TSN FOR JITTER MINIMIZATION IN RECONFIGURABLE FRONTHAUL

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FRONTHAUL TECHNOLOGIES

C-RAN proposes radio interface using high-bandwidth media (optical or wireless) between REC and RE

Sampled RF data is transferred from RE to REC

Baseband processing is done in REC

Fronthaul is the connection between RE and REC

Several fronthaul technologies exist for C-RAN, e.g., Common Public Radio Interface (CPRI), Open Base Station Architecture Initiative (OBSAI) etc.

CPRI is a radio interface developed by several leading telecom vendors for transporting sampled RF data from RE to REC

Constant-bit-rate (CBR) interface with line options that goes from 614.4 Mbps (option 1) up to 12.16 Gbps (option 9)

RECONFIGURATION IN FRONTHAUL

5G systems aim to achieve flexibility and reconfigurability in both the radio access part and signal processing part

Classified into bandwidth reconfigurability and network reconfigur*ability*

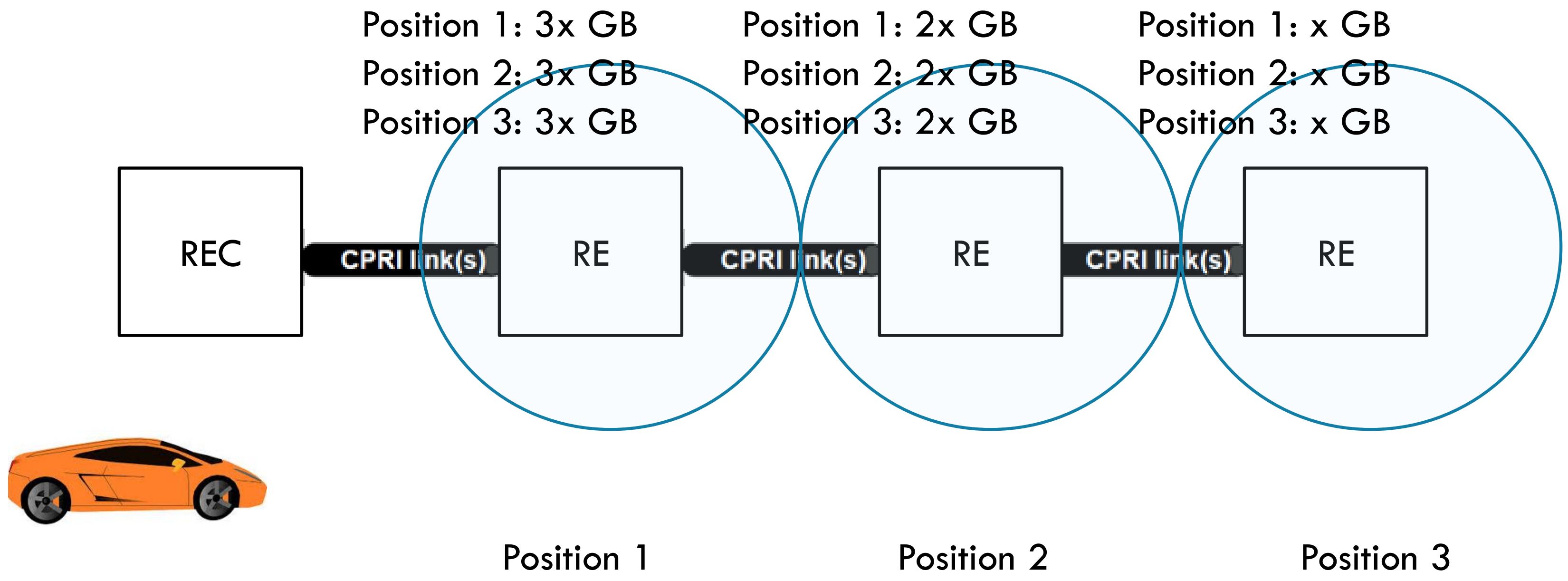
Bandwidth reconfigurability : flexible on-the-fly bandwidth allocation to fronthaul links depending on need of RE

