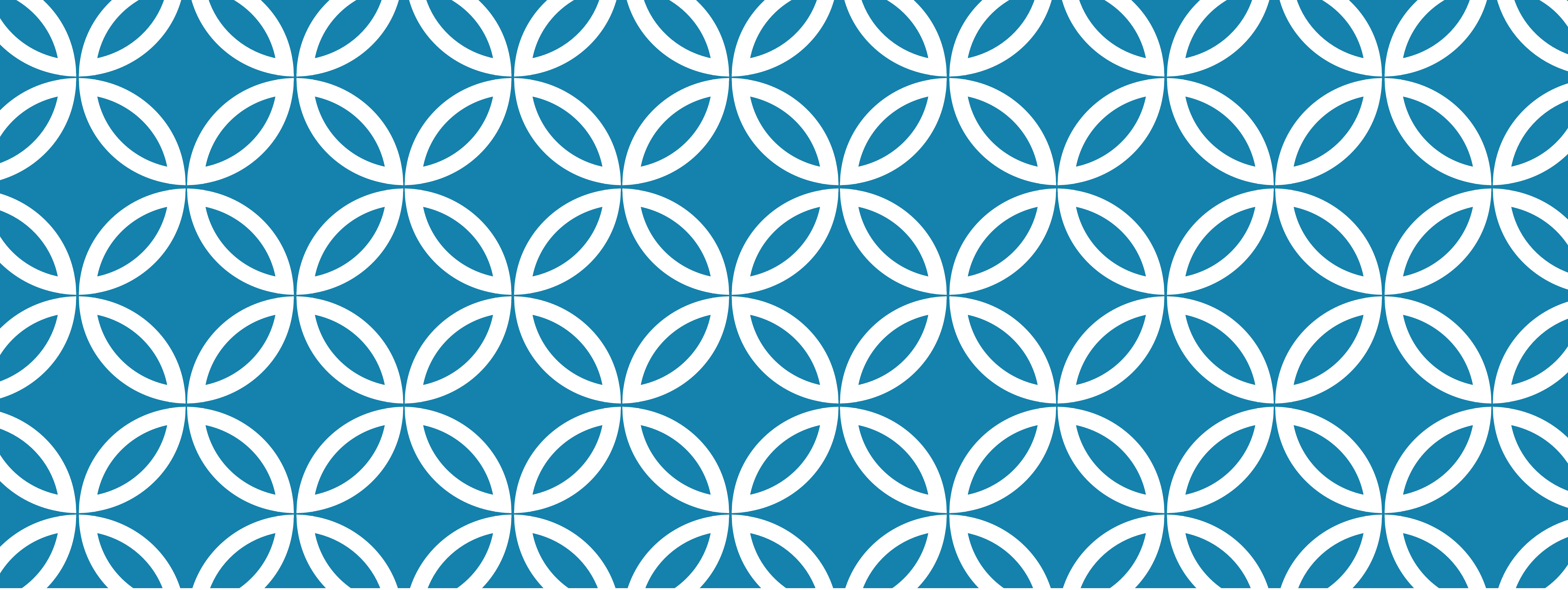


TSN FOR JITTER MINIMIZATION IN RECONFIGURABLE FRONTHAUL

Divya Chitimalla

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 - ANTENNA CONFIGURATIONS

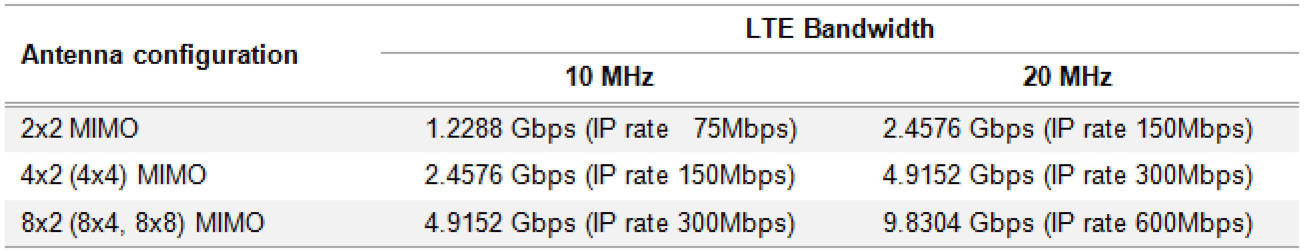
CPRI allows rate negotiation to switch to different line rate when the antenna configuration changes

