PON FOR TTC

Passive Optical Network for TTC

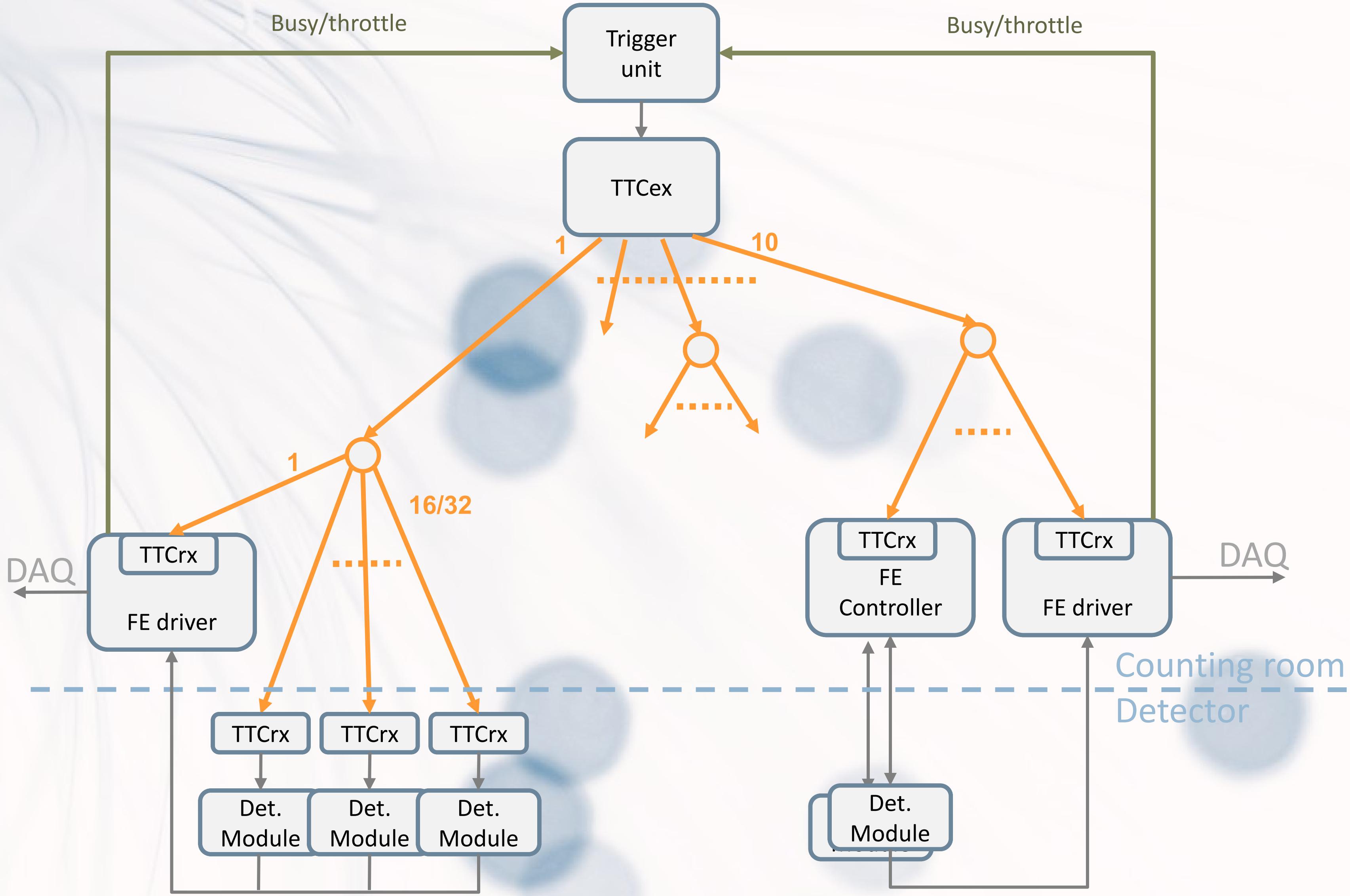
An investigation for
TTC upgrade

Sophie Baron, ACES2011

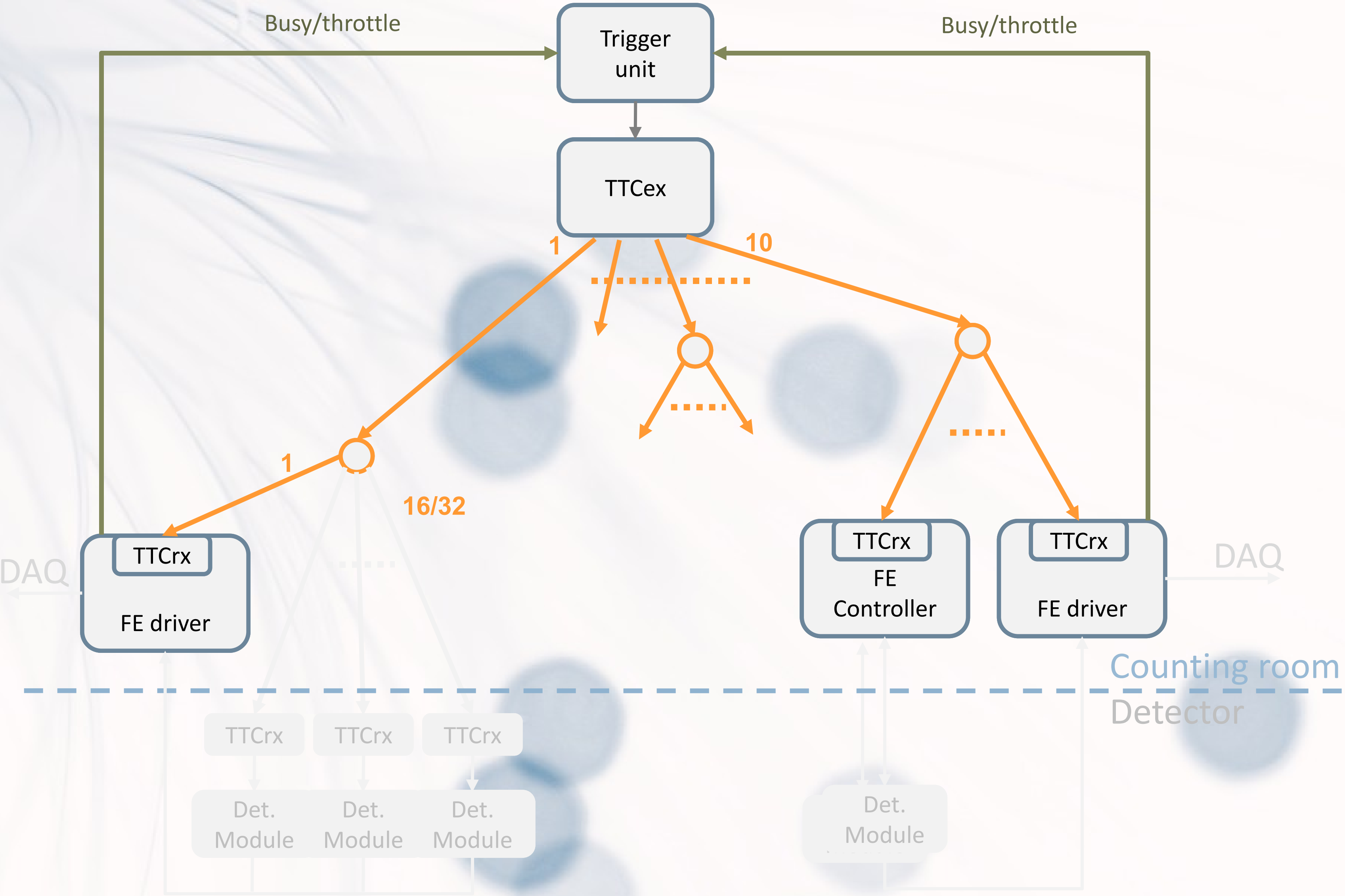
- Upgrading the TTC
- PON basics
- First PON demonstrator for TTC
- Future Plans

The work presented here was conducted during 2009-2010 by
Ioannis Papakonstantinou (Aceole Fellow),
Csaba Soos (CERN/PH/ESE)
and the Opto Team of PH/ESE/BE.
(References at the end of this presentation)

Current TTC – Generic View



Current TTC – Candidate for PON



Upgrading the TTC

A working group was settled between PH/ESE group and experiments‘ representatives in 2009 to:

- Collect and discuss feedback on the current TTC system
- Try to identify a common and preliminary set of requirements of an hypothetical new TTC
- Investigate potential solutions (PH/ESE)
- Report on investigations on a regular basis
- Progress track is available here: *http://indico.cern.ch/categoryDisplay.py?categId=2388*