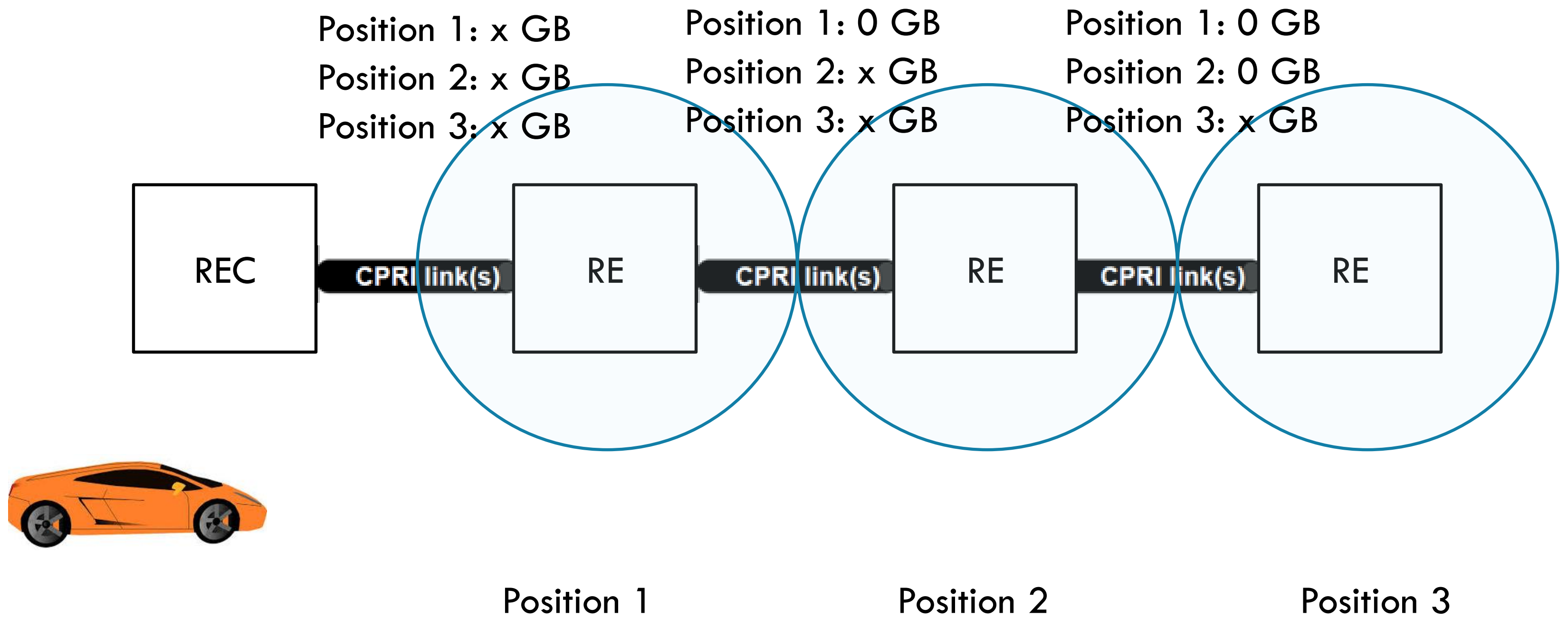
Fronthaul can be dimensioned for current traffic rather than peak traffic, saving capacity and network equipment based on traffic profile, antenna capacity, cell size, user level QoE

Network reconfigurability : ability to change fronthaul network topology on-the-fly based on requirements of cells

Network can change based on co-ordination scenarios (CoMP), energy-efficiency schemes, etc., thus changing fronthaul topology

Bandwidth Reconfiguration





BANDWIDTH RECONFIGURATION - ANTENNA CONFIGURATIONS

CPRI allows rate negotiation to switch to different line rate when the antenna configuration changes

Antenna reconfiguration on/off (sectors, antenna, cell) can happen depending on the user traffic requirement

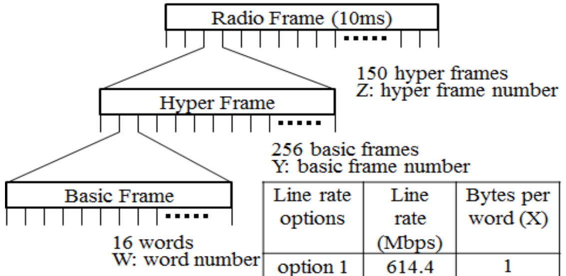
Power saving, interference reduction, frequency reuse etc. are use cases

LTE cell breathing – adaptive coding (each sector has different coding)

Vendor – cell adaptive (change frequency) 3GPP – each sector different modulation – within a sector different modulation (5Mhz to 20Mhz)

Antenna configuration	LTE Bandwidth	
	10 MHz	20 MHz
2x2 MIMO	1.2288 Gbps (IP rate 75Mbps)	2.4576 Gbps (IP rate 150Mbps)
4x2 (4x4) MIMO	2.4576 Gbps (IP rate 150Mbps)	4.9152 Gbps (IP rate 300Mbps)
8x2 (8x4, 8x8) MIMO	4.9152 Gbps (IP rate 300Mbps)	9.8304 Gbps (IP rate 600Mbps)

* Source: CPRI Specification v6.0 (Aug. 30, 2013)



Line rate options	Line rate (Mbps)	Bytes per word (X)
option 1	614.4	1
option 2	1228.8	2
option 3	2457.6	4
option 4	3072.0	5
option 5	4915.2	8
option 6	6144.0	10

http://www.netmanias.com/en/post/blog/6237/c-ran-cpri-fronthaul/why-wdm-is-essential-in-c-ran-fronthaul-networks-ultra-high-cpri-link-capacity

Antennas for MIMO	Sectors	LTE BW (MHz)	IQ DR	CPRI DR	Line Rate
1/2	1	10/5		614.4	1
1/2/4	1	20/10/5		1228.8	2
1/2	3	10/5		1843.2	3
2/4	1	20/10		2457.6	4
2 + 1	2	20 + 10		3072.0	5
1/2	3 + 3	10/5		3686.4	6
1/2 + 1	3 + 3 +1	10/5 + 10		4300.8	7
4/8		20/10		4915.2	8
4/8 + 1		20/10+10		5529.6	9
				6144	10
				6758.4	11
				7372.8	12
				7987.2	13
				8601.6	14
8/16		20/10		[illegible]	15

LTE Bandwidth
- 1.4 MHz
- 3 MHz
- 5 MHz
- 10 MHz
- 15 MHz
- 20 MHz ...

