A Novel IQ Data Compression Scheme in Fronthaul Link on C-RAN

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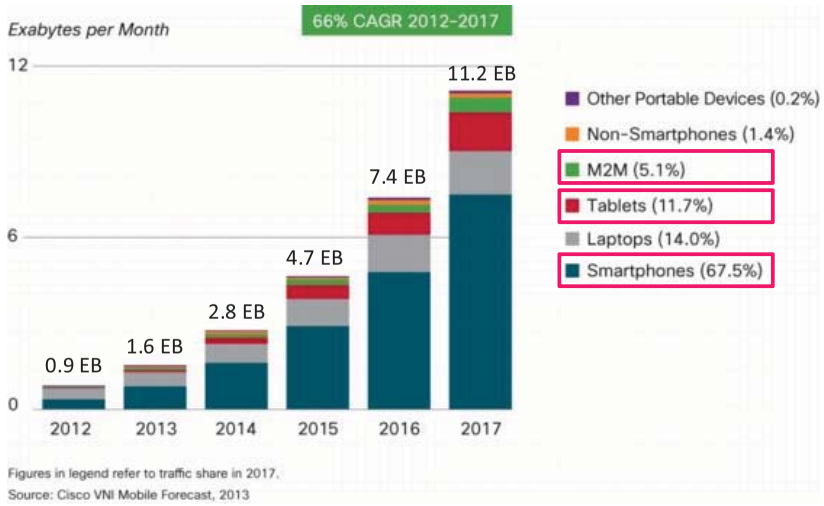
Background (1.1)

Expansion of mobile traffic!!

Background (1.2)

**Excerpt from Cisco white paper: "Global Mobile Data Traffic Forecast Update, 2012-2017"*



[1] http://www.cisco.com/en/US/solutions/collateral/ns341/ns525/ns537/ns705/ns827/white_paper_c11-520862.html

Background (2.1)

Evolution of mobile network architecture

Small cells for increase of system capacity

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Increase of the interference between cells

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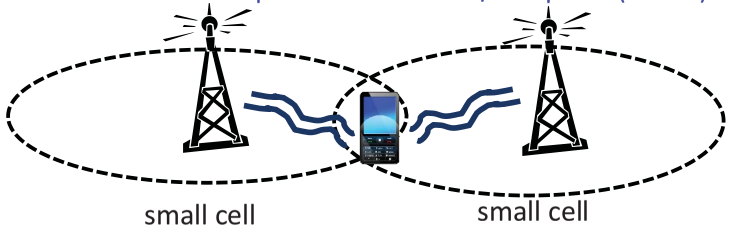
enhanced Inter-Cell Interference Coordination (eICIC)
Coordinated Multi-point transmission/reception (CoMP)



Background (2.2)

Evolution of mobile network architecture

Centralized control among *multiple cells* will be *of great importance* in future mobile network with *eICIC and/or CoMP*

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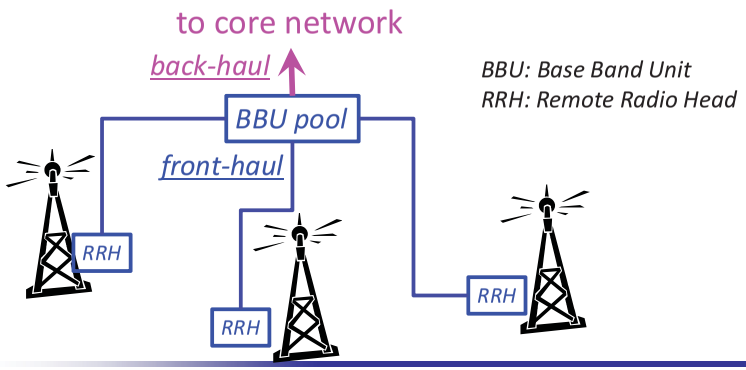
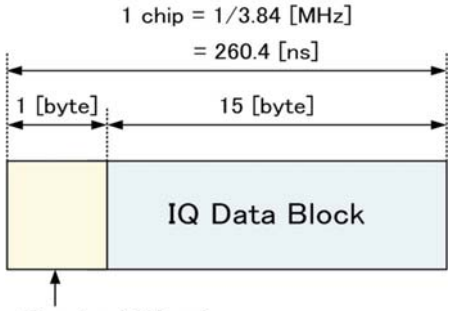
Centralized Radio Access Network (C-RAN) architecture



