change each time the link is established)
  - Achieved ToD alignment of ~100ps

ITU's Telecom Profiles for PTP

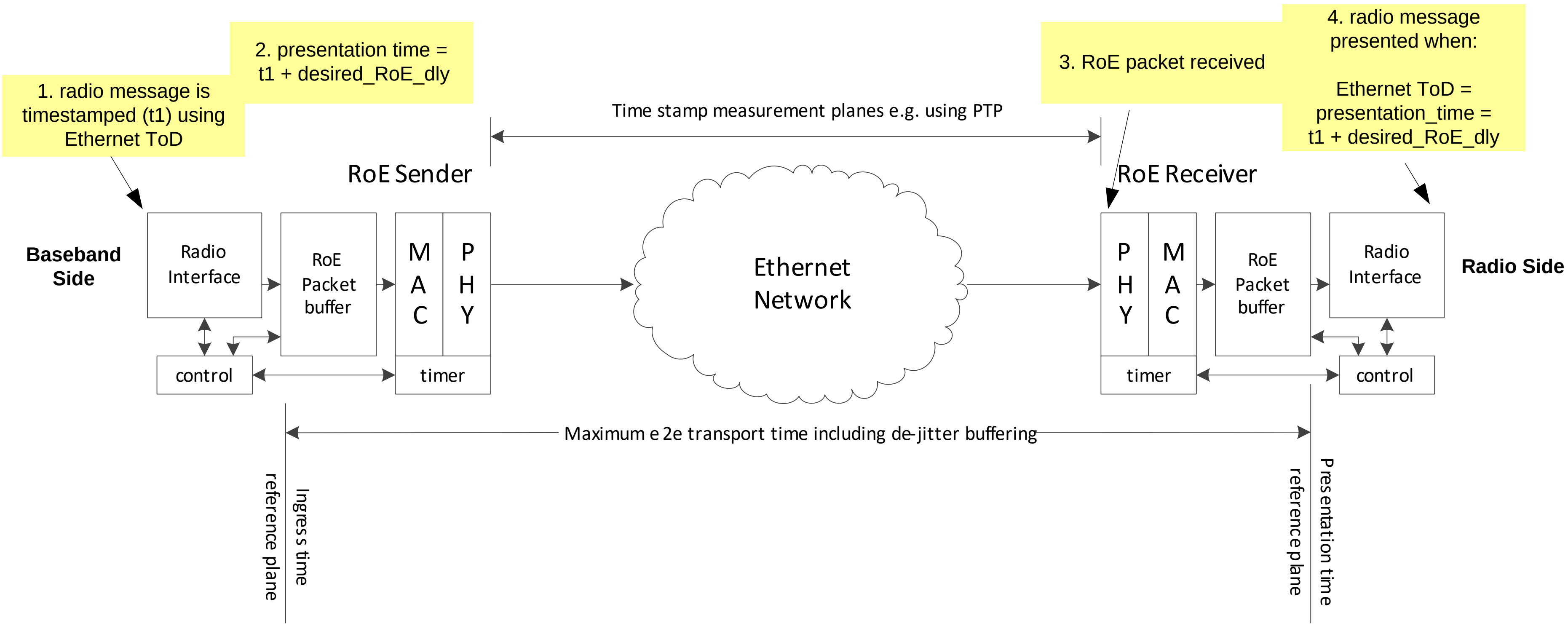
- G.8265.1
  - for frequency, without any timing support from network
  - No PTP-aware nodes between endpoints
- G.8275.1
  - for phase/time, with full timing support from network
  - PTP BCs or TCs at every node between endpoints
- G.8275.2
  - for phase/time, with partial timing support from network
  - PTP BCs are placed at strategic points in legacy networks between endpoints

SyncX and GNSS

- Frequency distribution:
  - T1/E1/SONET/SDH/SyncE physical clocks are well-known and commonly used references for radio clocks
  - A synchronized physical clock gives frequency to PTP and enhances its performance and enables holdover

- Global Navigation Satellite System (GNSS)
  - GNSS receivers could be placed at central and remote sites to provide common ToD
  - GNSS is stable when available, but may not be reliable
  - GPS can typically provide ToD accuracy of 100ns
  - Can be used in combination with PTP or SyncE

Sync Aspects of IEEE 1914.3 Frames: Presentation Timed



IEEE 1914.3 Presentation Time

- Eliminates the need for the fronthaul network to be symmetrical in latency for radio traffic
- Limits the max one-way latency to ~16ms
- Radio traffic does not need to be a continuous constant bit rate datastream
- Requires a common ToD on both ends of the fronthaul network

Synchronization in Fronthaul Networks

What is Important?

