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5G C-RAN Architectures: A Comparison of Multiple Optical Fronthaul Networks

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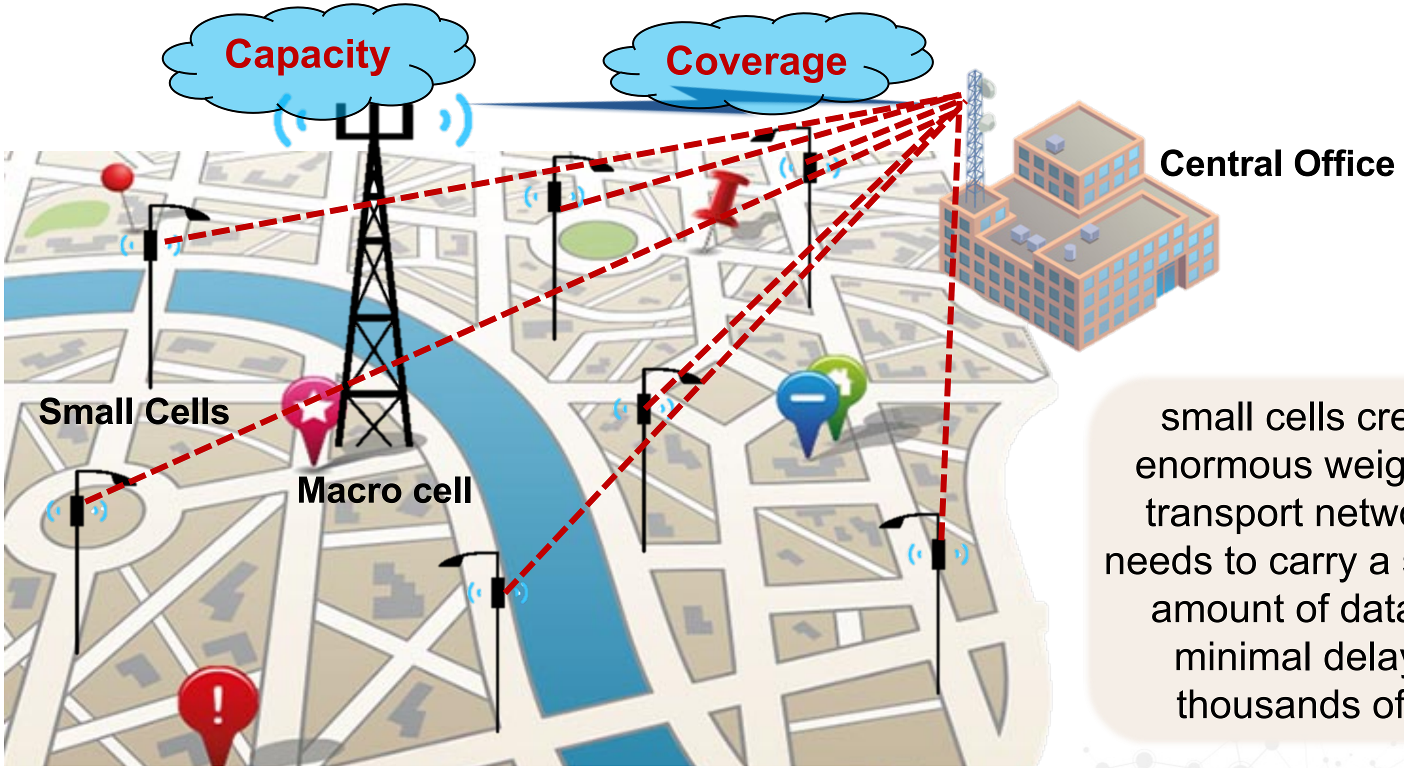
Why 5G?

- The development of the fifth generation (5G) wireless technology is in progress to address
  - The increasing demands for high capacity,
  - Low latency,
  - Ubiquitous mobile access
- 5G expedited to attain
  - 1000x higher data volume per unit area
  - 100x higher connecting devices,
  - 10x longer battery life and
  - 5x reduced latency
- Demands will be instigated by next-generation mobile and machine-centric applications.

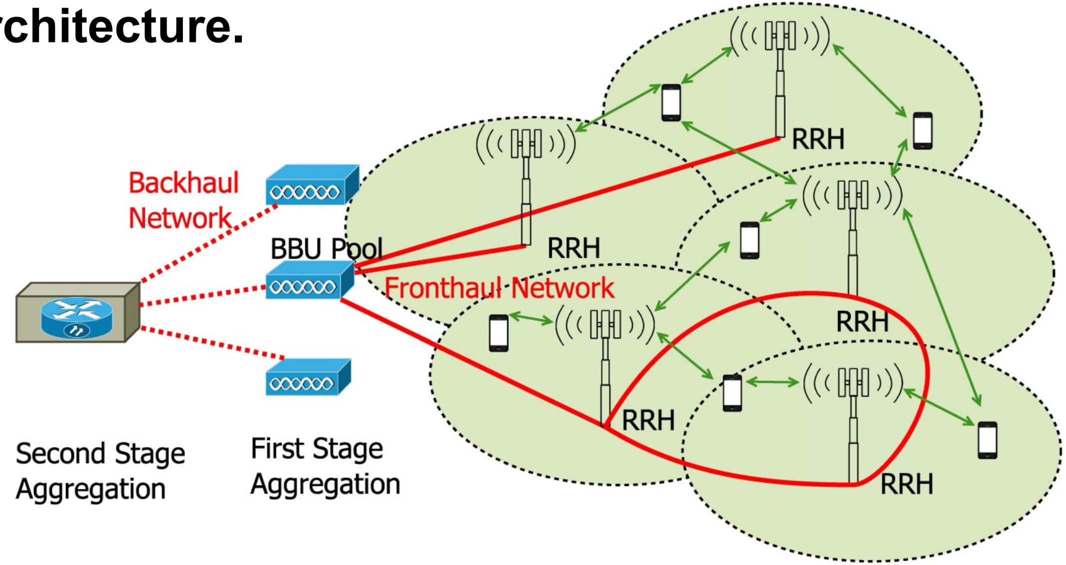
Key Feature of 5G :Small cells



small cells create an enormous weight in the transport network as it needs to carry a significant amount of data with a minimal delay from thousands of cells.