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

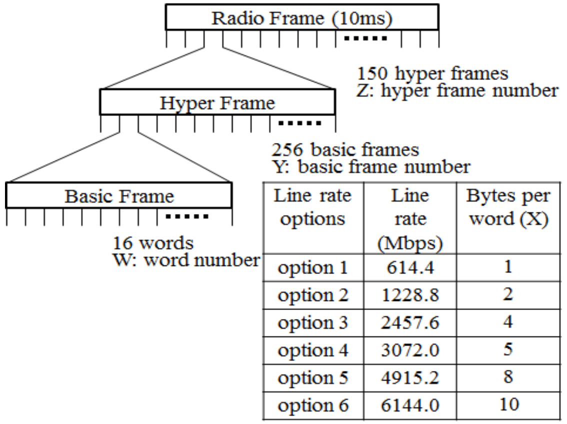
LTE cell breathing – adaptive coding (each sector has different coding)

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)

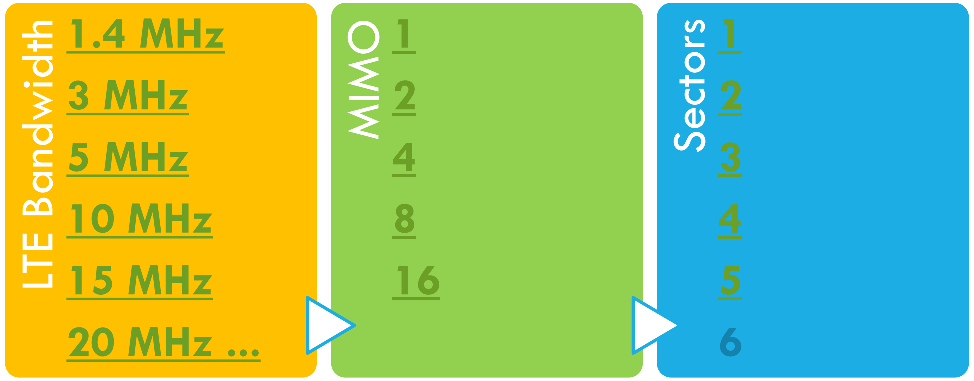
* Source: CPRI Specification v6.0 (Aug. 30, 2013)



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		9216	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