Background (3.1)

Major front-haul standard (transmission line between BBU and RRH)

Common Public Radio Interface (CPRI)



$$\left[\frac{16\ (\text{Byte})\ \times 8\ (\text{bit})}{3.84\ (\text{MHz})} = 491.52\ (\text{Mbit/s})\right] \times \frac{10\text{B}}{8\text{B}} = \mathbf{614.4\ (Mbit/s)}$$

Background (3.2)

CPRI option

option #	Y	IQ data + ctrl word bit rate (Mbit/s)	Line bit rate after 10B/8B (Mbit/s)
1	1	491.52	614.4
2	2	983.04	1228.8
3	4	1966.08	2457.6
4	6	2949.12	3686.4
5	8	3932.16	4915.2
6	10	4915.2	6144
7	16	7864.32	9830.4

Background (4.1)

Example: LTE with 20 MHz bandwidth and 2x2 MIMO

Sampling frequency (MHz)	30.72
Sampling bit-width	15
I and Q channels	2
Number of antennas (2x2 MIMO)	2
IQ data bit rate (Gbit/s)	1.8432
after control word insertion (Gbit/s)	1.9660
after 10B/8B (Gbit/s)	2.4576

CPRI #3

Background (4.2)

Required capacity for one base station site

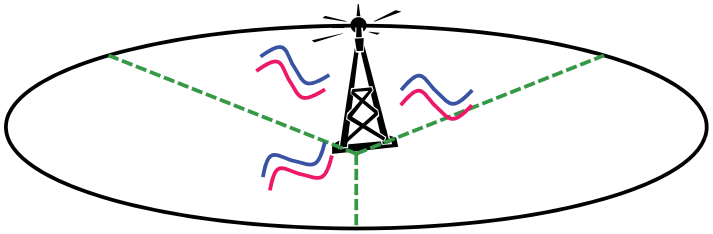
Example:

X 2 frequency bands

X 3 sectors per one band

then, 2.4576 Gbit/s X 2 X 3 = 14.7456 Gbit/s !!

+ In future, increase of frequency bands and number of antennas



Necessity of data compression (1)

Required capacity for one base station site

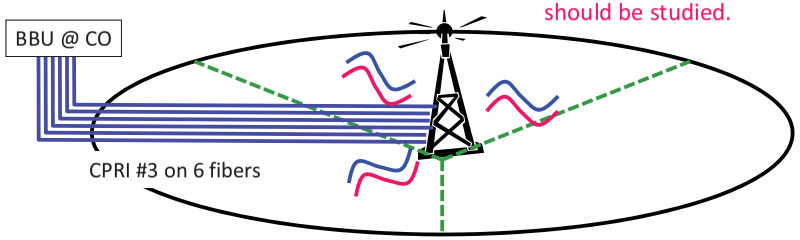
2.4576 Gbit/s X 2 X 3 = 14.7456 Gbit/s

Point-to-point = one CPRI channel per one fiber

Physical devices developed for Giga-bit class link are applicable

6 fibers / site ⇨ large fiber cost !!

Fiber utilization efficiency should be studied.



Necessity of data compression (2)

➢Data compression

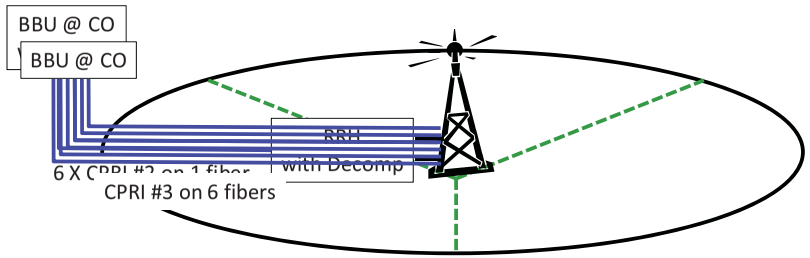
• Capacity per fiber can be increased

i.e., CPRI #3 down to CPRI #2 (X 1/2) or CPRI #1 (X 1/4)

realistic target

•Simple multiplexer dedicated for CPRI channels

1.2288 Gbit/s (CPRI #2) X 6 = 7.3728 Gbit/s on 10 Gbit/s optical transmission



Requirements for data compression

- ➢ The compression rate should be = 50 [%].
- ➢ The EVM-degradation should be ≤ 3 [%].
- ➢ The SNR-degradation should be ≤ 1 [dB].
- ➢ The buffering time should be ≤ 100 [us].