Why C-RAN ?

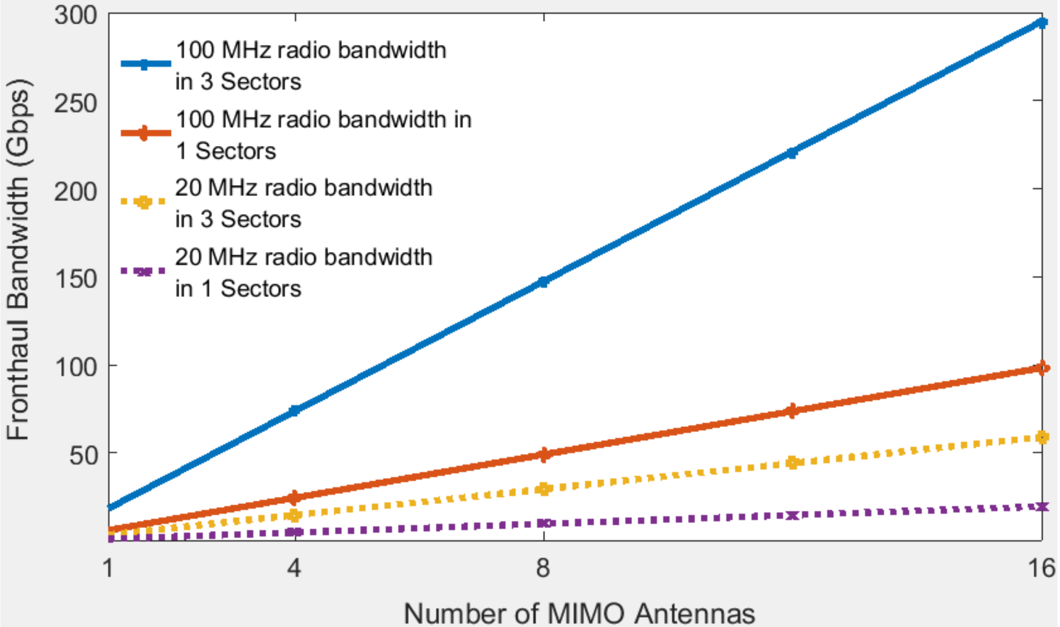
- Observation: the evolution of radio access network needs to be complimented by an evolution of the transport network.
- One architectural evolutionary solution: Centralised/Cloud Radio Access Network (C-RAN) architecture.
  - significantly lower cost
  - greener communication
  - supporting advanced wireless technologies Eg. Cooperative Multi-Point (CoMP)



Base-Band Unit (BBU)
Remote Radio Head (RRH)

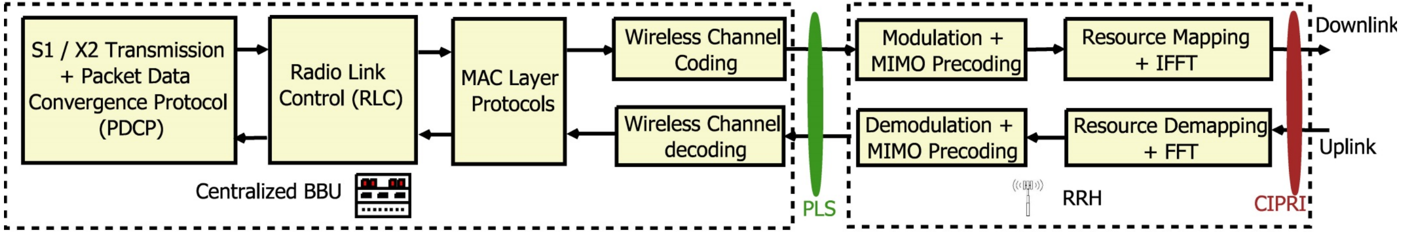
Challenges in C-RAN

- In the current C-RAN architecture (use in LTE-A): the fronthaul network uses common public radio interface (CPRI) [13] over fiber links.
- Ex: supports 150 Mbps of downlink bandwidth in LTE-A, more than 2 Gbps of optical bandwidth When using CPRI.
- If 5G fronthaul networks use CPRI →

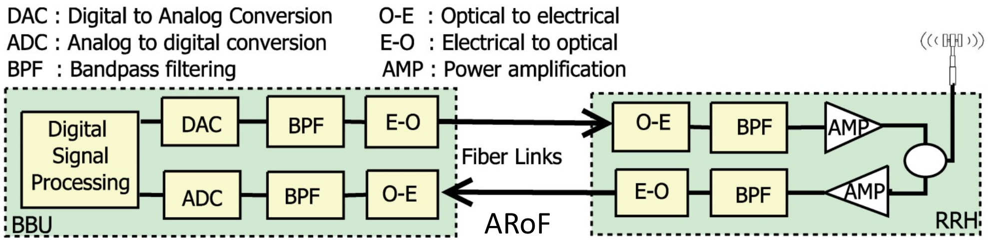


Architecture Comparison

- Three Fronthaul Network Architectures
  - CPRI
  - Physical Layer Split (PLS)
  - Analogue Radio over Fibre (ARoF)