Basic Requirements

- **Common** to all LHC experiments
- Based on **bi-directionality**
- **Backward compatible** with legacy TTC system
- **Flexibility in partitioning**
- **Re-use of the current optical** network would be a plus

Bi-directionality

- **Downstream, broadcast/unicast:**
  - Same requirements than for the TTC (BC, BCR, ECR, Calibration Pulses, etc)
  - Plus…
    - Even better recovered clock quality (<5ps rms)
    - 8 bit trigger type synchronous to the trigger
    - Higher bandwidth to allow more commands (region of interest readout, event routing information…)
- **Upstream:**
  - Feedback and acknowledgment for control
  - Busy/throttle signals transmitted with short and bonded latency
  - Possibility to send **latency controlled signals** (calibration requests)
  - Fiber latency monitoring

And here comes the PON…

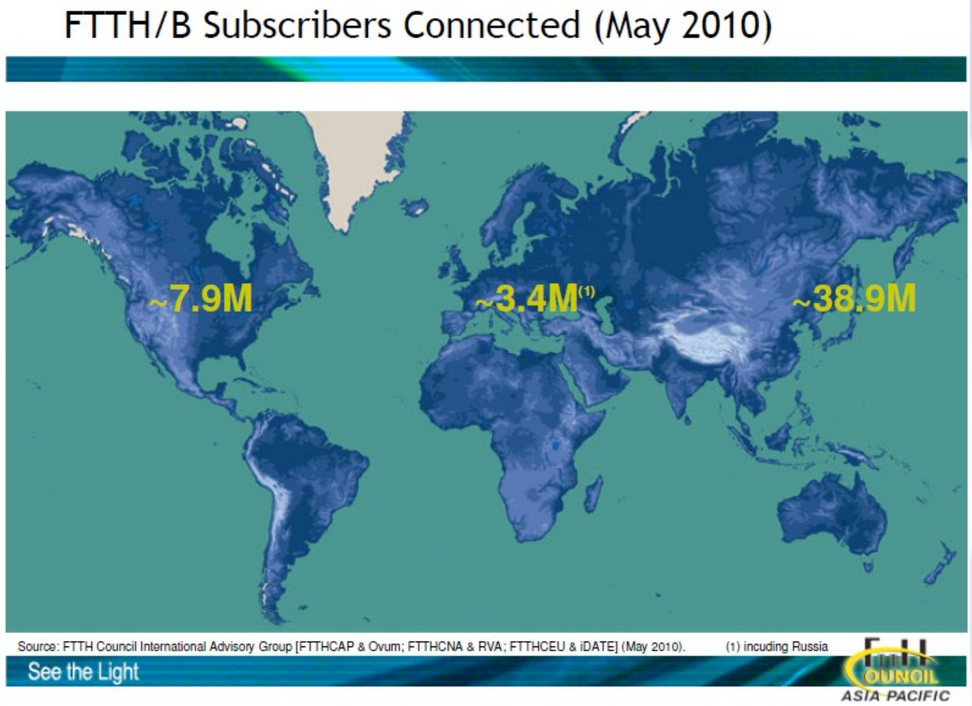
- *Bidirectional*
- *Current optical network: point to multipoint*
- *Relatively high bandwidth downstream*
- *Lower bandwidth upstream*

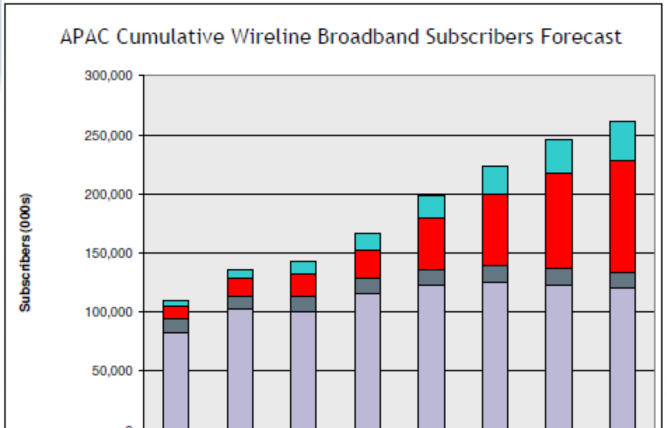
This is the typical topology of a PON system (Passive Optical Network), with some more constraints on clock recovery and fixed latency signals.

We investigated this option in the framework of the ACEOLE/Marie Curie program at CERN.

What is a PON?

- Passive Optical Network
- Also called FTTH/B/C/x
- Already mature technology
- Natural evolution of the wireline broadband market
- Very fast growing market (+20%/year in Asia-Pacific)
- Estimation 170 Millions of subscribers in 2013



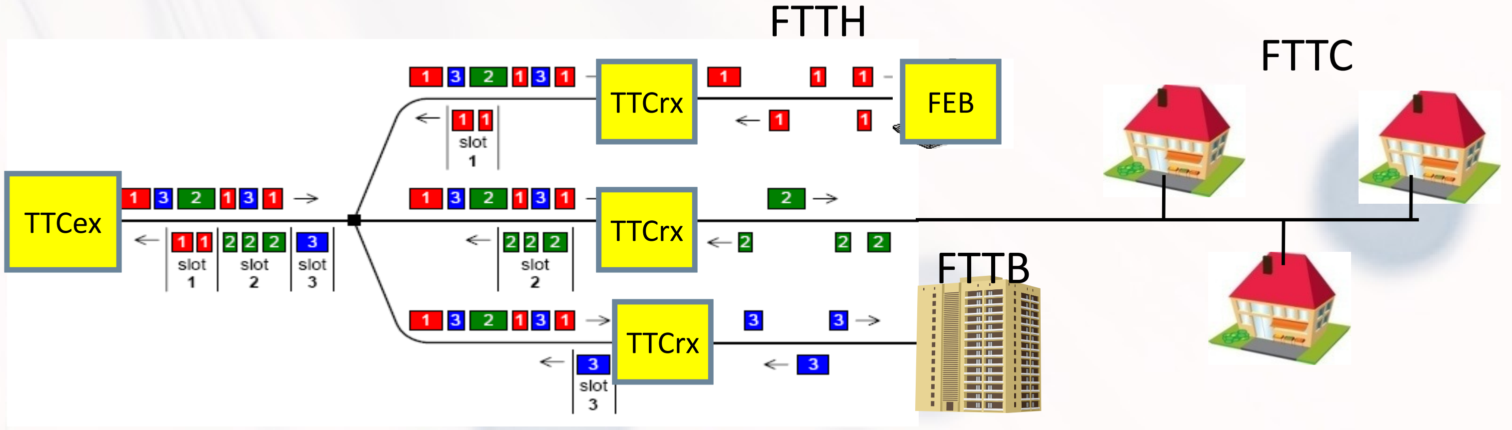


	2006	2007	2008	2009	2010	2011	2012	2013
FTTH	5,348	8,001	11,403	15,161	19,176	23,567	28,332	32,454
FTTB	10,618	14,492	18,645	23,816	42,872	60,921	80,851	94,959
Cable modem	10,872	11,665	12,157	12,540	12,925	13,337	13,769	14,230
DSL	83,611	102,037	100,962	116,063	123,611	125,514	122,877	119,683

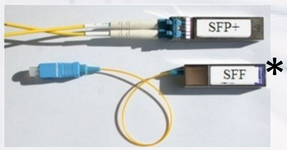
Sources: FTTH Council APAC/Ovum. Feb.2010

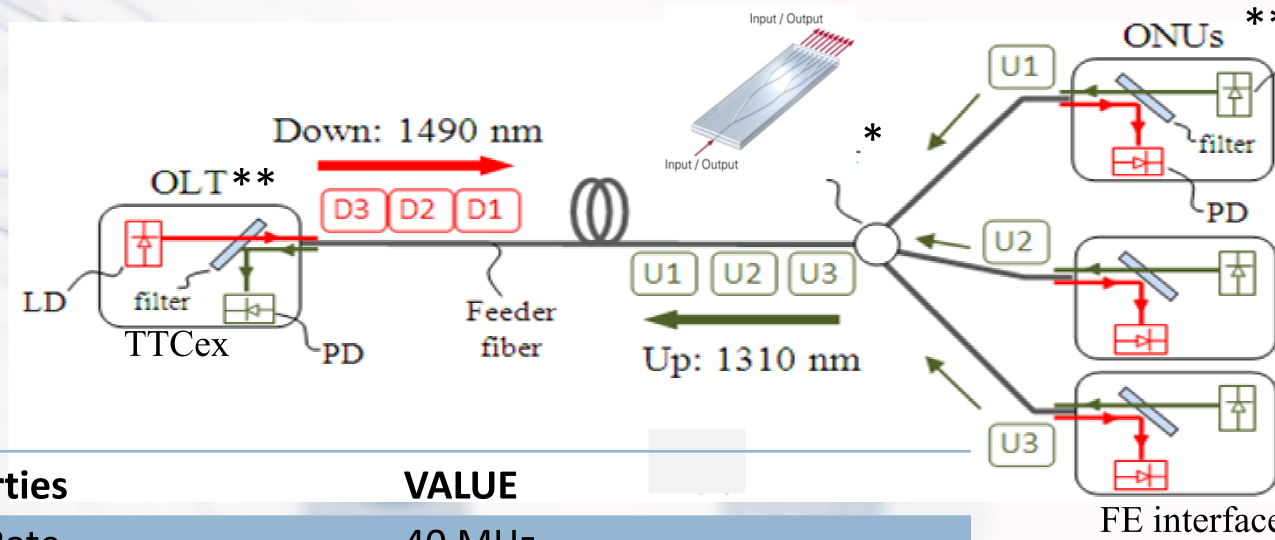
What is a PON?