- Time Alignment Error (TAE)
  - $\pm$1.5μs ToD alignment for basic service
    - As per 802.1CM, error is relative to a common “universal” timing master (e.g. 1588 Grandmaster, GNSS)
  - ~$\pm$10ns ToD alignment for the most demanding 5G services (precise location, MIMO, transmit diversity)
    - As per 802.1CM, error is relative to the last common source of time (e.g. 1588 master, GNSS)

- Frequency at Radio
  - Clock from transport network must have better than $\pm$15ppb long-term average frequency offset, but typically would be synchronized to 0ppb
  - Very good jitter/wander (e.g. $\leq$ 2ppb below 300Hz)

CPRI and IEEE 802.1CM TAE Requirements

- CPRI's time alignment error requirements for the fronthaul network for different radio categories are given in IEEE 802.1CM

Radio Category	TAE	Comment
Category A+	±12.5ns	TAE wrt last common PTP BC. Optional for MIMO and transmit diversity functions.
Category A	±45ns	TAE wrt last common PTP BC. Required for intra-band contiguous carrier aggregation functions
Category B	±110ns	TAE wrt last common PTP BC. Required for intra-band non-contiguous and inter-band carrier aggregation functions
Category C	±1380ns	TAE wrt PTP Grandmaster. Required for time division duplex functions

How Can Requirements be Met?

- Combine PTP and SyncE
  - Much better TAE results can be achieved when the physical clock is provided to the PTP time recovery algorithm
  - Recovered SyncE clocks, after a low-pass filter and a frequency converter, can be used as a radio's frequency reference
  - The combination also provides holdover if one of the two mechanisms fail
- Require the entire network to be PTP and SyncE aware
  - Non-aware components add error
    - Error due to asymmetry adds in a linear manner, which quickly becomes significant

How Can Requirements be Met?

- Require better timestamping for PTP
  - ±1ns is possible with current high-performance logic without any IEEE 1588 high-accuracy mechanisms
  - Better than ±1ns can be achieved using some of the IEEE 1588 high accuracy mechanisms

- Restrict the max number of timing hops
  - Every hop adds error (some linearly, some in RMS manner)

- Use IEEE 1914.3's Presentation Time mechanism
  - Eliminates the need for the fronthaul network to have symmetric uplink/downlink latency for the radio traffic

How Can Requirements be Met?

- Deal with fiber asymmetry (not easy!)
  - Use bidirectional fiber. However, transport networks typically use unidirectional links.
  - At plant start-up, run PTP over just one fiber to get an accurate ratio of all the fiber lengths
  - Manual comparison and tuning
    1. Run PTP between endpoints
    2. Get a clock with a very stable oscillator and lock it to the ToD at the PTP Master
    3. Carry this clock to the PTP Slave and compare its ToD to that of the PTP Slave
    4. Manually tune the slave to align its ToD to that of the stable clock
    5. Calculate and remember the asymmetry associated with the manually tuned offset
  - Use GNSS to help measure asymmetry at start-up
    - this is limited by the accuracy of GNSS
  - For WDM, mathematically calculate effect of different wavelengths

ITU G.8271.1 TAE Budget

Budget Component	Budget	Comment
PRTC	100ns, 30ns for ePRTC	N/A for the most stringent fronthaul TAE target, which is referenced to the last common BC
Holdover and network rearrangements	400ns	N/A if the services requiring finest timing are not offered during rearrangements
Random error of all PTP nodes	200ns	Accumulated low frequency random noise of all nodes (high frequency noise is filtered)
Constant error of all PTP nodes	11 hops x 50ns = 550ns	Could be reduced with better designs
	21 hops x 20ns = 420ns	
Link asymmetries	100ns for 11 hops	Could be reduced with fiber asymmetry measurement techniques
	230ns for 21 hops	
End application	150ns	20ns was specified by CPRI organization for IEEE 802.1CM
Total	**1500ns**	

Example TAE Budget for Fronthaul

Budget Component	End-to-End Budget from PTP Grandmasters	Budget from Last Common PTP BC
PRTC	30ns for ePRTC	N/A, timing is relative to last PTP BC
Holdover and network rearrangements	400ns	N/A, fine timing services not available during network failures
Random error of all PTP nodes	MTIE = 9.4ns at 10ksec, measured after 21 hops*	MTIE = 9.4ns at 10ksec, measured after 21 hops*
Constant error of all PTP nodes	11 hops x 0.5ns = 5.5ns	11 hops x 0.5ns = 5.5ns
Link asymmetries	10 links x 1ns = 10ns (limited by resolution of asymmetry measurement)	1ns for 1 link (limited by resolution of asymmetry measurement)
End application	N/A, this is in the radio's budget, not the transport network's budget	N/A, this is in the radio's budget, not the transport network's budget
Total	**455ns**	**15.9ns**

* MTIE of recovered 1PPS with 0.1Hz filter, Microsemi ZLAN-533 test case

Standardization Actions

- IEEE 1914 Scope
  - How timing is accomplished is outside the scope of IEEE 1914
  - However, we need to ensure that the mechanisms we define permit the appropriate timing mechanisms to be used

- 3GPP
  - We must continue to liaise with 3GPP to get their TAE, frequency offset, jitter, and other timing requirements

Standardization Actions

- ITU-T Q13/SG15
  - Q13 is the appropriate standardization committee to define the timing profile(s) for fronthaul network(s)
  - "There is an interest from the group to work on the fronthaul requirements and architecture."
  - Many introductory contributions on fronthaul have already been presented at Q13
    - Ethernet and OTN based solutions
  - Continuously liaise with Q13
    - Disclose our "presentation time" mechanism to Q13 so they understand how ToD will be used
    - Decide what traffic class(es) timing messages should use and include them in our RMIX profiles
    - Decide what synchronization mechanisms will be used and what restrictions apply