CPRI and PLS



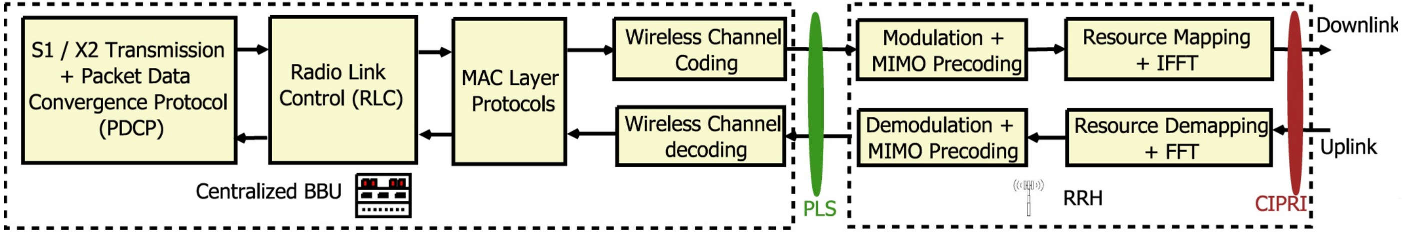
ARoF

Bandwidth Calculations - CPRI

N_s is the number of sectors per RRH
N_a is the number of antennas
S_f is the sampling frequency
S_{bw} is the sampling bit-width (I/Q)
B_e is the ratio for the controlling overhead
L_c is the coding induced capacity increase

Parameters	Current LTE	5G requirement
N_s	3	3
N_a	1	8
S_f	30	30
S_{bw}	30.72 (for 20 MHz)	30.72*5 (for 100MHz)
B_e	16/15	16/15
L_c	10/8	10/8

$$B_{CPRI} = N_s * N_a * S_f * S_{bw} * B_e * L_c$$



Bandwidth Calculations -PLS

TTI the transmission time interval ($=1mS$)
M modulation order ($=8$ $i.e.$ $64QAM$)
N_{sy} number of symbol within a TTI $(=12)$
N_{sc} number of subcarriers ($=12$)
N_{rb} number of resource blocks ($=500$)
N_{mimo} number of MIMO streams ($=8$)

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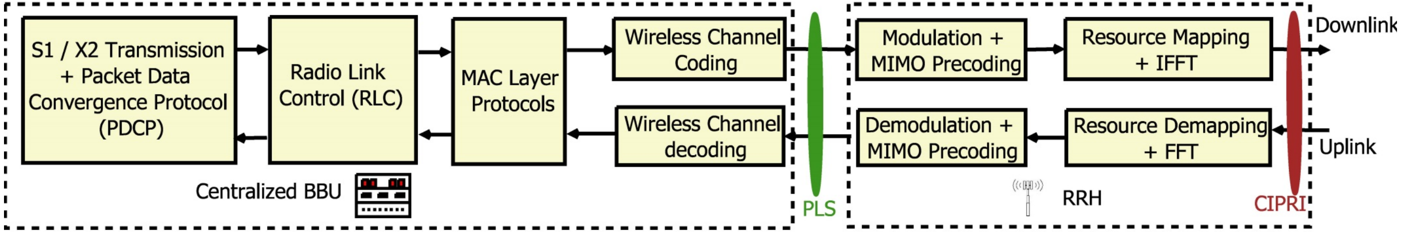
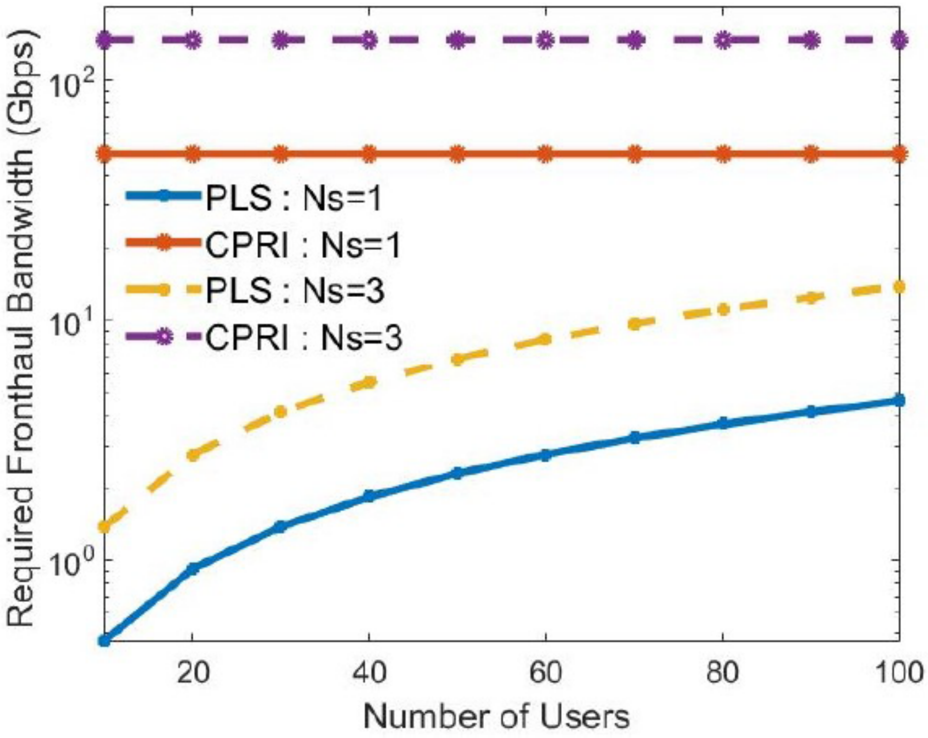
B_e	16/15	16/15
L_c	10/8	10/8

$$B_{PLS} = M * N_{sy} * N_{sc} * N_{rb} * N_{mimo} * N_s / TTI$$



5 Resource Blocks per user so maximum of 100 users considered

Comparison of Bandwidth Requirements



$$B_{CPRI} = N_s * N_a * S_f * S_{bw} * B_e * L_c$$

$$B_{PLS} = M * N_{sy} * N_{sc} * N_{rb} * N_{mimo} * N_s / TTI$$

- **ARoF: required fronthaul bandwidth depends on the wireless carrier frequency and the bandwidth in use, a typical low-cost transceiver can be used to achieve the 5G targeted data rates when 5G uses the frequency range below 6GHz (IF conversion can be used with very low cost component for higher frequencies).**