- PON is a **Passive** Point-to-MultiPoint (PMP) optical network with no active elements in the signal path from the source to the destination
- **One single fibre** in charge of both downstream and upstream transmissions
- In the **downstream** direction (OLT→ONUs) PON is a **broadcast** network , using typically EPON (IEEE) or GPON (ITU) protocols
- In the **upstream** direction (ONUs→OLT) a number of customers share the same transmission medium
  - Some channel arbitration mechanism should exist to avoid collisions and to distribute bandwidth fairly among ONUs
  - Several multiplexing schemes exist (TDMA, WDM, SCM, OCDMA..)



PON for TTC



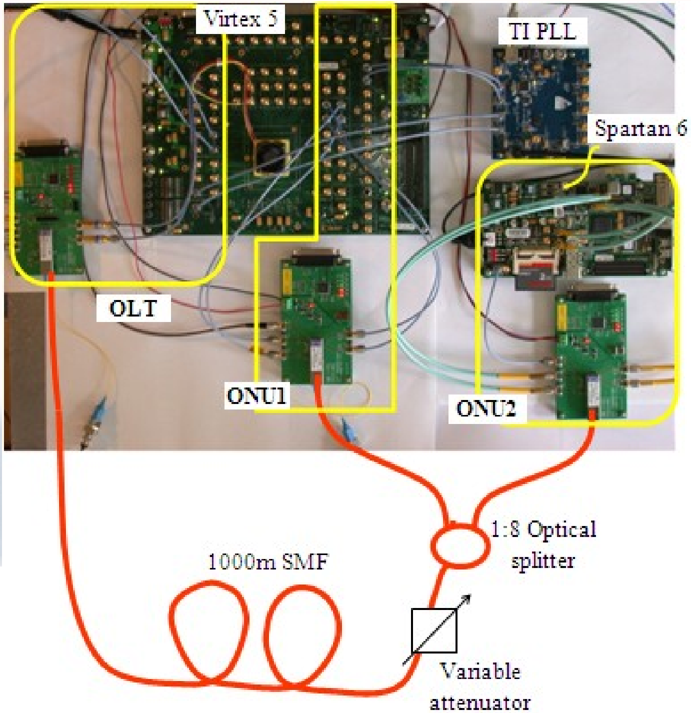


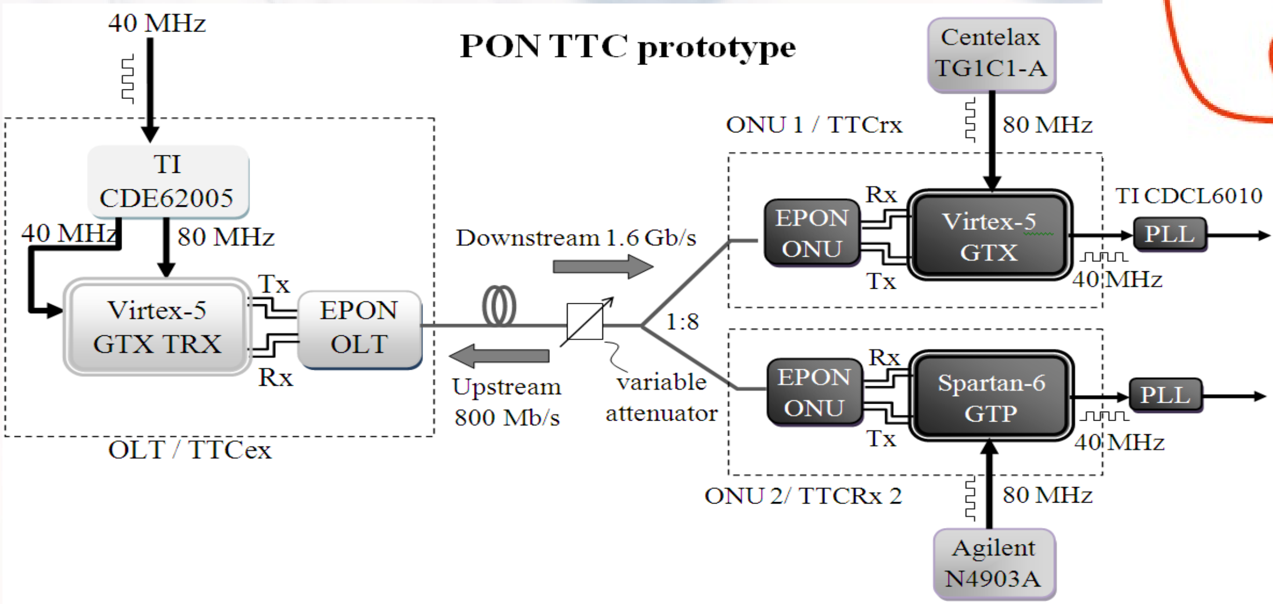
	Properties	VALUE
	Clock Rate	40 MHz
←	Distance	100 m ÷ 1000 m
→	Splitting Ratio	Flexible, Up to 64
	Encoding	NRZ 8b/10b
	Protocol	Custom
→	Bit Rate Downstream	1.6 Gb/s
	Wavelength Downstream	1490 nm
	Latency Downstream	Fixed and Deterministic
	Bit Rate Upstream	800 Mb/s
←	Wavelength Upstream	1310 nm
	Latency Upstream	Bonded
	Upstream BW Allocation	TDMA, Fixed, Round Robin