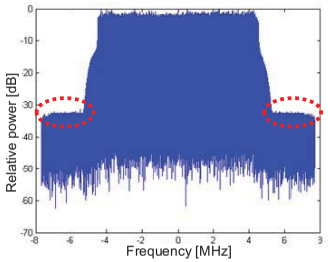
[2] ORI(13)M16006, "IQ data compression proposal," (2013).

Characteristics of proposed scheme

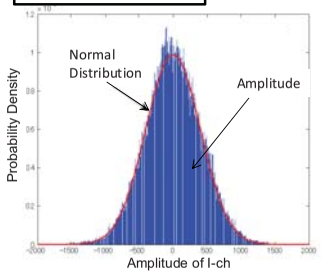
Analysis of CPRI data for data compression

- Target data: ADC sampling data for both Ich and Qch (IQ data)
- 1.5 times over sampling for bandwidth ➔ Redundant part reduction
- Normal distribution of amplitude ➔ Bit width reduction by nonlinear quantization

LTE Spectrum (10MHz)



I-ch amplitude distribution



Proposed compression scheme (1)

Proposed data compression scheme

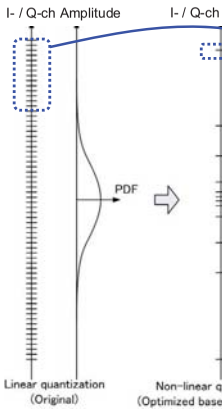
- **Target compression rate: 50%** (to keep the CPRI line rate after compression)
- Lossy compression with low signal degradation using the previous characteristics
- Following two steps
  - ① Down sampling ➔ 3/4 reduction of data
  - ② Nonlinear quantization that makes the most of characteristics of amplitude distribution ➔ 2/3 reduction of data

$$Compression\ rate = \frac{3}{4} \times \frac{2}{3} = \frac{1}{2}\ (50\%)$$

Proposed compression scheme (2)

- Reducing the resolution of amplitude with low PDF
- Determine the nonlinear sampling threshold by using CDF

Nonlinear quantization



A sample of nonlinear quantization

IQ value	ADC output	NL quantization output
31	011111	011
⋮	⋮	
15	001111	
14	001110	010
⋮	⋮	
5	000101	
4	000100	001
⋮	⋮	
2	000010	
1	000001	000
0	000000	
−1	111111	111
−2	111110	
−3	111101	110
⋮	⋮	
−5	111011	
−6	111100	101
⋮	⋮	
−15	110001	
−16	110000	100
⋮	⋮	
−32	100000	

Bit width is reduced without causing significant signal degradation.

Evaluation results

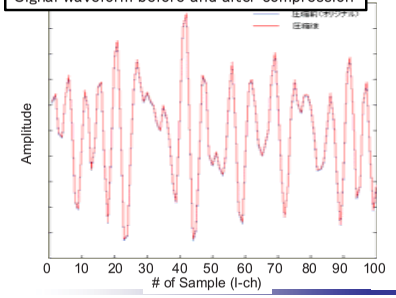
Analytical simulation

- Actual LTE signal waveform (Bandwidth: 5MHz, data length: 5 seconds)
- Evaluation index: EVM(Error Vector Magnitude) and SNR (Signal to Noise Ratio)

Signal quality degradation due to data compression

	EVM [%]	SNR [dB]
Original	2.8	39.9
After compression+decompression	2.8	39.6

Signal waveform before and after compression



Proposed scheme can achieve 50% compression rate without signal quality degradation.

Summary

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- Expanding mobile data traffic requires new mobile networks architecture, C-RAN.
- For introduction of C-RAN architecture, sub-ten Gbit/s/λ-class optical transmission line is essential among central office and antenna sites.
- To carry signals with such a large capacity, fiber utilization efficiency should be much more enhanced.
- Possible technologies for that purpose is data compression.

The proposed data compression scheme has the following advantages:

- It can satisfy all of the constraint conditions required for implementation to the system while realizing 1/2 compression rate.
- It can be implemented with a relatively low-performance.

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It leads to cost reduction for installing the optical fibers.