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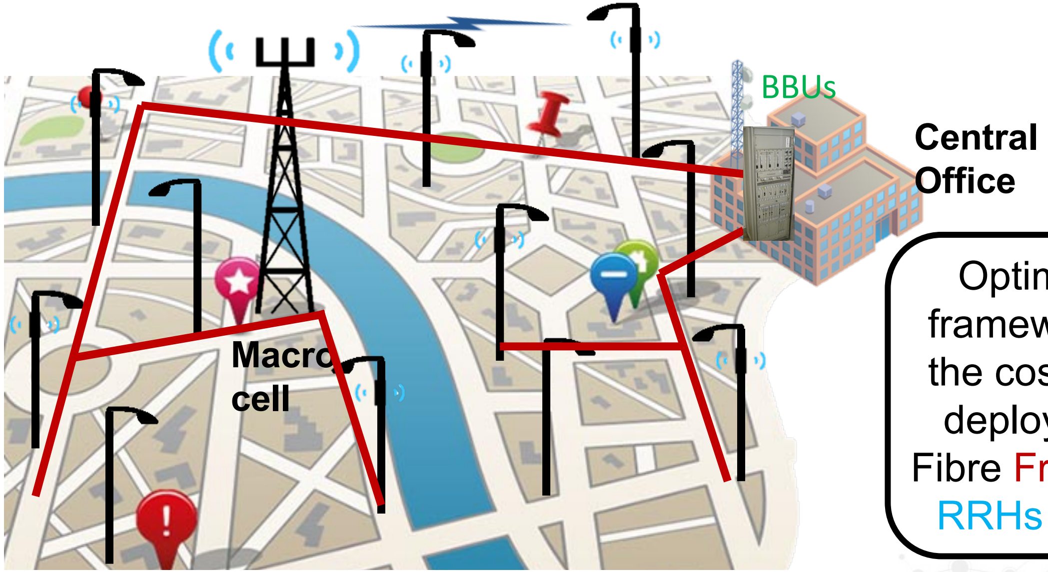
Comparison: Delay, Advanced Wireless Functions and RRH complexity

	Delay	Advanced Wireless Functions	Complexity of RRH
CPRI	A few hundreds of μs including the propagation delay, round trip CPRI processing delay, and the other fronthaul equipment processing delays.	Facilitate advance wireless cooperation technologies	Simple. However, for higher transmission data rates, Fronthaul needs high data rate optical transceivers.
PLS	An additional processing delay at the RRH compared to the CPRI: symbol level processing implemented in RRH (however, additional delay is less than few μs).	Wireless coding functions and MAC layer functions are centralized in the BBU: can facilitate advance wireless cooperation technologies	RRH related equipment and software need to be upgraded. Network function virtualization (NVF) paradigm can be used to overcome the difficulty in upgrading
ARoF	RRH will be more delay efficient compared to the CPRI. Fronthaul link range will be low compared to other architectures (however still facilitate few km that confirm with 5G BBU-RRH range).	Facilitate advance wireless cooperation technologies all the wireless signals are processed centrally at the BBU	Simple architecture

Deployment Cost comparison

- **Optimal Deployment Cost : ILP-based optimization framework**
- **The total cost consists of the cost of BBU placement, fronthaul and Deploying RRHs.**



Optimization framework finds the cost-optimal deployment of Fibre Fronthaul + RRHs + BBUs

Optimization Framework

Minimize the total deployment cost of CRAN deployment

$$\min \boxed{(\eta_s + \eta_{ri}) \sum_{i \epsilon V} x_i} + \boxed{(\eta_t + \eta_{fb}) \sum_{i \epsilon V} \sum_{j \epsilon V} c_{i,j}\, d_{i,j}} + \boxed{\eta_{fs} \sum_{i \epsilon V} \sum_{j \epsilon V} y_{i,j}\, d_{i,j}} + \boxed{\eta_e \sum_{i \epsilon V} x_i} + \boxed{(\eta_b + \eta_{bi}) \sum_{i \epsilon V} Z_i}$$

Equipment & installation costs of RRHs and Fronthaul

New fibre routes, and fibre bundles installation costs

Fibre preparation

Fibre connections at the central office for using existing fibre facility.