*: Splitters, OLT and ONU transceivers are **COTS based on 1G-EPON**

**: OLT and ONUs logic implemented in FPGAs

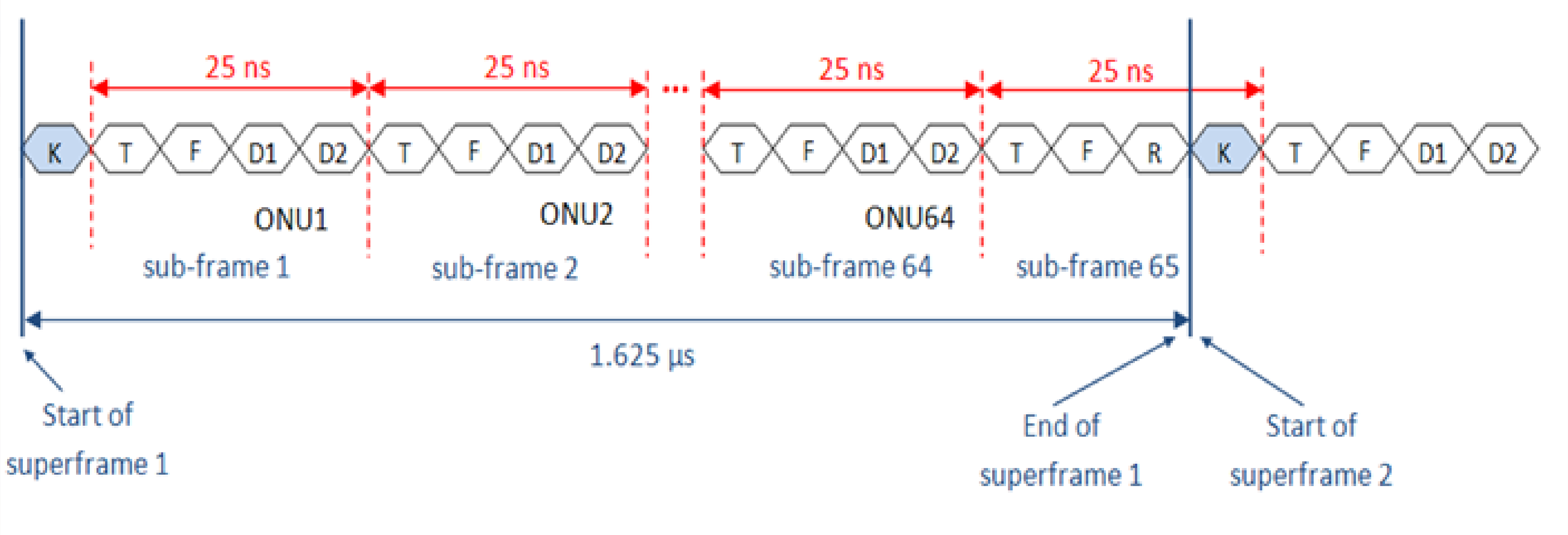
Hardware Demonstrator Implementation





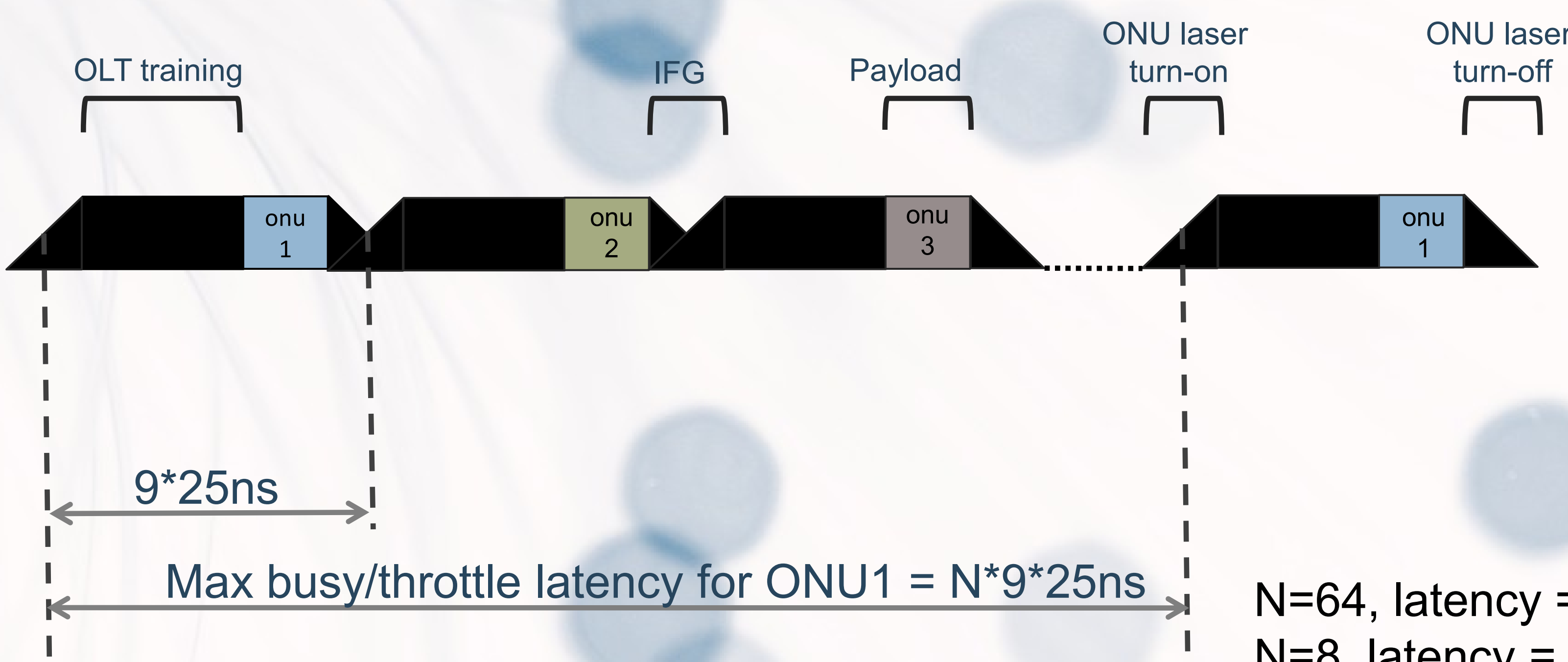
Downstream Frame

- Raw rate 1.6Gbit/s
- 590.8 Mb/s are available for data downstream, for example if broadcast only
- 9.23 Mb/s per ONU (if 64 ONUs individually addressed)



Upstream Frame

- Technology choice: TDMA with 1G-EPON components
- Splitting ratio: 1:N
- 800MHz
- ONU payload data = 4 bytes per turn
- OLT training = 34 bytes
- Inter Frame Gap (IFG) = 50ns min



N=64, latency = 14us
N=8, latency = 2us

Demonstrator Performance

CURRENT TTC AND PON-TTC DOWNSTREAM LATENCY CHARACTERISTICS

PON-TTC	LATENCY	Current TTC	LATENCY
GTX TX	75 ns	TTCex	25 ns
EPON OLT TX	2.11 ns		
EPON ONU RX	2.16 ns	TTCrx	65-85 ns
GTX-GTP RX	137.5 ns		
Total	**216.8ns**	Total	**90-110 ns**
Optical Fiber	5ns/m	Optical Fiber	5ns/m

PON-TTC JITTER CHARACTERISTICS

Point of Measurement	RMS C2C JITTER (PS)
Ref 40MHz	3.17
Recovered 40 MHz, ONU1 Filtered 40 MHz, ONU1	36.72 **3.6**
Recovered 40 MHz, ONU2 Filtered 40 MHz, ONU2	53.12 **3.8**

UPSTREAM LATENCY BREAKDOWN ANALYSIS

Field	1G-EPON (CURRENT)	10G-EPON	2GPON	10GPON
No. of bunch-cycles between transmissions of one ONU for a splitting ratio of 1:N	9*N	3*N	4*N	2*N

References

- *Passive Optical Networks in Particle Physics Experiments*, Ioannis Papakonstantinou, 24th November 2009, PH-ESE Seminar
- *A Fully Bidirectional Optical Network with Latency Monitoring Capability for the Distribution of Timing-Trigger and Control Signals in High-Energy Physics Experiments*, Ioannis Papakonstantinou et al., accepted for publication in IEEE TNS in 2011.

Achievements

- Successful proof of concept for a TTC upgrade
  - Bi-directionality with one fiber only
  - Much higher bandwidth
  - Compatible with legacy TTC
  - Excellent quality of the recovered clock
  - "Soft-partitioning"

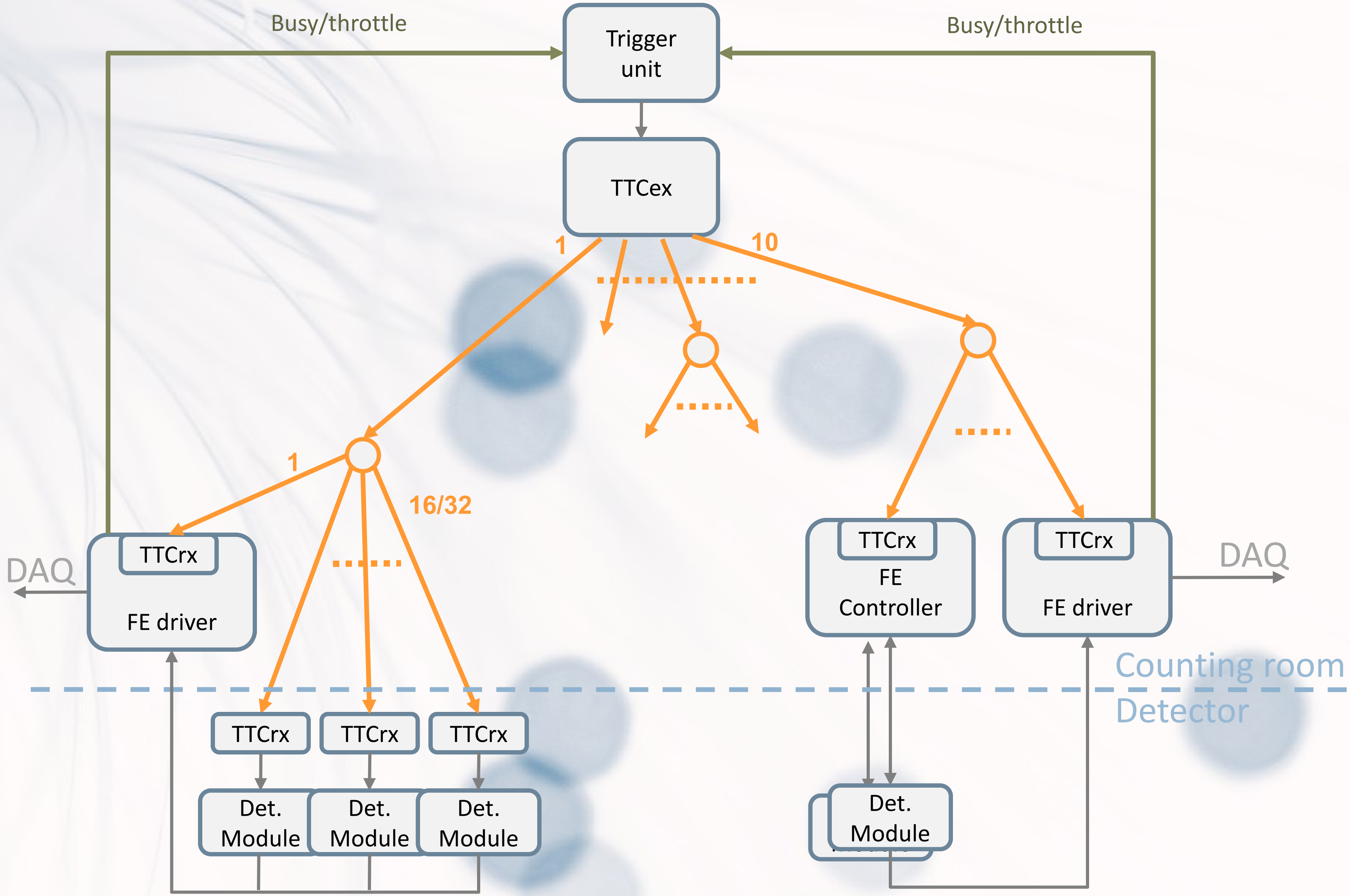
  ... **With the same optical infrastructure**!!