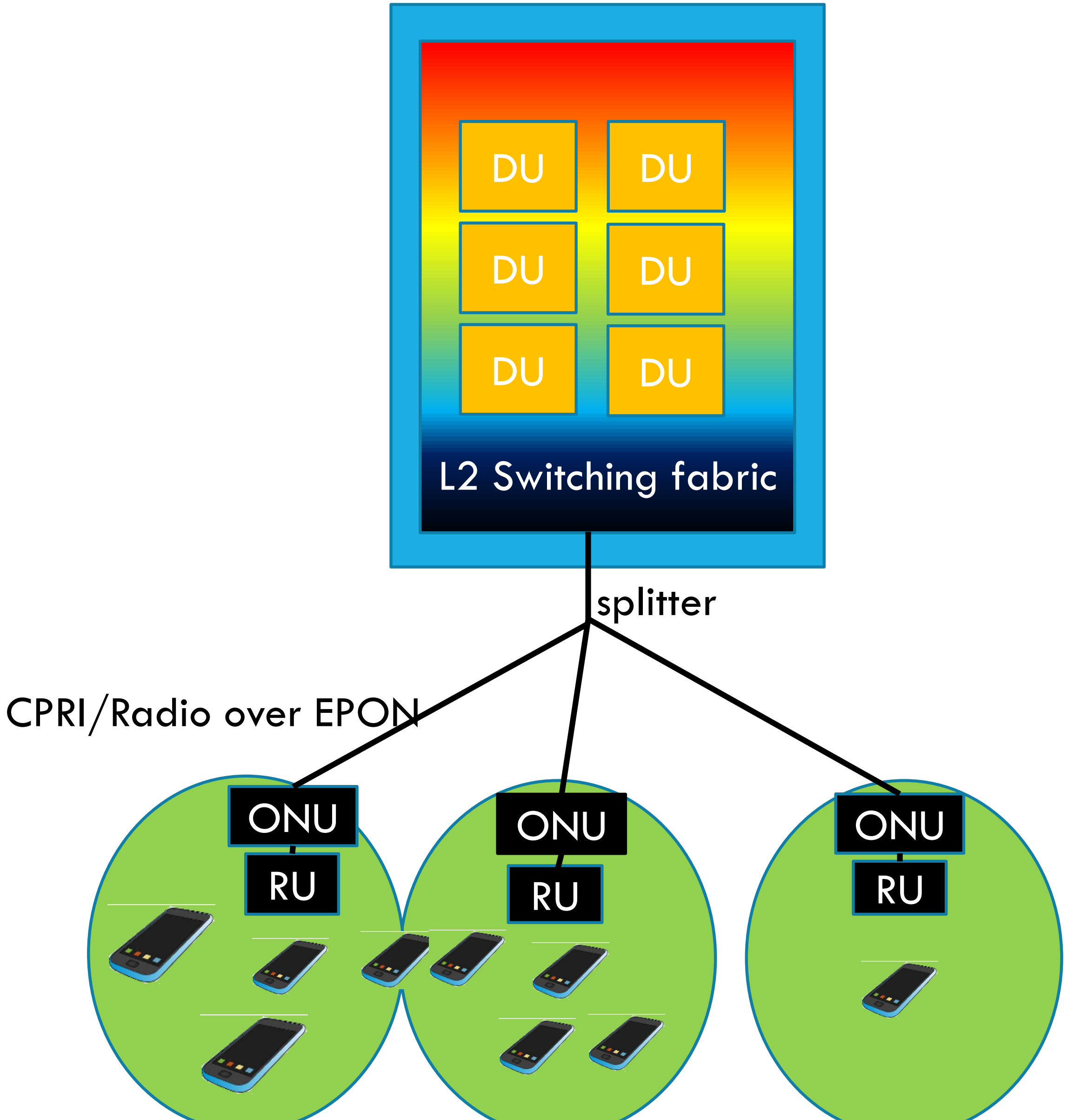
3) up to 10Gbps of throughput per RRH

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

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

JITTER

Variation in delay

2 types:

- Intra frame jitter – due to different cycle lengths in the frame – more prominent
- Reconfiguration jitter – due to adapted line rate .. Change in scheduling – happens in larger timescale

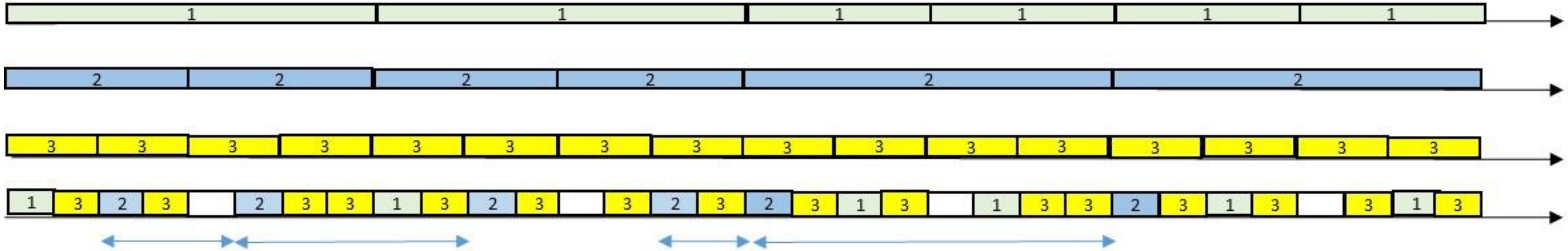
TDM signals are isochronous meaning that the time between two consecutive bits is theoretically always the same. This time is called the unit interval(UI)