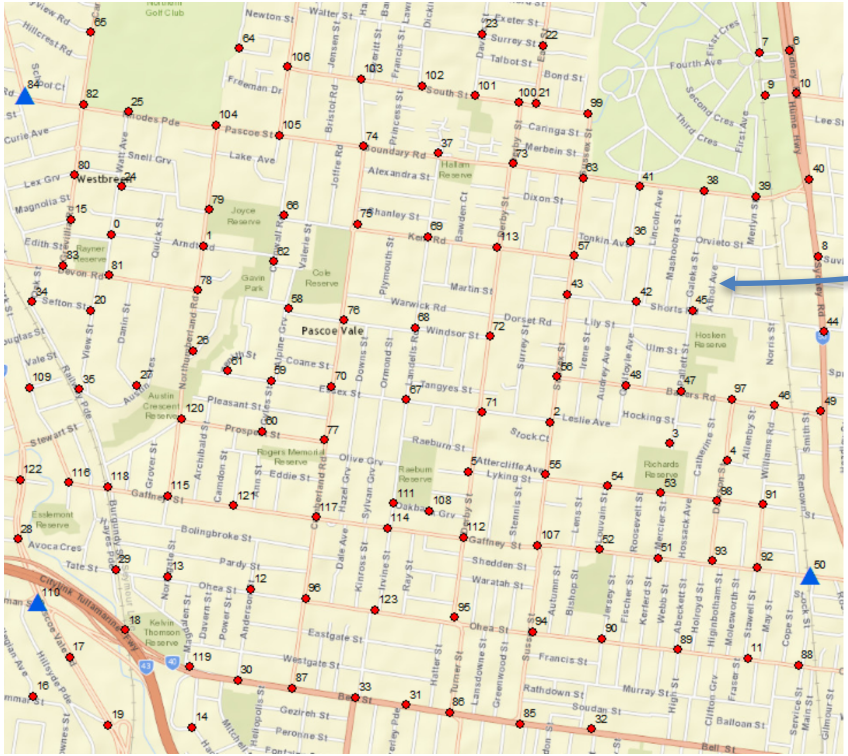
Cost of BBUs and their installation

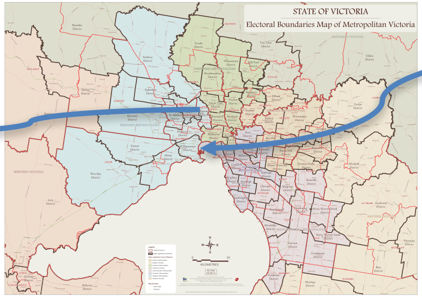
Subject to a range of constraints imposed by requirements of the network such as,

- Population coverage
- The maximum number of BBUs in one central office
- The maximum distance from a RRH to its BBU
- Fibre connectivity

Cost parameter	Description
η_s	Equipment cost of RRH and fronthaul
η_{ri}	Cost of RRH Installation
η_t	Fibre trenching cost/ m
η_{fb}	Cost of a Fibre bundle/ m
η_{fs}	Cost of fibre preparation
η_e	Cost of connecting a fibre at existing fibre facility
η_b	Cost of a BBU
η_{bi}	Installation cost of the BBU at the fibre facility

Data Set for Cost Comparison

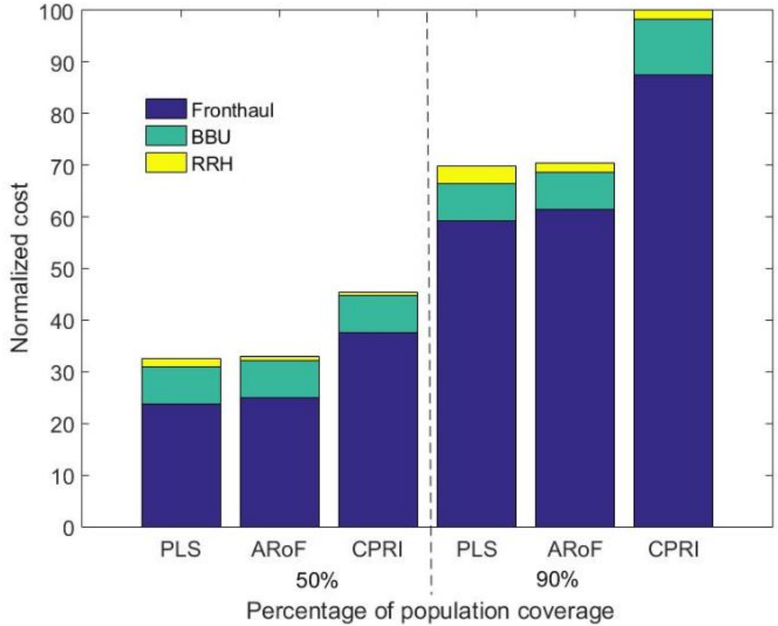




- 18 km^2 suburban area in state of Victoria, Australia

- Population : 30,000

Cost – Summary of Optimal Solutions



Contribution of fronthaul, RRH, and BBU cost when the population coverage is 50% and 90%

Normalized Cost Values*	
CPRI: Fronthaul	2912
PLS: Fronthaul	200
ARoF: Fronthaul	200
CPRI: RRH	220
PLS: RRH	300
ARoF: RRH	200
BBU	10000
Fibre bundle cost	1

* Normilized to cost of fiber bundles/m

Summary

- We investigated the applicability of different optical fronthaul technologies for CRAN
  - CPRI, PLS and ARoF
- Comparatively analysed their ability to fulfil requirements of delay, bandwidth, and cost-effectiveness of 5G CRAN, ability to support advanced wireless cooperation technologies, and complexity of RRH.
- Comparative cost analyses carried out using developed optimization framework showed that cost-effective fronthaul for 5G could be achieved using PLS and ARoF architectures
- Overall, our analyses provide insight into how a future proof fronthaul network can be realized for 5G C-RAN.

For any more details

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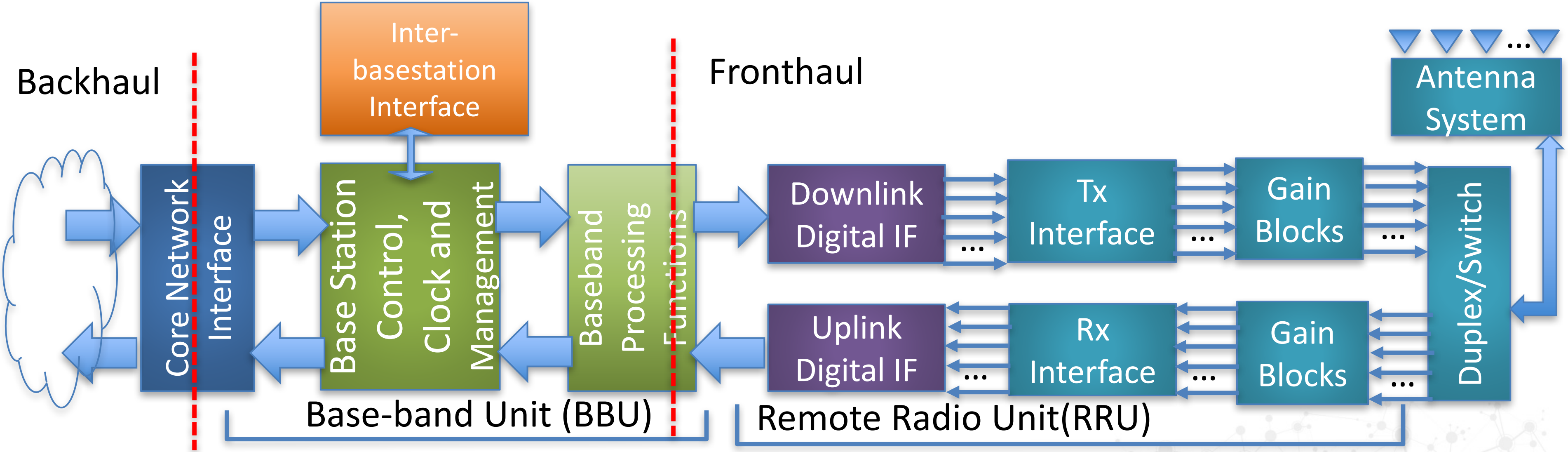
Variables