- And still many possibilities for improvement...

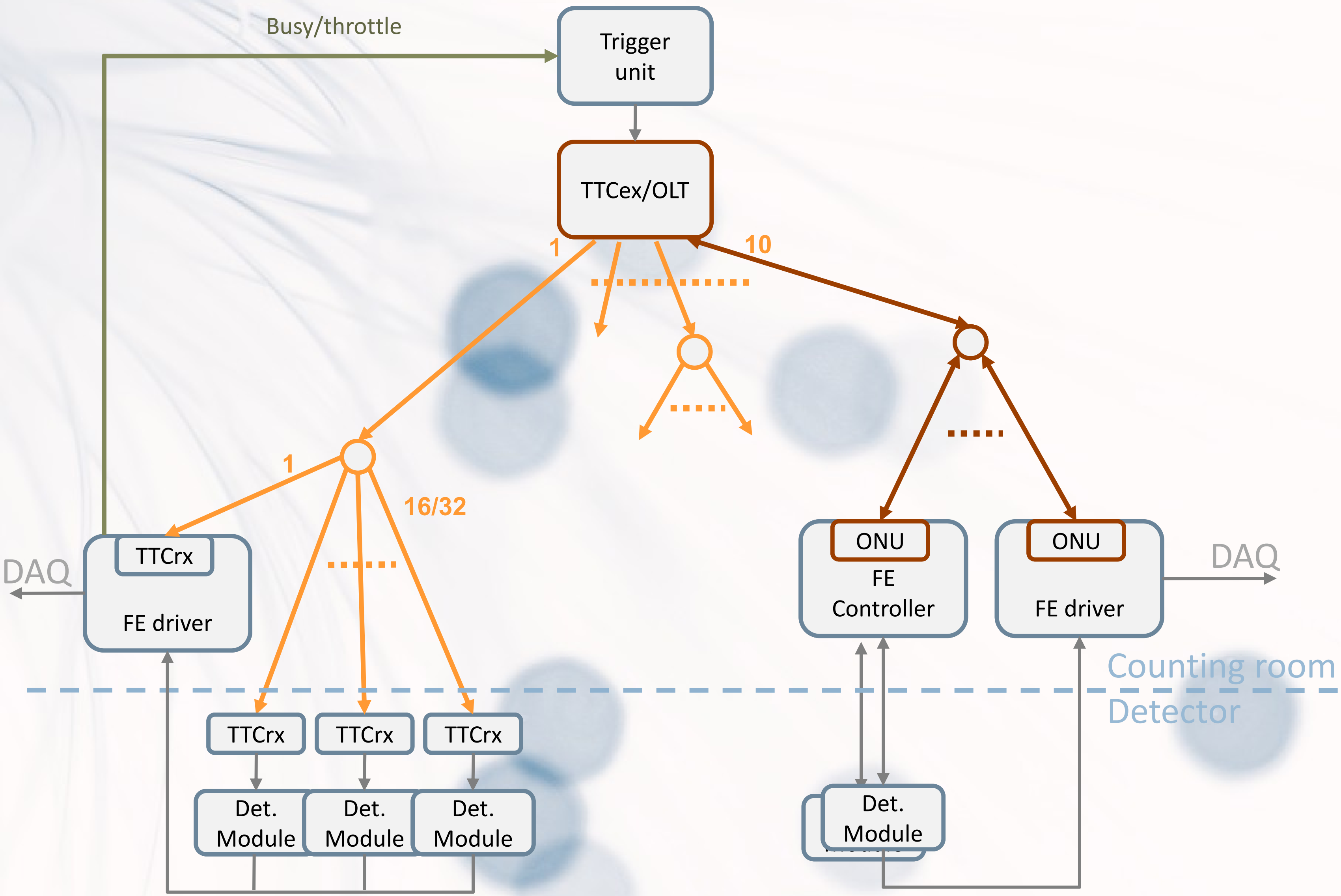
Possible Future Developments

- **Reducing downstream and upstream latency**
  - Using better PON technologies and faster FPGAs
  - Improving the protocol (currently simple proof-of-concept)
- **Fiber latency finding and monitoring at ONU level**
  - Implement monitoring of both feeder and distribution fiber latencies, on an ONU per ONU basis (feeder fiber latency monitoring is already implemented).
- **Non-blocking fixed latency upstream architecture**
  - Eliminate blocking time by using for instance spread spectrum technique like OCDMA. Typically, could support 64 users @ 10Mbps each (continuous & unshared!).
- **Overlaying wavelengths**
  - Services could be added on-demand
  - Example: tri-band PONS
    - Reserve one wavelength for trigger only
    - Legacy TTC + PON TTC on a same network