Jitter is conventionally measured in Uipp that is, the difference between maximum and minimum time intervals in units of the nominal UI. For example, for an E1 signal with a UI of 488 nanoseconds, if the maximum interval were 500 nanoseconds and the minimum 476, the jitter would be(500-476)/488 = 0.05 UIpp

INTRA FRAME JITTTER & RECONFIGURATION JITTER

Flow 1: CPRI output 250Mbps
Flow 2: CPRI output 500Mbps
Flow 3: CPRI output 1Gbps
Ethernet output 2Gbps

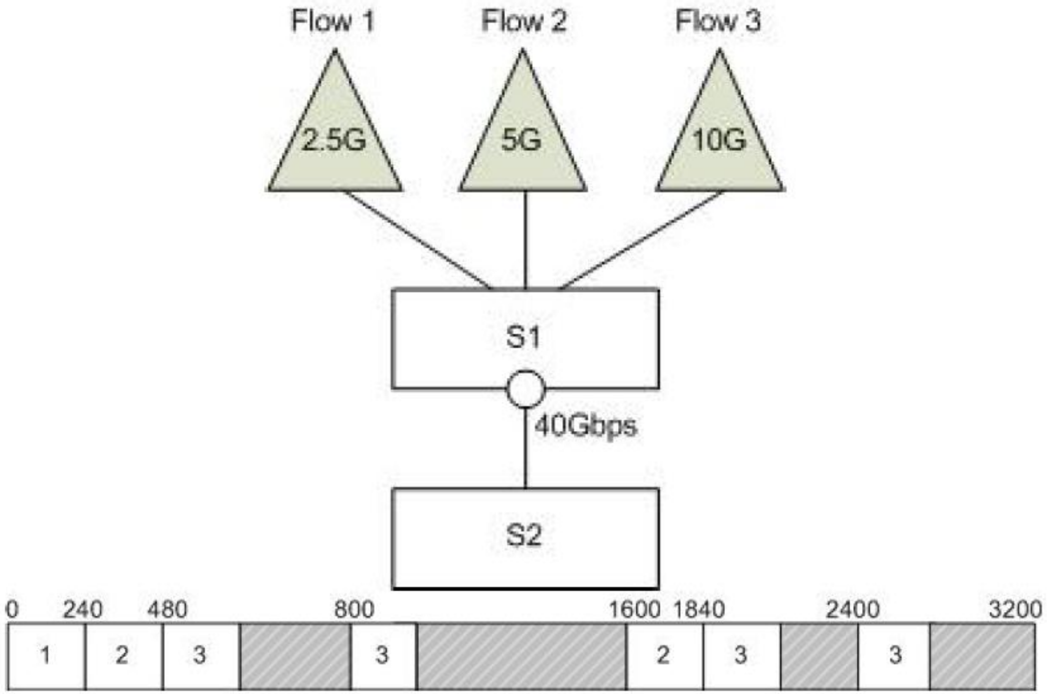
Flow 1: CPRI output 500Mbps
Flow 2: CPRI output 250Mbps
Flow 3: CPRI output 1Gbps
Ethernet output 2Gbps



