5G를 위한 광액세스망 기술

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정철석 (chung@etri.re.kr)

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5G & C-RAN

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5G 광액세스망 관계? 광통신?
5G Key Services

**Enhanced Mobile Broadband**
- High data rate
  - 4K/8K UHD
  - Hologram
  - VR/AR (Virtual/Augmented Reality)

**Low Latency Services**
- Ultra-high reliability/low latency
  - Tactile Internet
  - Remote-control robot/machines

**Massive Internet of Things**
- Massive connectivity
  - Connected cars (V2X)

**Demanding conditions**
- Broadband Access in Dense Areas
- High-speed Mobility
  - Massive hot spots /Smart office
  - Moving hot spots /High-speed train

5G Vision & Key Capabilities

**Key capabilities of IMT-2020**
*Inter-relation between the three usage scenarios & Key capabilities*

- **Peak Data Rate**: 20 Gbps
- **User Experienced Data Rate**: 100 Mbps
- **Area Traffic Capacity**: 10 Mbps/m²
- **3 Times** Spectrum Efficiency
- **Network Energy Efficiency**: 100 Times
- **Mobility**: 500 km/h
- **Connection Density**: 10⁶ per km² (1 per m²)
- **Latency**: 1 msec (Radio Interface)

[Note] Each of the three usage scenarios does not need to meet all the Key Capabilities
Mobile traffic Growth: 57% CAGR (compound annual growth rate)
- 2015: 4.2 EB (Exa bytes), 2019: 24.3 EB (exa bytes)
- 10x traffic growth in next 5 years
- Worldwide 4G LTE subscriber: ~$1.8 billion in 2020 (25% of world population)
- 5x growth in 5 years
- 5G prototype service in 2018, commercial service in 2020

Mobile network Capex
- Average Capex $35 billion (Y2014~Y2018)
- Revenue growth: 2%
- Big gap between traffic growth and revenue growth
What is C-RAN?

기지국의 진화

Conventional Architectures
- Standard BS
- BBU Remoted

Cloud RAN Architectures
- BBU Centralized
- Intra BBU Pooling+CoMP
- Inter BBU Pooling+CoMP

Possible future Products
- Virtualized or vRAN

Multiple site per BBU

Phase 1 C-RAN
- Site 1
- Site 2
- Multiple site per BBU

Phase 2 C-RAN
- Multiple site per BBU

Future C-RAN
- Virtualized or vRAN

Switching Layer

참고: OFC2015 Workshop “Access Networks for High Speed Applications and Mobile Xhaul”
Radio Access Network: Traditional Architecture

- Standard BS
- Traditional Site
- Site
- BS
- Radio
- BBU
- Backhaul
- Copper
- M-Wave
- Fibre
- Antenna
- Co-axial cable
- Base Band Unit

Radio Access Network: C-RAN

- The current mobile architecture with centralized RAN equipment:
  - Phase 1: BBU centralisation (BBU-RU link based on CPRI/OBSAI)
  - Phase 2: BBU pooling
- Optimal architecture for CoMP RAN features (intra and inter-cell sites).
- Down sizing the form factor of equipment at the cell site
Advantage of C-RAN (ref: http://www.fiercewireless.com/)

- **Capex/Opex Reduction**
  - **CAPEX Reduction 30%**
    - 28.33
    - 8.29
    - 36.14
    - 5.47
    - 15.49
  - **OPEX Reduction 53%**
    - 59.6
    - 8.5
    - 31.9
    - 12.1
    - 51.7

- **In-building DAS network**
  - **DAS (distributed antenna system)**
  - **Antennas**
  - **RRHs**
  - **Central Office**
  - **IP/MPLS network**

- **Fronthaul**
  - **CCU (Central Control Unit)**
  - **DU (Data Unit)**
  - **RU (Remote Unit)**