From TTC …

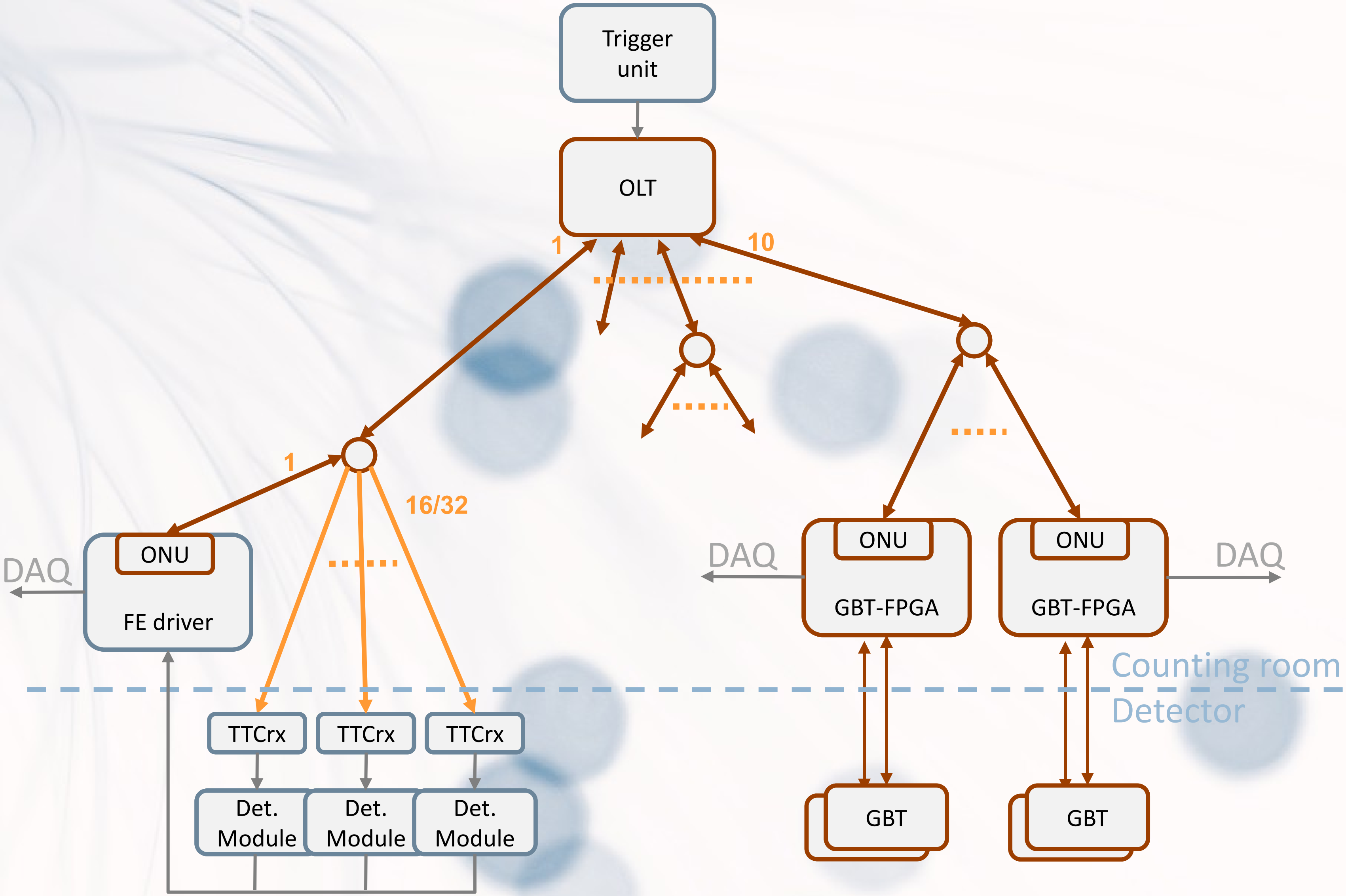

Busy/throttle
Trigger unit
Busy/throttle
TTCex
1
10
1
16/32
DAQ
TTCrx
FE driver
TTCrx
FE
Controller
TTCrx
FE driver
DAQ
Counting room
Detector
TTCrx
TTCrx
TTCrx
Det. Module
Det. Module
Det. Module
Det. Module

...To PON-TTC...



Busy/throttle
Trigger unit
TTCex/OLT
1
10
1
16/32
DAQ
TTCrx
FE driver
TTCrx
TTCrx
TTCrx
Det. Module
Det. Module
Det. Module
ONU
FE Controller
ONU
FE driver
DAQ
Counting room
Detector
Det. Module

Or even …


Trigger unit
OLT
1
10
1
16/32
ONU
FE driver
DAQ
TTCrx
TTCrx
TTCrx
Det. Module
Det. Module
Det. Module
DAQ
ONU
GBT-FPGA
ONU
GBT-FPGA
DAQ
GBT
GBT
Counting room
Detector

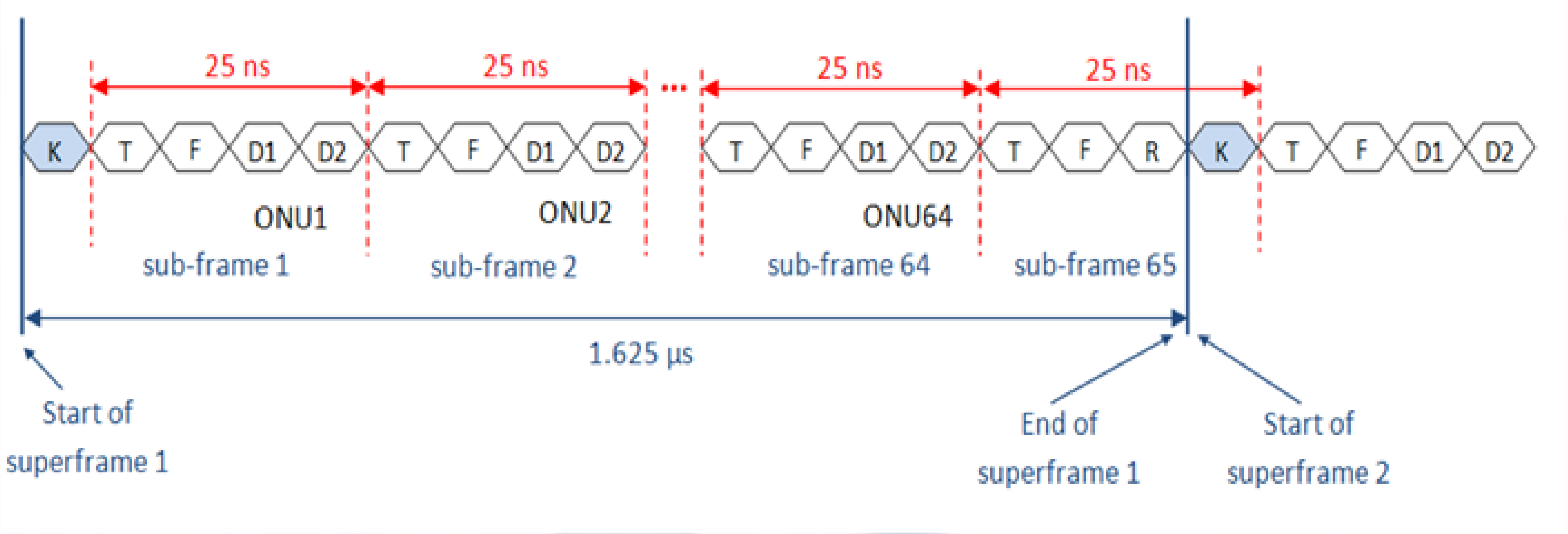
THANK YOU!

BACKUP SLIDES

Downstream Frame

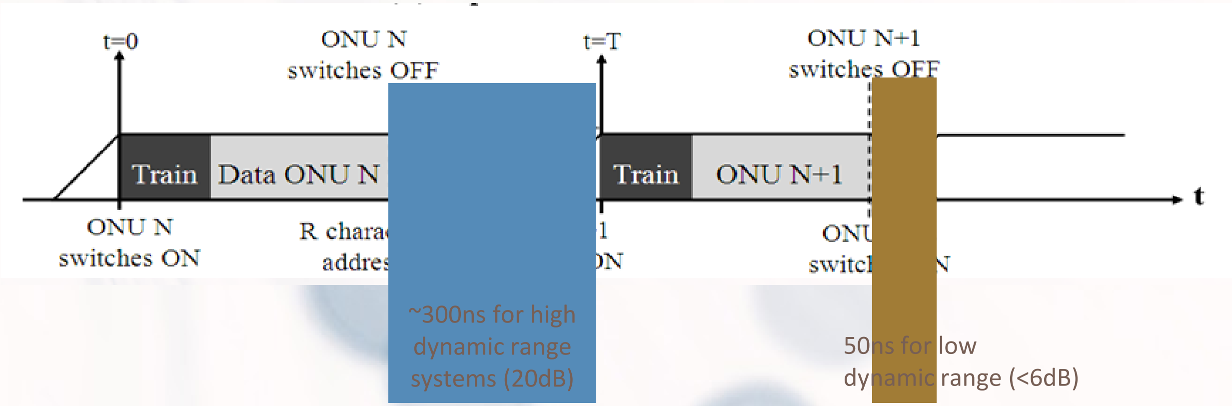
- Raw rate 1.6Gbit/s
- Synchronous transmission of super-frames with a period of 1625ns = 65*25ns at 1.6Gbit/s
- 8b/10b encoding (1Field = 1 symbol)
- 590.8 Mb/s are available for data downstream, for example if broadcast only
- 9.23 Mb/s per ONU (if 64 ONUs individually addressed)

Field	Operation
<K>	Frame alignment and synchronization
<T>	L1A trigger accept decision, real time transmission
<F>	Auxiliary, to be defined in the future (could be used for upstream channel arbitration to reduce buffering capacity)
<D1>, <D2>	Broadcasted/individually addressing commands (depending on first bit of D1)
<R>	Upstream channel arbitration (address of the next ONU allowed to transmit upstream)



Upstream Frame

- Channel arbitration at the OLT (based on a simple round-robin scheme)
- Slave N1 receives an R/F character with its address and switches its laser ON
- IFG between successive emissions allows receiver to adapt between bursts
- Long sequence of idle bytes for CDR & frame alignment
- 4 bytes of payload
- Total BW 800Mb/s
- Latency not fixed but bonded
- Optimized latencies with 1G-EPON components
  - if **64 ONUs**: **14 us** (BW/slave=2.2Mb/s)
  - If **32 ONUs**: **7 us** (BW/slave=4.5Mb/s)
  - If **8 ONUs**: **2 us** (BW/slave=18Mb/s)
  - …