Intra-frame-jitter on flow 2

Reconfiguration jitter on flow 2

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

BASIC OFFSET ALGORITHM

BASIC OFFSET ALGORITHM

Input: Input rates R_i, Ethernet rate E, Packet sizes P_i

Output: Schedule of CPRI flows on Ethernet

Step 1: T_i is transmission time of flow i packet on Ethernet link,

$T_i = P_i / R_i$

Ethernet super-frame (denoted, S) is calculated as lowest common multiple of T_i

$S = LCM(T_i)$

Ethernet slot size M = Ethernet_frame_size/E

Number of slots in a super-frame for each flow (denoted, d_i)

$d_i = S/T_i$, total slots in super-frame $N = S/M$

Each flow in super-slot is represented by a matrix called $comb_i$

Step 2: mat is temporary matrix that holds the contents of $comb_i$, mat(j,1) represents start time of slot for packet j in a certain flow, mat(j,2) represents end time for packet j.

```
for i = 1 to S
      mat = combs{1,i};
      off = 0;
      for j = 1 to $d_i$
         mat(j, 1) = off
         mat(j, 2) = mat(j, 1) + eth_slot
         off = off + $T_i$
       end
          off_f = off_f + eth_slot;
          combs{1,i} = mat;
  end
```

COMB FITTING ALGORITHM

```
COMB FITTING ALGORITHM
Input:   Schedule of flows given by basic offset algorithm
Output: Non-conflicting schedule of CPRI flows on Ethernet

Step 1: Form all possible permutations of order of flows from 1 to N (N! different sequences) denoted by {$SE_i$}
Step 2: for each sequence $SE_i$ € {$SE_i$}
            for i = 1 to $SE_i$
                Combine sequence $SE_i$ with combined sequence    formed before using matcombine subroutine
            end
                Calculate jitter for combined sequence
        end
      Pick the combined sequence with least amount of jitter
```

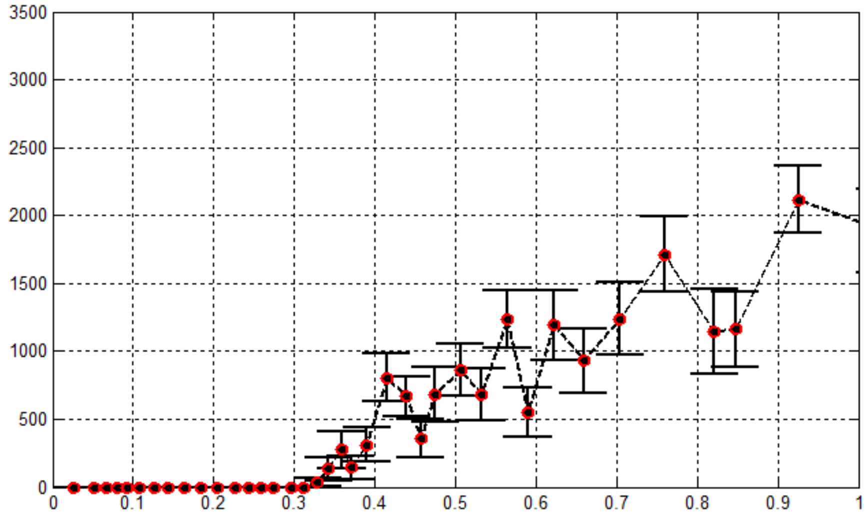
MATCOMBINE SUBROUTINE

```
MATCOMBINE SUBROUTINE
Input: $mat_i$, $mat_j$ having start and end time of Ethernet packet sequence
Output: mat_comb (combined non-conflicting sequence)

Step 1: Initialize: mat_comb as a matrix with length as sum lengths of $mat_i$, $mat_j$
Step 2: Take the longest sequence out of $mat_i$, $mat_j$ and add its contents to mat_comb, call the other matrix mat_temp
Step 3: Shift mat_temp by the multiples of ethernet_slot to a perfect non-conflicting sequence with mat_comb
Step 4: If there is a success in this procedure
        return mat_comb
Step 5: Else
        copy the non-conflicting elements of mat_temp to mat_comb
        For all conflicting elements in mat_temp
        Find the nearest open slot which can fit in the packet and update mat_comb
        end
```

NUMERICAL EVALUATION

Over 5000 randomly generated tree topologies are generated to schedule the flows on Ethernet, every 100 instances are sampled to form mean and standard deviation.