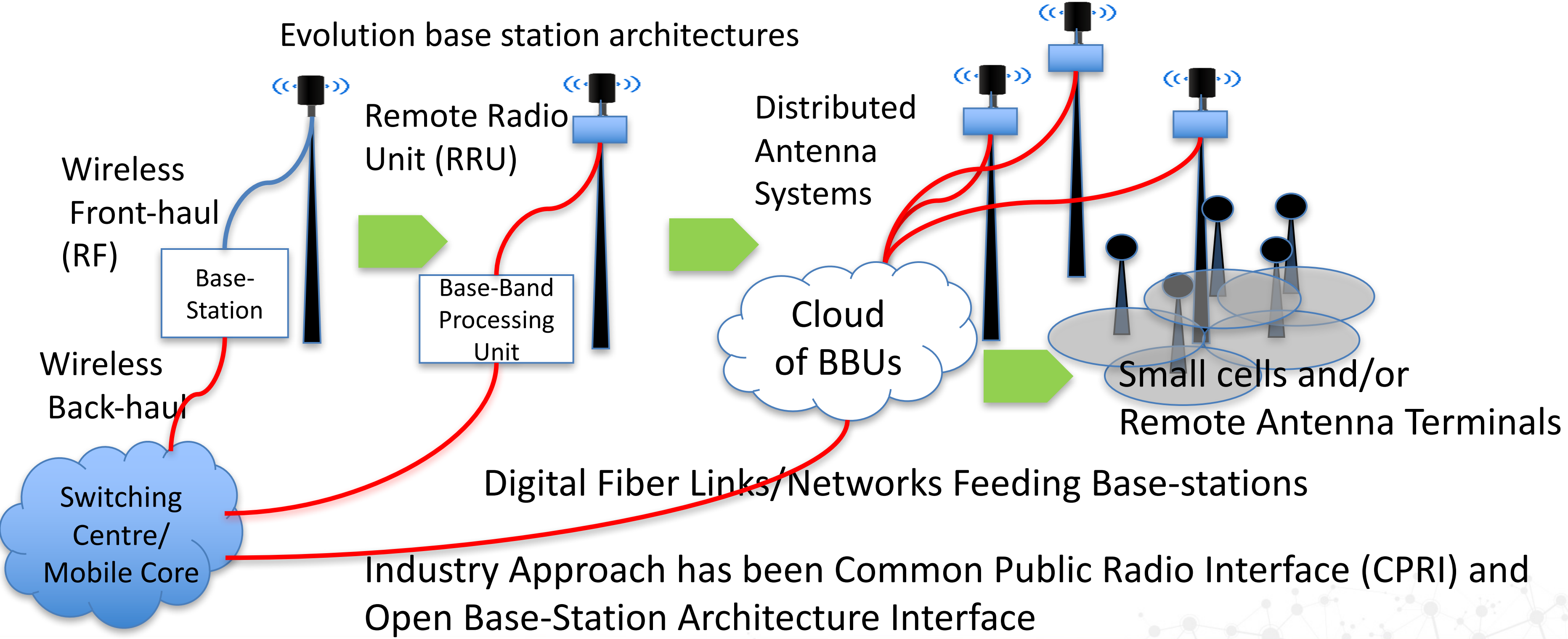
Variable	Values	Description
X_i	1	If i^{th} location is selected for the deployment of a RRH
	0	otherwise
Z_i	1	If i^{th} fibre facility is selected for the deployment of BBU
	0	otherwise
$C_{i,j}$	1	If there is a fibre route from i^{th} node to j^{th} node
	0	otherwise
$Y_{i,j}$	integer	Number of fibres in the path from i^{th} node to j^{th} node
B_i	1	If i^{th} household is covered
	0	otherwise

Antenna Base-Stations

- Multiple Sectors, MIMO, Multiple Bands, Carrier Aggregation – leads to complexities or complex requirements for backhaul/front-haul



Networking of Base-Stations(BSs)



Industry Approach has been Common Public Radio Interface (CPRI) and Open Base-Station Architecture Interface

Optical-Wireless Integration

Increase in Base-station densities due to more smaller Cells > 85/25km^2

Increasing share of power consumption of cellular networks ~60%

Rapidly rising bandwidth requirements for backhaul/fronthaul

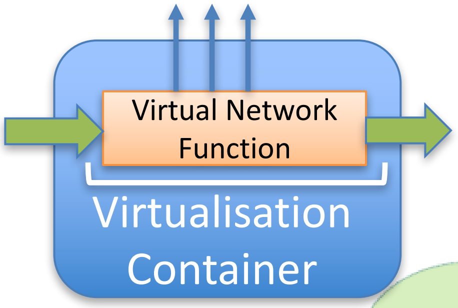
Why optical – wireless network integration makes sense