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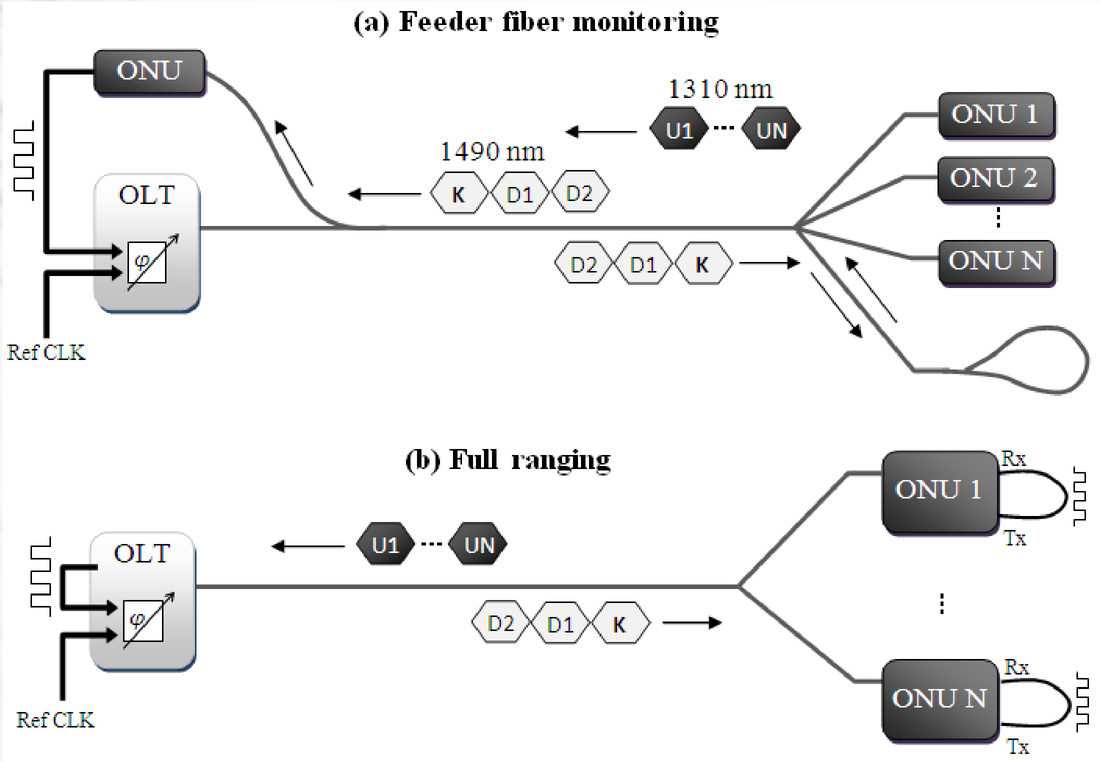
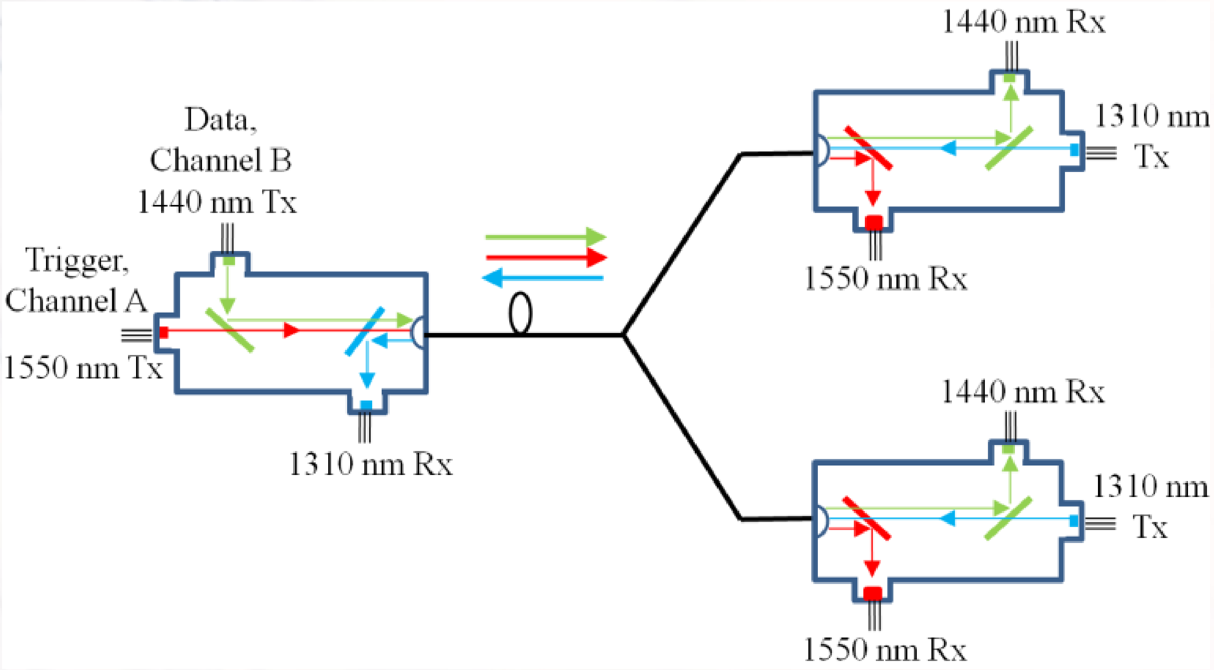
MIN UPSTREAM FRAME DURATION BREAKDOWN ANALYSIS

Field	1G-EPON (CURRENT)	10G-EPON	2GPON	10GPON
Overlapping IFG (ns)	50	50	16	16
Training (ns)	125	12.5	62.5	12.5
4B Payload (ns)	40	4	20	4
Total per frame (ns)	**215**	**66.5**	**98.5**	**32.5**
No. of bunch-cycles between transmissions	9	3	4	2

Latency monitoring

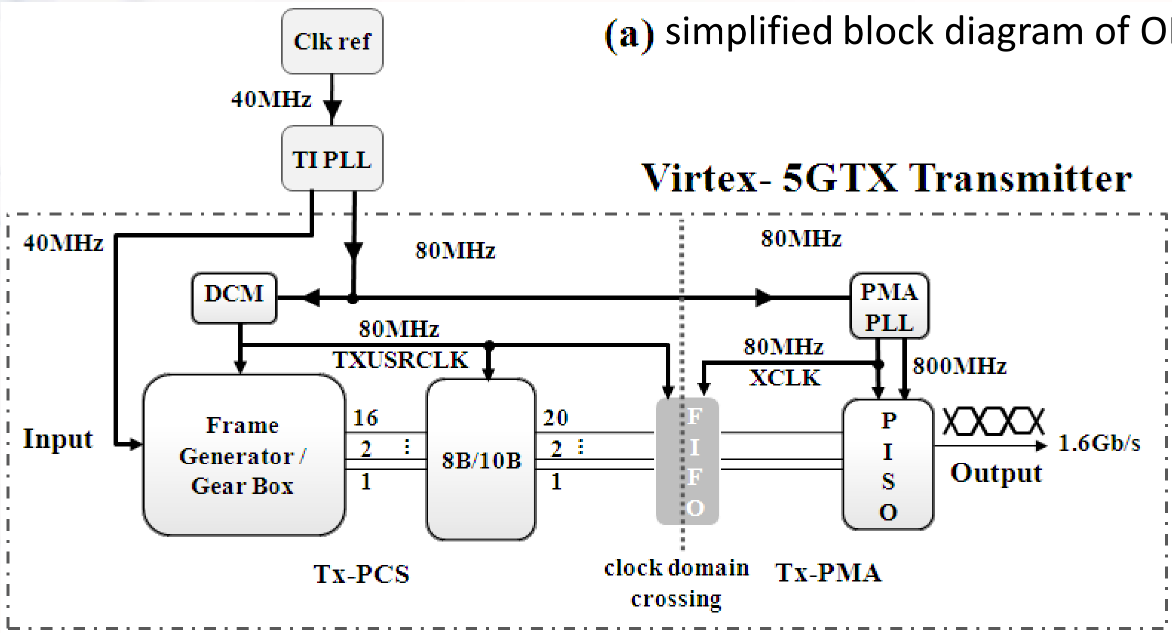


Tri-band PON

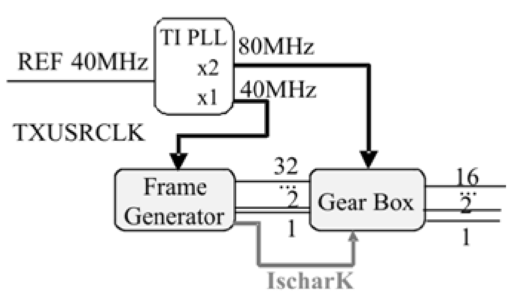

Data,
Channel B
1440 nm Tx
Trigger,
Channel A
1550 nm Tx
1310 nm Rx
1440 nm Rx
1310 nm
Tx
1550 nm Rx
1440 nm Rx
1310 nm
Tx
1550 nm Rx