- **Backhaul**

- **In-building DAS**
  - **Antenna sites**
  - **Fronthaul**
  - **Backhaul**

- **모바일용 광인프라 기술**
  - **인도어 DAS 정의**: 건물내 무선 서비스 제공을 위해 호스트장치에 접속된 공간적으로 분리된 다수의 안테나 네트워크
  - **인도어 DAS 역할**: 다수의 안테나를 공간적으로 분산시켜 실내 환경의 높은 트래픽 용량 문제와 음영지역 해소
  - **인도어 DAS 기술현황**: 국내 4G망은 디지털 샘플링 방식 기반의 광전송 기술을 적용한 사업자별로 독립된 망을 운용

- **Fronthaul 정의**: C-RAN 구조의 이동통신 기지국에서 BBU (DU) 와 RRH (RU)를 연결하는 광 전송망을 지칭
- **Fronthaul 역할**: 모바일 가입자의 음성 및 데이터를 RRU에서 모아 BBU가 위치하는 전화국으로 전달
- **Fronthaul 기술현황**: 현재 국내 LTE 기반의 4G망에서는 CPRI & OBSAI 와 같은 디지털 방식의 광전송 기술을 적용
5G Key Technologies

**The Coming 5G**

- **100Gbps**: The ultimate 5G
- **25Gbps**: 5G+
- **2Gbps**: First 5G
- **1Gbps**: 4G Adv

- Mm Waves
- High bandwidth
- Full Massive MIMO

- 700MHz (wide range of coverage)
- 3.5GHz with Massive MIMO
- Ultra Low latency

- More Carrier Aggregation
- 256 QAM
- MIMO 4*4

**Expected peak cell site throughput**

**Time**
Mobile fronthaul

### Speed Limitation of Fronthaul

<table>
<thead>
<tr>
<th>Type</th>
<th>Data-rate</th>
<th>Required data-traffic (CPRI-formatted)</th>
</tr>
</thead>
<tbody>
<tr>
<td>LTE (20MHz) 2x2 MIMO</td>
<td>0.15 Gb/s</td>
<td>((2^{\text{antenna}}) x 30.72 Msp (sample rate) x 16 (bit/sample) x 2 (IQ) x 1.25 (8B/10B)) = 2.45 Gb/s</td>
</tr>
<tr>
<td>5G (125MHz) 2x2 MIMO, SBA</td>
<td>5 Gb/s</td>
<td>((2^{\text{antenna}}) x 8 (FA) x 184.3 Ms (sample rate) x 16 (bit/sample) x 2 (IQ) x 1.25 (8B/10B)) = 117.95 Gb/s</td>
</tr>
<tr>
<td>5G (125MHz) 4x4 MIMO, SBA</td>
<td>10 Gb/s</td>
<td>((4^{\text{antenna}}) x 8 (FA) x 184.3 Ms (sample rate) x 16 (bit/sample) x 2 (IQ) x 1.25 (8B/10B)) = 235.9 Gb/s</td>
</tr>
<tr>
<td>5G (125MHz) 8x8 MIMO, SBA</td>
<td>20 Gb/s</td>
<td>((8^{\text{antenna}}) x 8 (FA) x 184.3 Ms (sample rate) x 16 (bit/sample) x 2 (IQ) x 1.25 (8B/10B)) = 471.8 Gb/s</td>
</tr>
</tbody>
</table>


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### 5G 를 위한 광액세스 기술

5G Vision from IMT-2020
“Information a finger away, everything in touch”

- **Speed**: 1000X (20Gbps)
- **Latency**: Less than 1ms
- **Capacity**: 1000X (Capacity/km²)
- **Energy**: 1000X Reduce

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3GPP Family Technology Evolution

---|---|---|---|---|---
GSM | GPRS | EDGE | HSPA | HSPA+ | LTE | LTE-A

**Distributed-RAN**

*Cost-effective approaches for infrastructure will be very important*
5G Field Test 1
### 5G를 위한 광액세스 후보 기술

<table>
<thead>
<tr>
<th>기술 분류</th>
<th>Requirement</th>
<th>Approach</th>
<th>Solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bandwidth</td>
<td>Capacity Increase</td>
<td>Large Capacity Transmission</td>
<td></td>
</tr>
<tr>
<td>Latency</td>
<td>Data Reduction</td>
<td>Data Compression</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Function Split</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>New Technology</td>
<td>Analog RoF</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fast Signal Processing</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