MIMO
- 1
- 2
- 4
- 8
- 16

Sectors
- 1
- 2
- 3
- 4
- 5
- 6

FRONTHAUL STRINGENT REQUIREMENTS AND PROBLEMS

CPRI switching can be very difficult (as it is very highrate)

Need to enable statistical multiplexing by evolving from CBR CPRI to packet-based fronthaul

Fronthaul must be dimensioned for peak traffic rather than current traffic

Stringent performance requirements imposed by CPRI

1) 100us of one way delay – previous study shows this is met
2) 65ns of maximum variation in delay (i.e., jitter) – doubtful
3) up to 10Gbps of throughput per RRH
4) 10^{-12} of maximum bit error rate.

DELAY - MAPPING CPRI ONTO 10G ETHERNET

Line rate [Mb/s]	Ethernet packets per radio frame (1250 bytes payload)	Payload gen time [µs]	Switch delay [µs]	Header overhead (for radio frame) [µs]	Header overhead for four sub-frames [µs]	Ethernet overhead for CoE (Round Trip) [µs]	Distance supported [km]
614.4 (option 1)	615	16.27	1.0	11.8	4.72	11.44	23.456
1228.8 (option 2)	1229	8.135	1.0	23.6	9.44	20.88	22.512
2457.6 (option 3)	2458	4.067	1.0	35.4	18.88	39.76	20.624
3072.0 (option 4)	3073	3.254	1.0	59.0	23.60	49.20	19.680
4915.2 (option 5)	4916	2.033	1.0	94.4	37.76	77.52	16.848
6144.0 (option 6)	6144	1.627	1.0	118.0	47.20	96.40	14.960
Line rate [Mb/s]	Ethernet packets per radio frame (1500 bytes payload)	Payload gen time [µs]	Switch delay [µs]	Header overhead (for radio frame) [µs]	Header overhead for four sub-frames [µs]	Ethernet overhead for CoE (Round Trip) [µs]	Distance supported [km]
614.4 (option 1)	512	19.53	1.2	9.83	3.932	10.264	23.573
1228.8 (option 2)	1024	9.76	1.2	19.66	7.864	18.128	22.787
2457.6 (option 3)	2048	4.88	1.2	39.32	15.728	33.856	21.214
3072.0 (option 4)	2560	3.906	1.2	49.15	19.660	41.720	20.428
4915.2 (option 5)	4096	2.44	1.2	78.64	31.456	65.312	18.068
6144.0 (option 6)	5120	1.953	1.2	98.30	39.320	81.040	16.496

TIME SENSITIVE NETWORKING – 802.1

IEEE 802.1 Audio Video Bridging (AVB) Task Group (TG) Started in 2005

Address professional audio, video market

Consumer electronics

Automotive infotainment

AVnu Alliance: associated group for compliance and marketing

- ›IEEE 802.1 Time-Sensitive Networking (TSN) TG AVB features become interesting for other use cases, e.g. Industrial
- Automotive

AVB was not an appropriate name to cover all use cases

AVB TG was renamed to TSN TG in 2012

Interworking TG and TSN TG were merged in 2015

IEEE 802.1 TSN PROJECTS

- P802.1Qbu – Frame Preemption – ready
- P802.1Qbv – Enhancements for Scheduled Traffic – ready
- P802.1Qcc – Stream Reservation Protocol (SRP) Enhancements and Performance Improvements
- P802.1Qci – Per-Stream Filtering and Policing
- P802.1Qch – Cyclic Queuing and Forwarding
- 802.1Qcj – Auto-attach to PBB services
- P802.1AS-Rev – Timing and Synchronization – Revision
- P802.1CB – Frame Replication and Elimination for Reliability
- P802.1CM – Time-Sensitive Networking for Fronthaul

SOME TSN NETWORKING PARADIGMS

802.3br Interspersing Express Traffic (Frame Preemption)