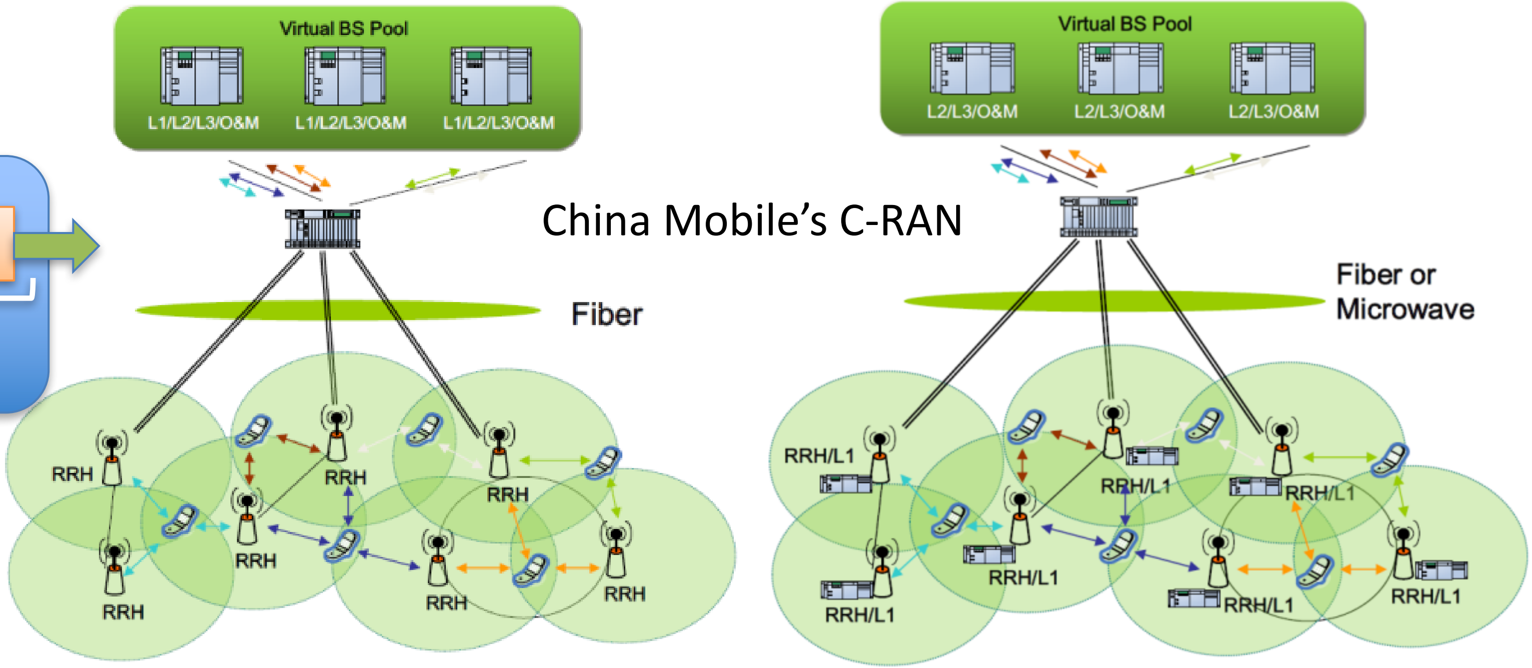
Increased foot print of installed fiber and planned deployment (>>180 Mkm)

Maturing of optical Transceiver (10Gbps and beyond)

Pathways for lowering the cost of deployment

Cloud/Virtualisation/Software Defined





Fully Centralised and Virtual Pool of BBUs

Partially Centralised

4G-5G: Challenges and Opportunities

RF Bandwidth
10x

Spectral Efficiency
20x

Cell Density
10x

Latency
1/10

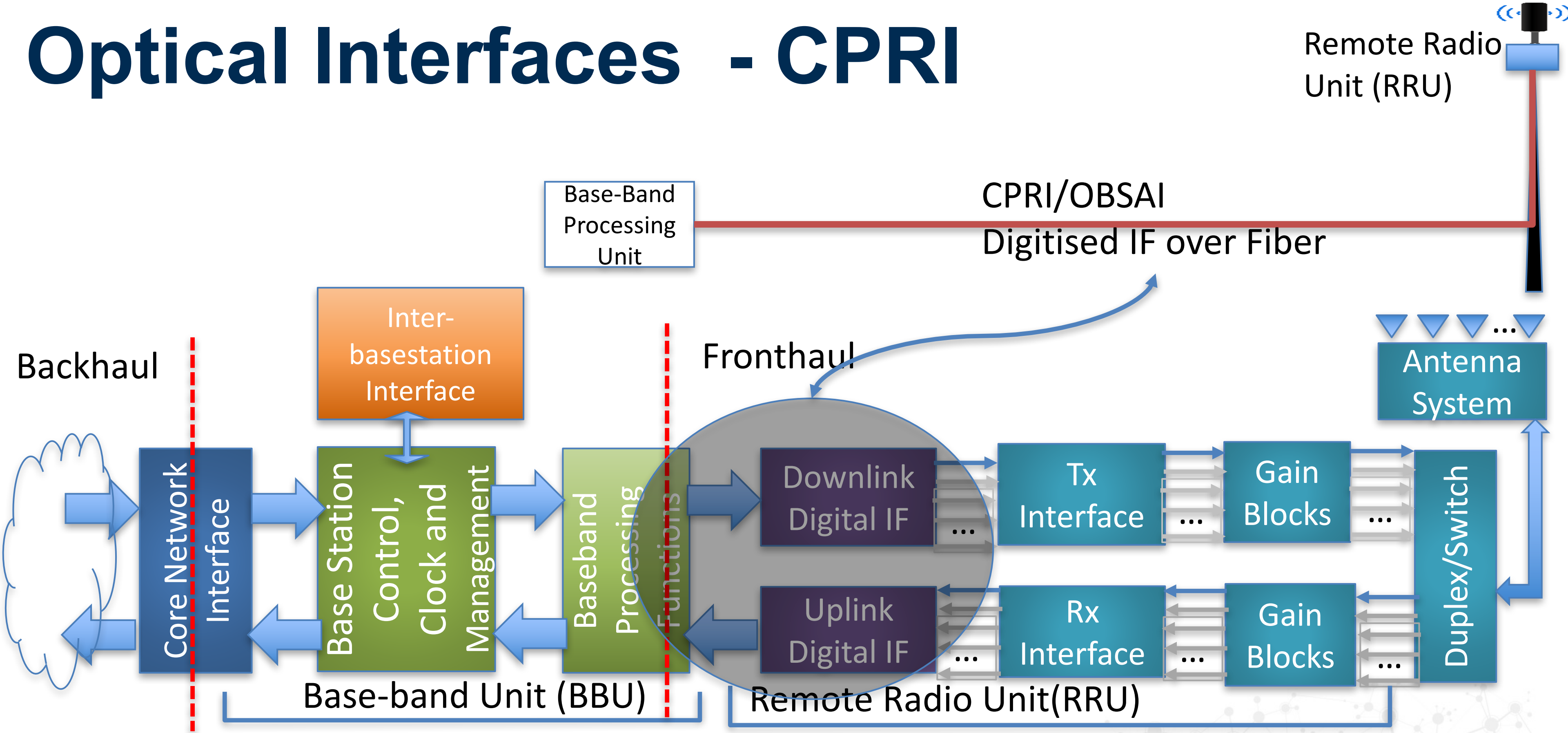
- Antenna Arrays in Massive MIMO?
- Millimeter-waves or Spectral farming
- Virtualisable and Software defined
- Cloud access network
- Storage in the network
- Secure
- Critical services