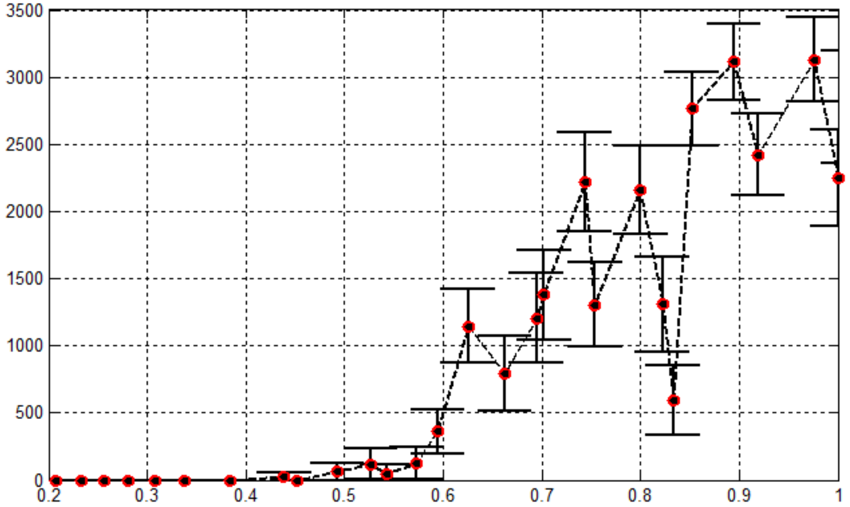
Plot of Jitter vs Load ratio (total load/Ethernet rate), number of flows – rand (2, 5), rates (1, 9)

Value of jitter vs. increasing load to ethernet ratio

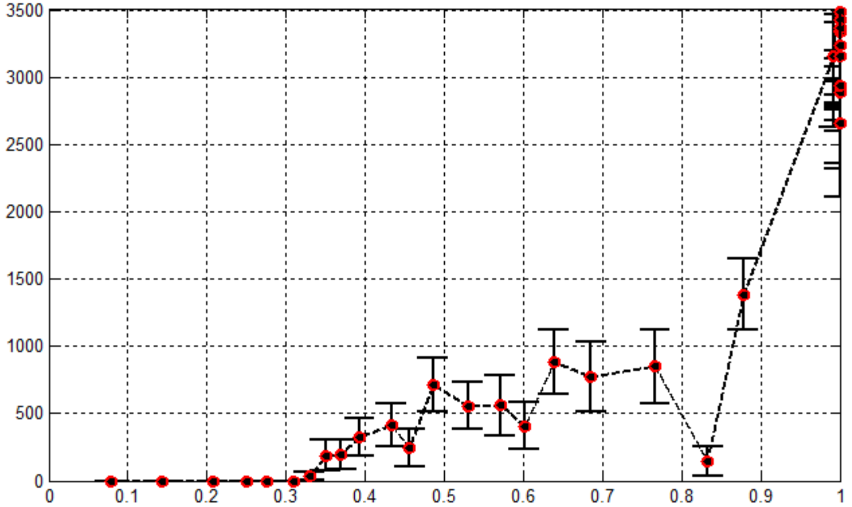
Load is the sum total of all the CPRI flows that are multiplexed on the Ethernet link

The CPRI rates are uniformly picked from option 1 to option 9, and the number of flows that are multiplexed are randomly selected to form a given topology