Express frames can suspend the transmission of preemptable frames

802.1Qbv – Enhancements for Scheduled Traffic

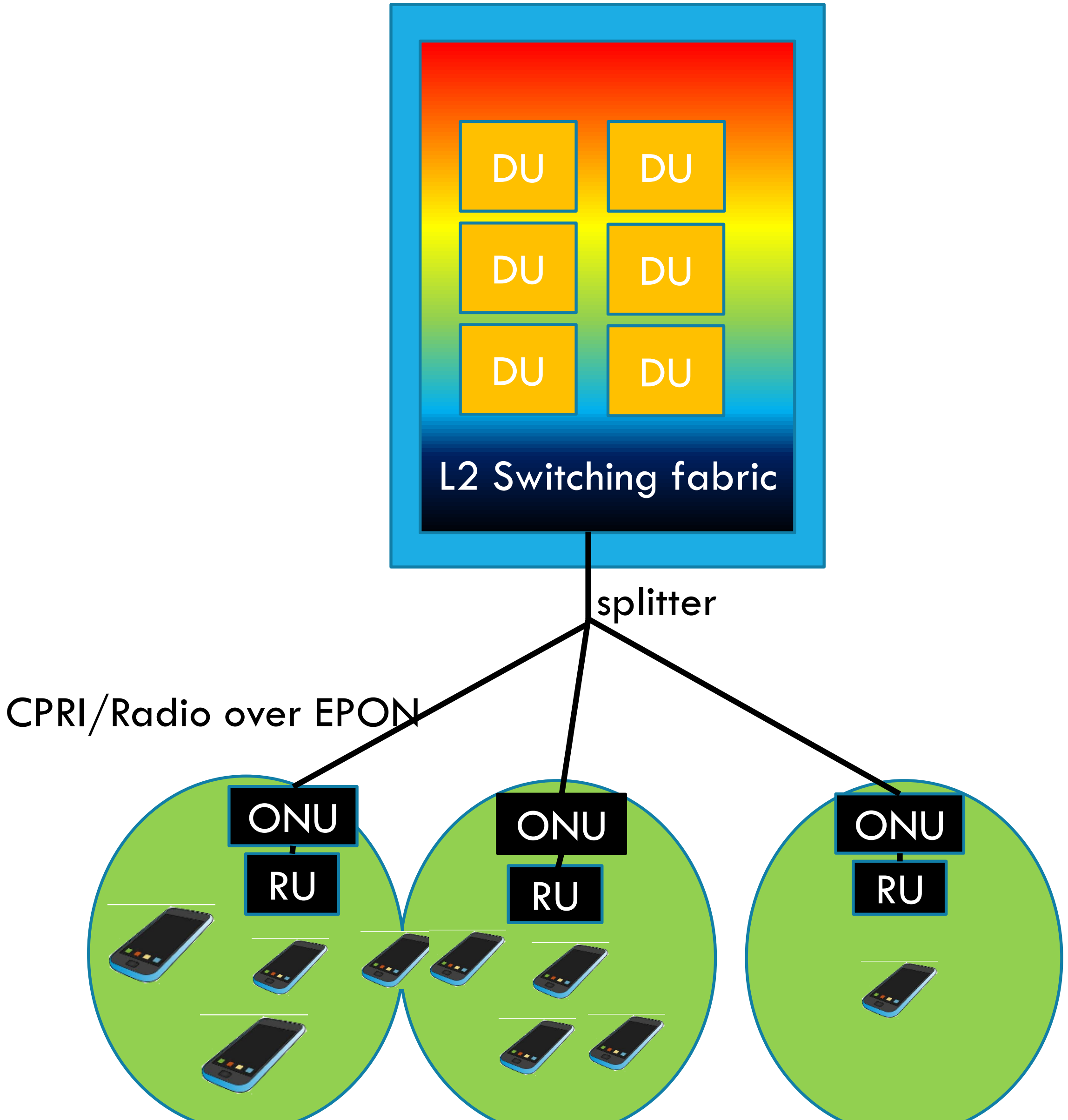
Transmission from each queue to be scheduled relative to a known timescale

›A transmission gate is associated with each queue the state of the gate determines whether or not queued frames can be selected for transmission

Open: queued frames are selected for transmission, (according to the transmission selection algorithm associated with the queue)

Closed: queued frames are not selected for transmission

PROPOSED ARCHITECTURE



CONCERN OF JITTER IN RECONFIGURABLE CPRI

Delay is met for CPRI over Ethernet

Normal Ethernet - jitter is 400ns in the worst case

Ethernet with preemption - jitter of 410ns in the worst

Ethernet with scheduling does not seem to perform consistently, in most cases, the jitter is completely removed , while in a few cases, it is increased to 1000ns

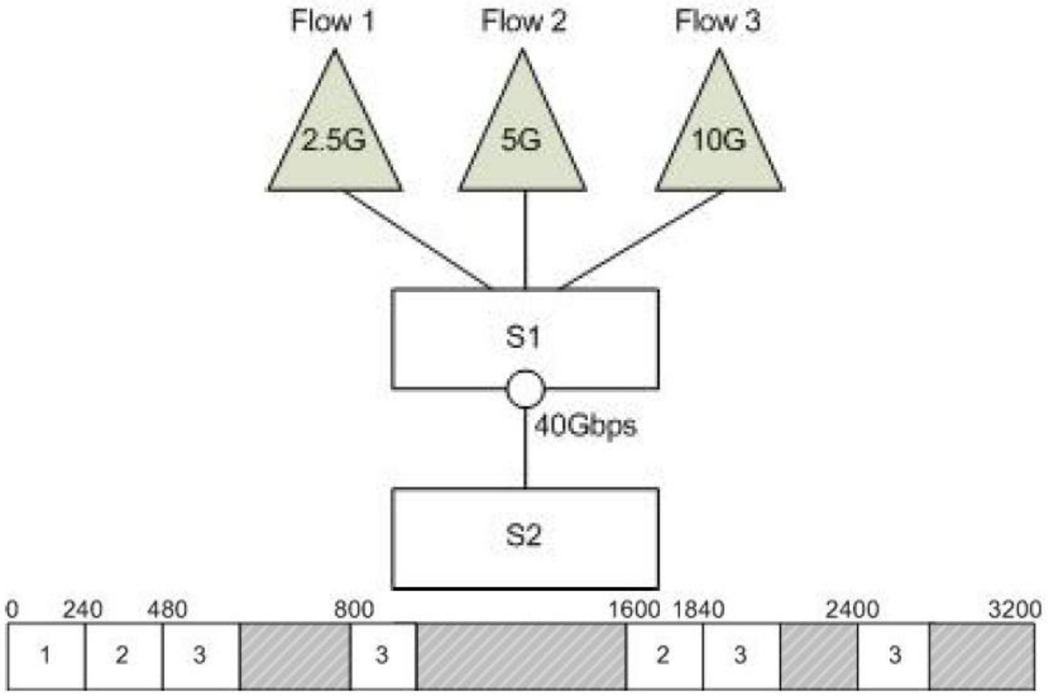
Ethernet could meet the one-way delay requirement of 100us, but could not meet the jitter requirement of 65ns, with or without any proposed new enhancement