#### CPRI 기반 모바일 프론트홀

**CPRI (Common Public Radio Interface)**

무선 장비 제어기(Radio Equipment Controller, REC)에서 무선 장비(Radio Equipment, RE) 사이의 기지국간 디지털 접속을 정의한 규격

- CRPI 규격은 현재 버전 7까지 완료되었으며, 24.3Gbps (option 10) 까지 정의
- 광링크의 전송속도를 줄이기 위해 IQ data 압축기술이 연구되고 있으며, 전체의 93.75%를 차지하는 IQ data sample을 대상으로 함.

![CPRI Interface](image)

![CPRI Protocol](image)
**IQ Data Compression**

- CPRI frame: IQ data (93.7% of total data), control, timing sync
- Requirement of IQ data compression
  - Compression ratio: ~ 50%
  - Delay: < 20 μs
  - EVM degradation: < 3%

---

**CPRI Protocol Overview**

1. **1st step: IQ Data Down-sampling**
   - Original IQ data
   - Down-sampled IQ data

2. **2nd step: IQ bit width reduction**
   - Compressed IQ data

---

**CPRI Compression Algorithms**

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Concept</th>
<th>Pros &amp; Cons</th>
</tr>
</thead>
<tbody>
<tr>
<td>1st Step</td>
<td>Down sampling</td>
<td>+ : high compression quality &amp; relatively low EVM degradation</td>
</tr>
<tr>
<td>2nd Step</td>
<td>Non-linear quantization</td>
<td>+ : best in EVM degradation</td>
</tr>
<tr>
<td></td>
<td>Block scaling</td>
<td>- : worst in FPGA logic utilization</td>
</tr>
<tr>
<td></td>
<td>Partial bit sampling</td>
<td>+ : good in EVM degradation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>- : need a time for processing time</td>
</tr>
<tr>
<td></td>
<td>Original signal</td>
<td>+ : best performance for latency &amp; FPGA logic utilization, relatively good in EVM degradation</td>
</tr>
<tr>
<td></td>
<td>Lower-bit decimation</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Compress signal</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Decompress signal</td>
<td></td>
</tr>
</tbody>
</table>

---

**IQ Data Compression**

- 2nd step: IQ bit width reduction
- Data Compression Ratio: ~50%
### CPRI Compression Requirements

<table>
<thead>
<tr>
<th>Requirements</th>
<th>Standardization (ORI)</th>
<th>Real Field (Telco needs)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compression Ratio</td>
<td>&gt; 50 % (based I/Q data)</td>
<td>50 % (based CPRI)</td>
</tr>
<tr>
<td>EVM degradation</td>
<td>&lt; 3 %</td>
<td>&lt; 0.5 % *</td>
</tr>
<tr>
<td>One-way latency</td>
<td>&lt; 100 μsec (preferably 20 μsec)</td>
<td>&lt; 10 μsec</td>
</tr>
</tbody>
</table>

### CPRI Compression System

- VSG
- Software Development Kit & Integrated Logic Analyzer
- FPGA board #1, #2
- VSA
- SFP+ #1, #2
- 20km of SMF

[Photograph test-bed for IQ data compression/decompression]
EVM degradation

![EVM degradation graph](image)

- EVM = 0.70%, \( \Delta \text{EVM} = 0.55% \)
- EVM = 1.64%, \( \Delta \text{EVM} = 0.16% \)
- EVM = 2.89%, \( \Delta \text{EVM} = 0.08% \)

[ Measured EVM degradation versus EVM of input signal, and constellation of 64QAM ]

(PB: partial bit sampling, BS: block scaling, NL: non-linear quantization)

One-way latency

![One-way latency graph](image)

[ One-way latency of additional compression+decompression ]
Function Split & Virtual Access Network

- The reach extension of the fronthaul: natively possible due to SFP
- More data processing capacity of BBU

Software in a server Adherent to hardware

Digital Signal Analog Signal

Upper Layer MAC OFDM PHY CPRI Framer/Deframer CPRI Framer/Deframer ADC

BBU (DU) RRH (RU)