- Photonic Systems for Massive MIMOs
- Microwave/Millimeter-wave/ Photonic integration
- Joint Network Planning and Optimisation
- Software Defined Optical Networking

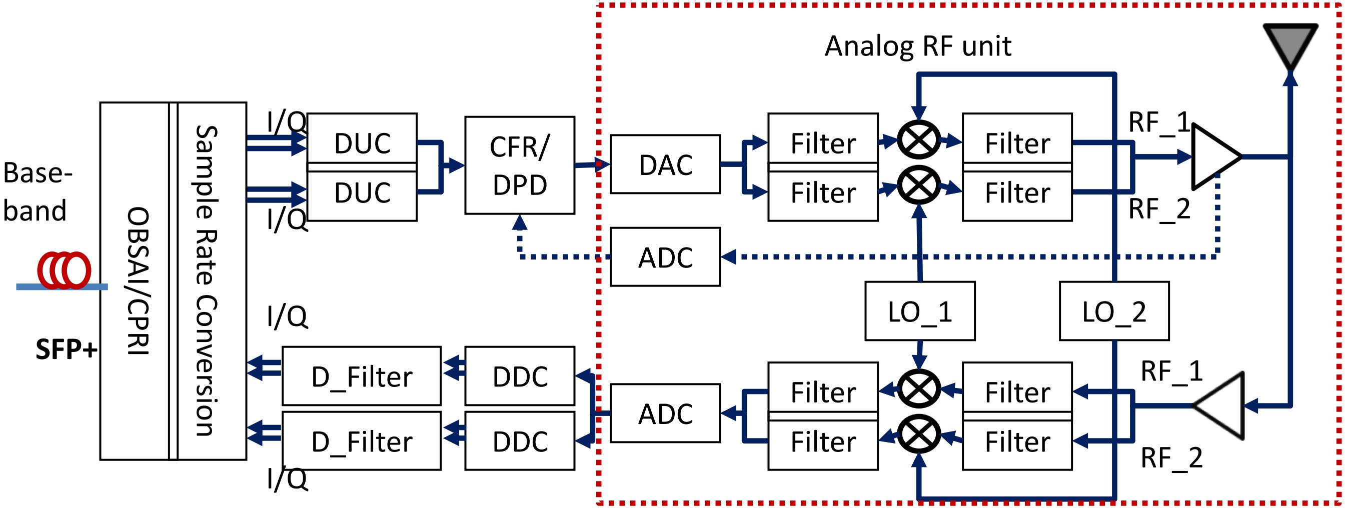
5G – Early Demonstrations

- Use of 1GHz is useful for coverage (rural and indoor)
- above 6GHz is useful for very high data rates and shorter-range connectivity (15GHz, 28GHz, 60GHz, 70-85GHz)
- Samsung: 1.2Gbps transmission at 110km/h speed using 28GHz frequency. The stationary transmission test is up to 7.5Gbps
- Ericsson: 5 Gbps throughput at 15 GHz

Optical Interfaces - CPRI



Digital Interface – CPRI/OBSAI



Total flow = Data + Control Management + SYNC

CPRI bandwidth

$$B \sim F_s * N_q * N_B * N_{ANT} * N_{OH}$$

Sampling Rate

Number of Quantized Bit

Number of Frequency Band

Number of Antennas

CPRI overhead

Example:
100 MHz (20 MHz x 5) bandwidth
8 layer MIMO
F_s = 30.72 MSa/s
N_q = 30 (15 bit x 2(IQ))
N_B = 5
N_{ANT}= 8
N_{OH}= 16/15
B~40 Gb/s

OBSAI Vs CPRI

OBSAI	CPRI
8B/10B line coding	8B/10B line coding
up to 6.144/3.072 Gbps	up to 3.072 Gbps
Fixed IQ sample envelope size at 16	Programmable 8-20 in downlink 4-20 in uplink
Include transport and application layers	Only Physical and data link layers

- OBSAI - higher overheads (+15.75%) for enabling flexibility
- CPRI- capacity advantage (+13.75%) for optimized bandwidth allocation

	OBSAI	CPRI
User Data (IQ)	80%	93.75%
Control Data (O&M)	4%	6.225%
Synchronization (K-char)	0.25%	0.025%
Fixed Overheads	15.75%	0%

	OBSAI	CPRI
LTE 10MHz @12 bits	4	6
LTE 20MHz @12 bits	2	3
LTE 10MHz @16 bits	4	4
LTE 20MHz @16 bits	2	2

- OBSAI capacity - independent of sample envelope size;
- CPRI - optimized sample envelope size => more carrier space