OLT implementation in Virtex5

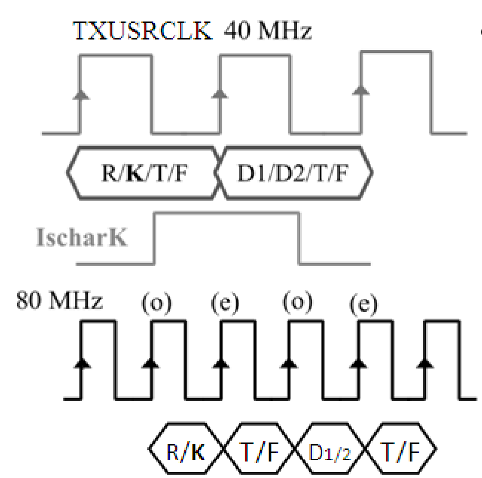
(a) simplified block diagram of OLT transmitter



(b) gear-box operation

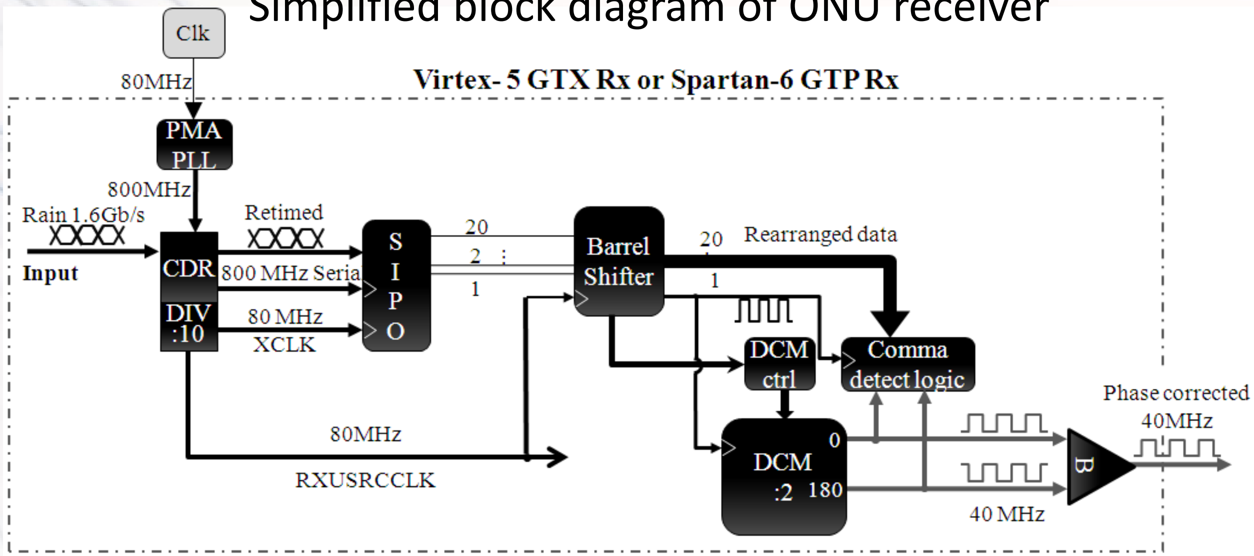


(c) timing of frames before and after gear-box.

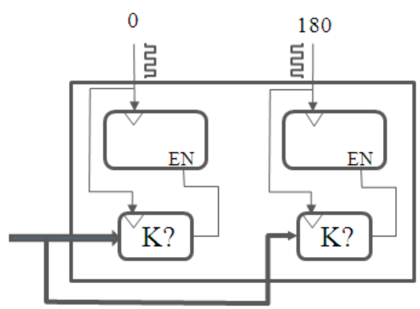


ONU implementation in V5/Spartan6

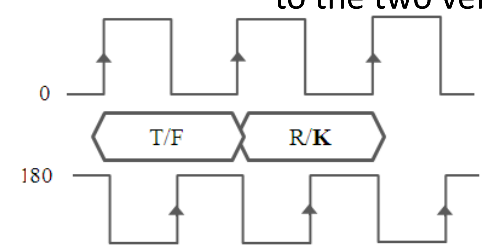
Simplified block diagram of ONU receiver



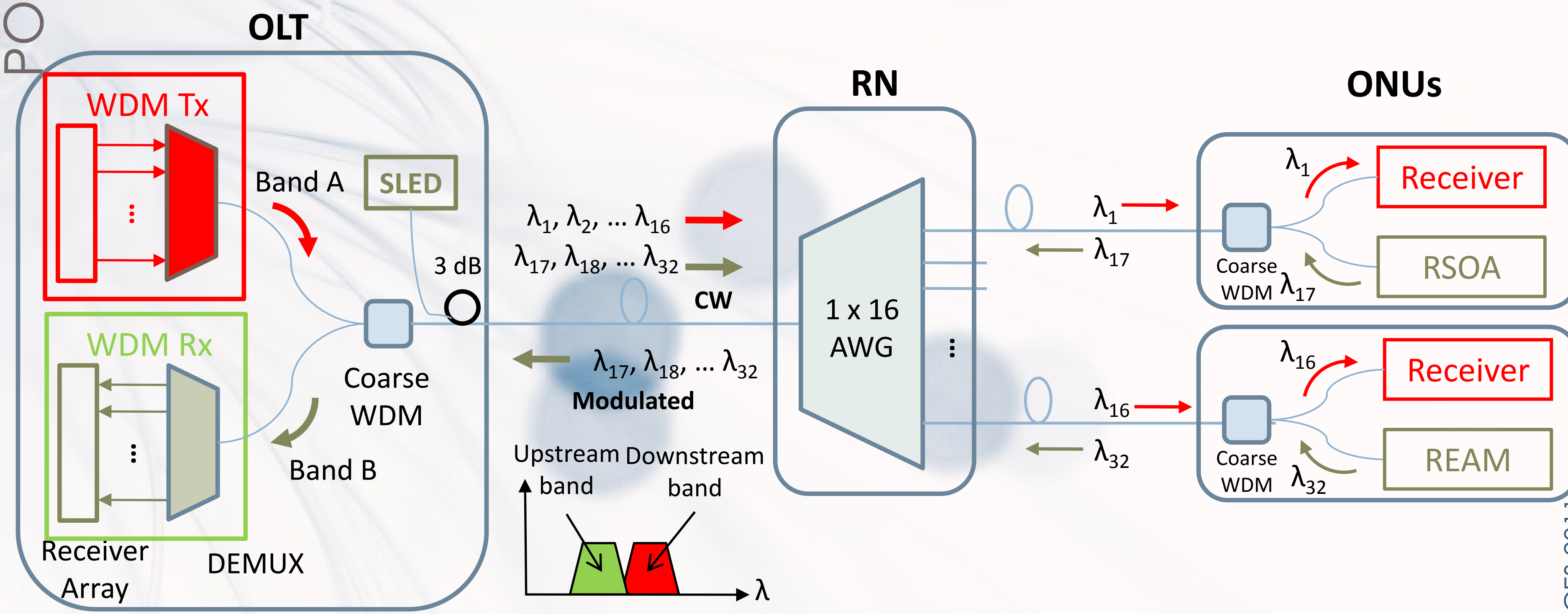
(b) comma detect logic implementation



(c) timing of incoming frames relative to the two versions of the recovers 40 MHz clock.

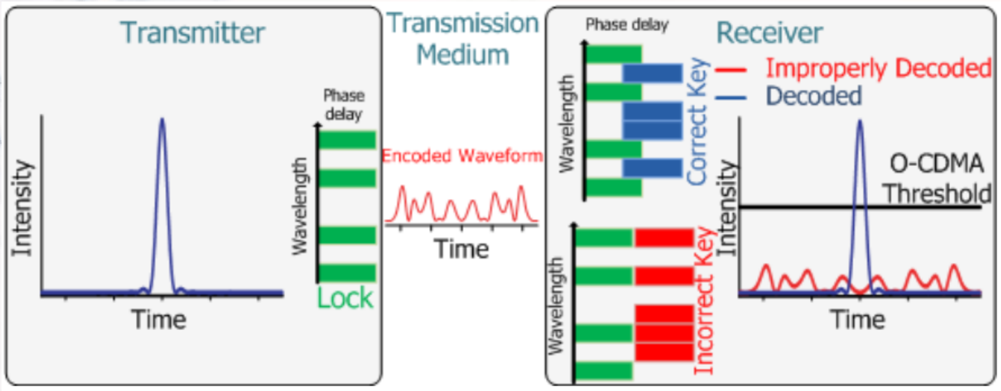


WDM technique



OCDMA technique

Frequency spreading



Time spreading