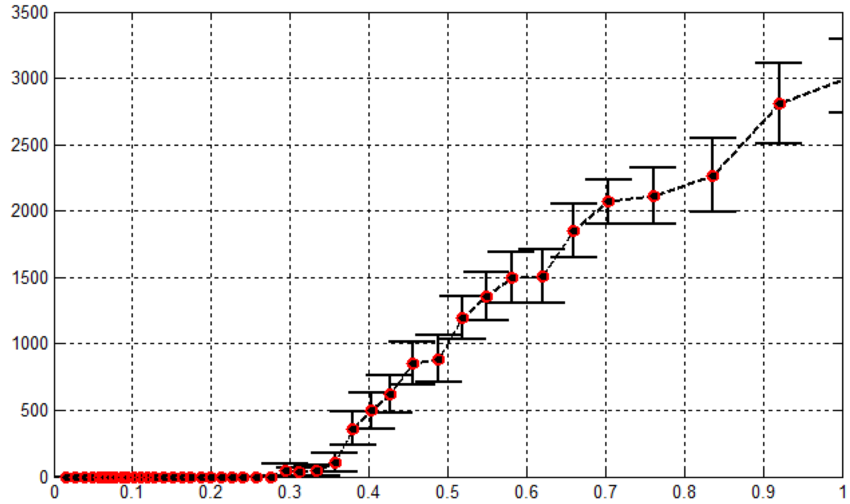
It can be seen that jitter remains zero until the load ratio of 0.3 and then increases. We call the point of load ratio until which jitter remains zero and then increases to non-zero value as the inflection point



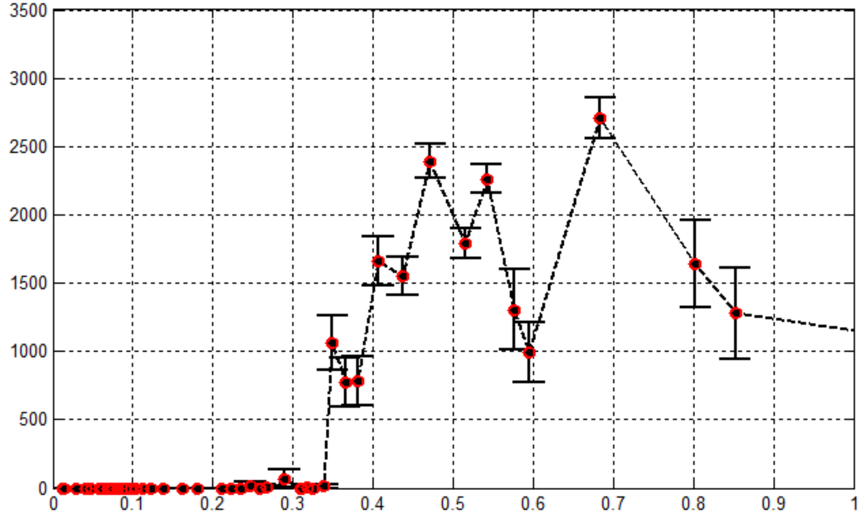
Plot of Jitter vs Load ratio (total load/Ethernet rate), number of flows – rand (2, 5), rates (1, 5)



Plot of Jitter vs Load ratio (total load/Ethernet rate), number of flows – rand (1, 3), rates (1, 9)



Plot of Jitter vs Load ratio (total load/Ethernet rate), number of flows – rand (4, 6), rates (1, 9)



Plot of Jitter vs Load ratio (total load/Ethernet rate), number of flows – rand (2, 5), rates (5, 9)

RESULTS

Mean of jitter increases with load after a certain point till which it is zero.

Jitter is not only dependent on load but also the periodicity of the flows, some flows fit-in well if they are multiples of each other and others don't.

However if the Ethernet rate is very high, hence ratio of load and Ethernet is low, there is enough room for the flows or combs to fit in perfectly, hence leading to zero jitter.

THANK YOU ☺