Authors proposed scheduling scheme that reduces jitter – however did not consider reconfiguration

Ethernet with reconfigurable CPRI would have even higher jitter

[2] A Performance Study of CPRI over Ethernet, Tao Wan and Peter Ashwood, Huawei Canada Research Center

SCHEDULED TRAFFIC FOR ETHERNET

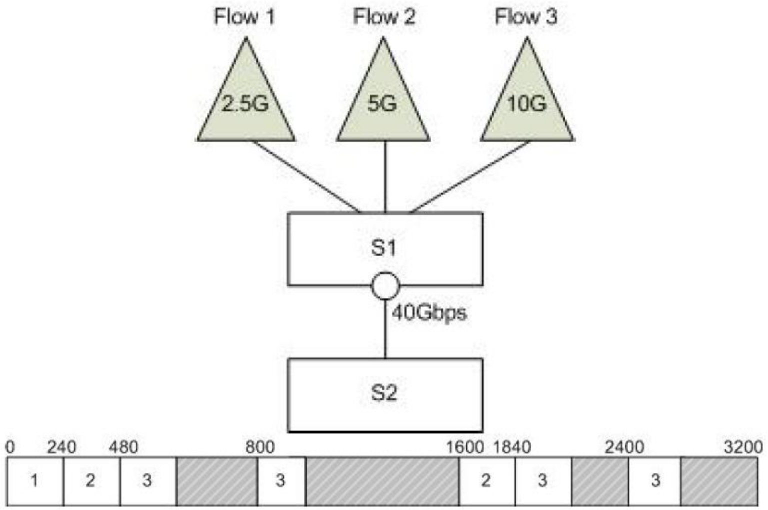


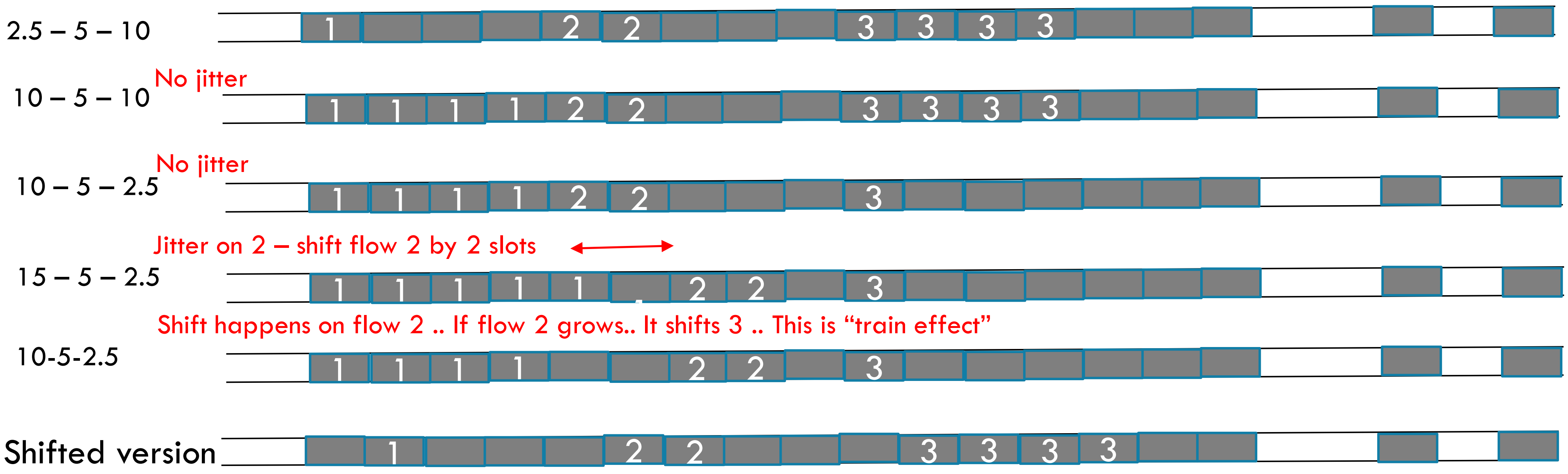
Contention based scheduling [1] – poor jitter performance in case of reconfiguration

[2] A Performance Study of CPRI over Ethernet, Tao Wan and Peter Ashwood, Huawei Canada Research Center

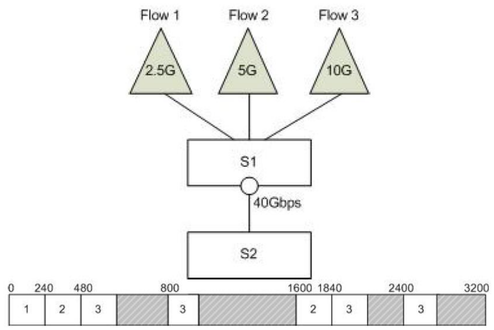
Equal gap scheme

3200/200 = 16 slots
16 – 1 – 2 – 4 = 9
9/3 = 3 gap





Predictive gap scheme



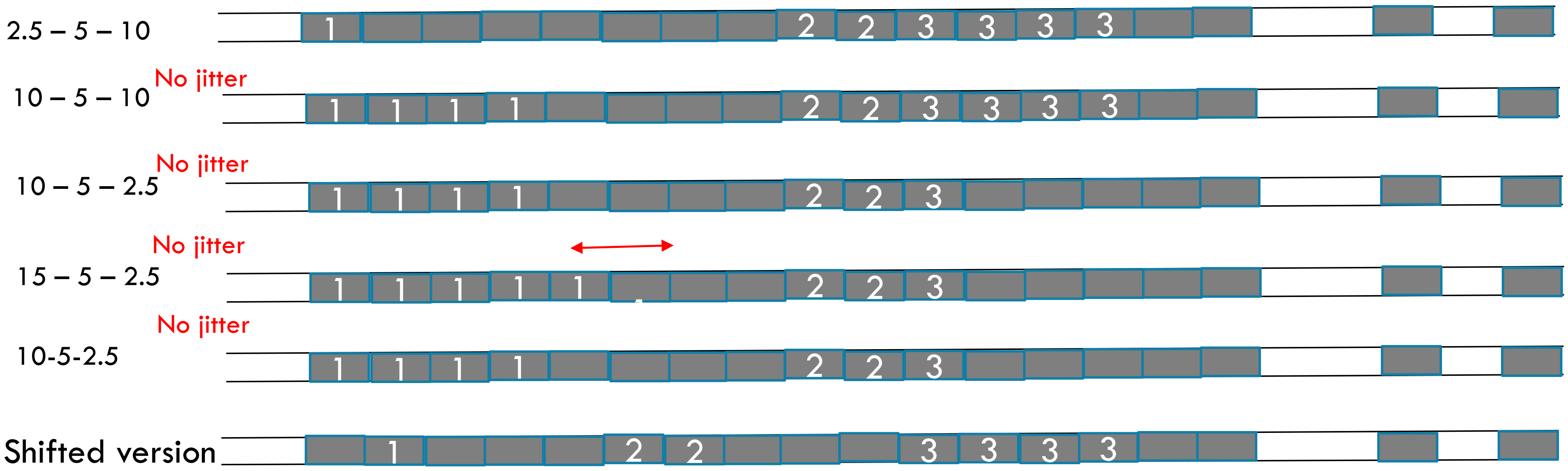
3200/200 = 16 slots

16 – 1 – 2 – 4 = 9

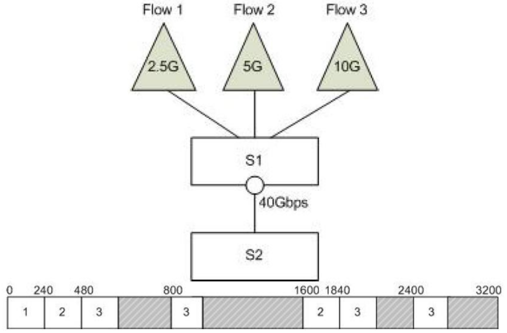
1st cell – traffic varies a lot (v = 3) => gap = (3/4)*9 = 7

2nd cell – constant profile (v = 0) = 0

3rd cell – varies slightly (v = 1) = 2



Jitter balancing scheme



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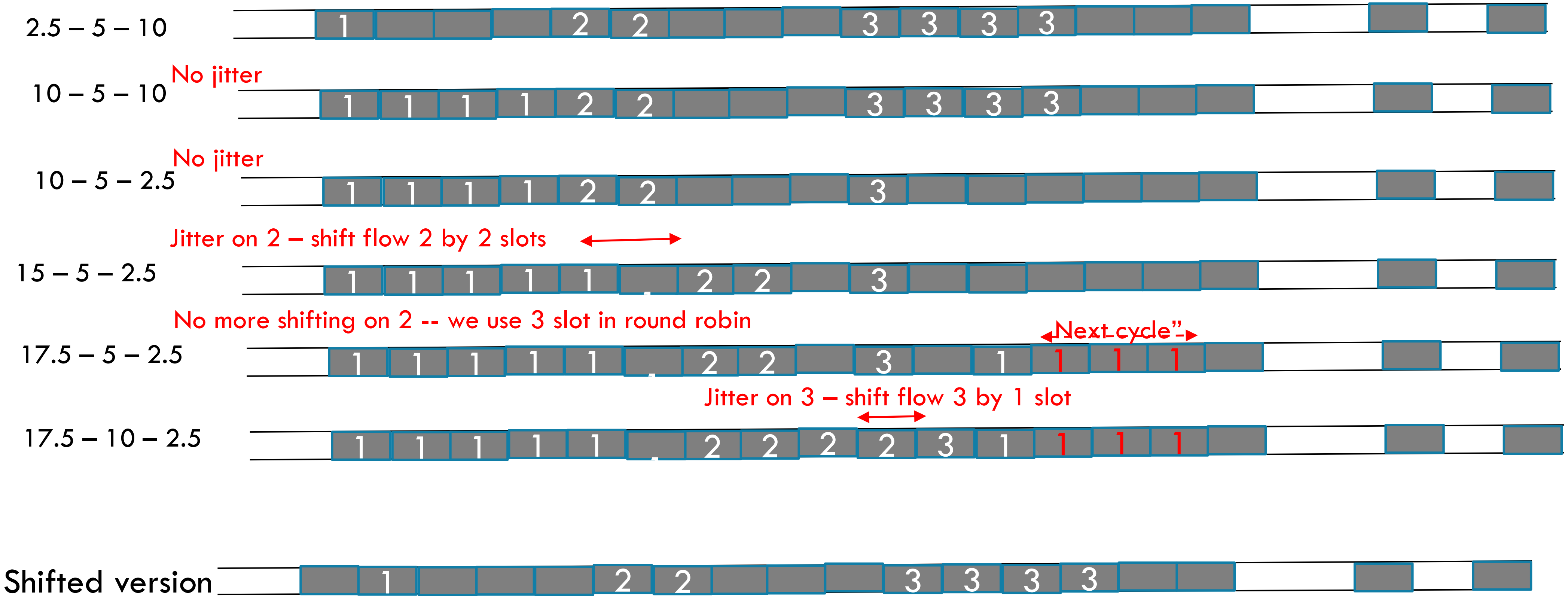
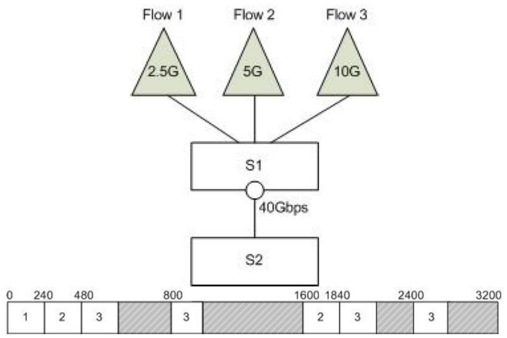
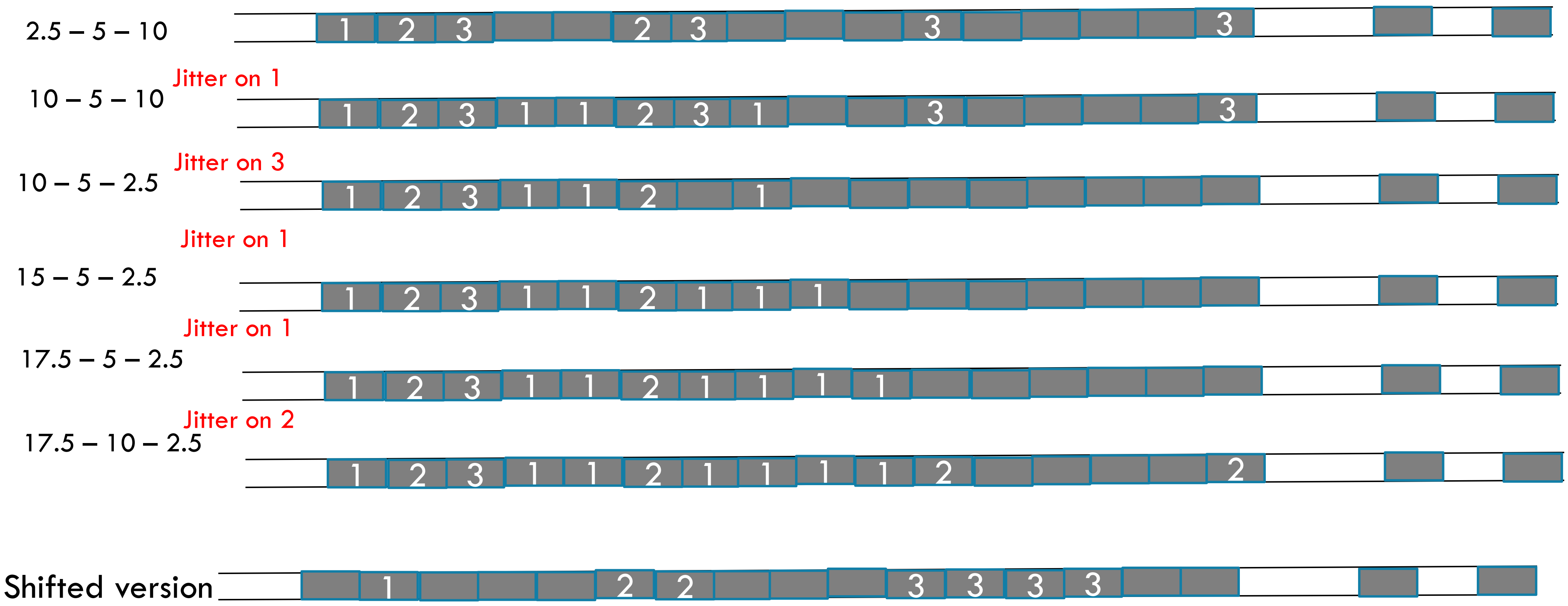


First available slot scheme periodic



3200/200 = 16 slots

Spacing = 13/3 = 4



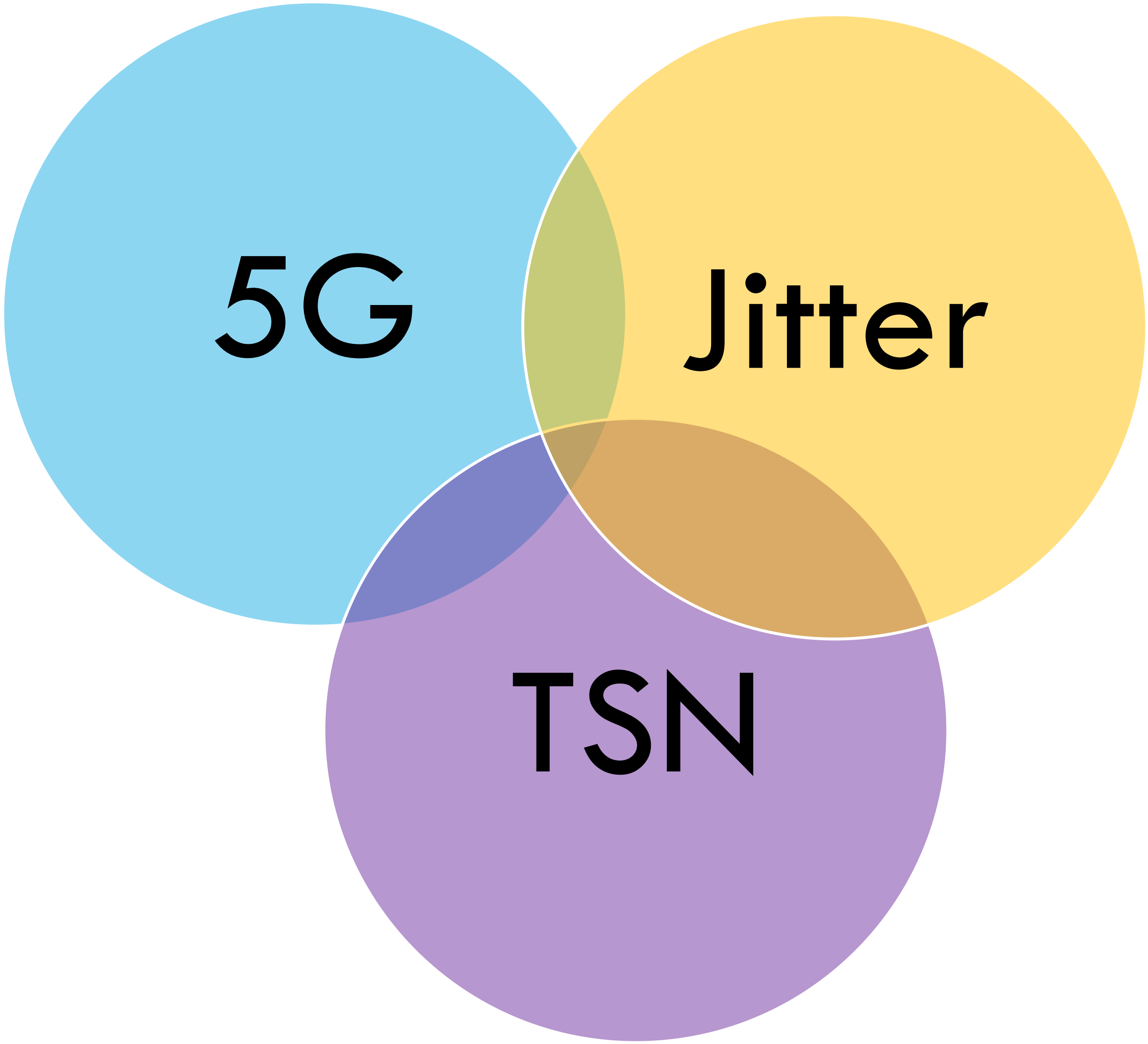
TIMELINE AND FUTURE WORK

Study performance of CPRI over Ethernet for reconfigurable fronthaul in terms of jitter

Study benefits of proposed/propose scheduling schemes that utilize Ethernet amd TSN to make achieve statistical multiplexing

Statistical multiplexing gain vs. jitter

EPON DBA that takes this into consideration


5G
Jitter
TSN