MAC/PHY 기능 재분리를 통한 데이터 저감

참고: Keiji Tanaka et al., "Next-Generation Optical Access Networks for C-RAN", OFC 2015 LA

상대적 데이터율 1612 121
1.2~1.5

-Extraction of User Data -Header Removal -8B/10B coding

-MAC layer overhead
DU Function Split 및 종류

DU에 위치하든 PHY/MAC 기능을 RRH로 이동시켜 기지국을 운용하는 기술

Trade off

1. split within L1
   - DU-RU간 “PHY 계층 분리”
   - CPRI Fronthaul
   - Function Split
   - 5 Gb/s ~400 us latency

2. split within L2
   - DU-RU간 “MAC 계층 분리”
   - CPRI Fronthaul
   - Function Split
   - 1 Gb/s ~400 us latency

IP Backhaul

- CPRI Fronthaul
- 100 Mbps ~4 ms latency

* Bandwidth는 LTE-A (20 MHz, 2 FA, 2 Ayrıca 기준으로 산정)

Antenna Configuration and RAN Split

DEFINE TRANSPORT REQUIREMENTS

Functional RAN split has significant impact on required transport interface:
e.g. small cell, one sector, 125 MHz - 256 QAM - 16x16 MIMO

<table>
<thead>
<tr>
<th>Data rate (Gb/s)</th>
<th>Split I</th>
<th>Split II</th>
<th>Split III</th>
<th>Split IV</th>
</tr>
</thead>
<tbody>
<tr>
<td>S1</td>
<td>18</td>
<td>36</td>
<td>43</td>
<td>78</td>
</tr>
<tr>
<td>Transport (Gb/s)</td>
<td>25</td>
<td>40</td>
<td>100</td>
<td>100</td>
</tr>
</tbody>
</table>

*Source: “Small Cell Virtualization Functional Splits and Use Cases” by SmallCell Forum
5G Field Test 2

Gigabit data per second
Transport Options for new 5G Access Points

- IP connection
- Dedicated optical fiber
- Optical PON
- XG_fast
- XG-cable
- mmWave point-to-point systems

Passive Optical Network (PON)

- No needs to use electrical power btw. central office and subscriber
- PON consists with OLT, ONT, and power splitter or WDM filter at Remote node
**Sub-Channel CWDM Technology**

- Colored dual and multi sub-channel CWDM can support up to 108 WLs.  
- To get more wavelength resource in the limited fiber facilities for beyond 4G and 5G mobile fronthaul, we need to develop the evolving technology.  
- Colorless CWDM sub-channel technology with 0.8nm channel spacing is the one of promising solutions.

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**Dual Sub-Channel/Multi Sub-Channel**

- **Dual sub-channel CWDM**
  - Colored DML
  - OTX
  - OTX: Optical Transceiver
  - OTX: Colored DML

- **Multi sub-channel CWDM**
  - Colored or Colorless DML
  - OTX
  - OTX: TFF or AWG
  - OTX: Colored or Colorless DML
Colorless Operation

- Simple structure with F-P LD + LC tunable filter
- Wide tuning range of 40nm to cover 2 CWDM bands
- Low cost wide range wavelength locker inside TOSA
- 100/50GHz channel spacing
- Up to 10Gbps@20km with pre-dispersion compensator
- High optical power of +3 ~ +7dBm by direct modulation
- Needs only 18 or 9 different F-P LDs to cover all CWDM band

NG-PON2

NG-PON2 = 40 Gigabit Capable Multi-Wavelength PON System

- Ch. # ⇒ Base = 1 – 4 TWDM (TDM/WDM) and Option = up to 8
- PTP WDM (Ch# 8)
- TWDM Ch. Rates ⇒ Base = 10/2.5G and Options =10/10G and 2.5/2.5G
- PTP WDM Ch. Rates ⇒ 1G, 2.5G and 10G classes

ONUs are colourless and can tune to any assigned Channel
Incremental Upgrade (Pay-as-you-grow)

Incremental capacity can be added by provisioning additional NG-PON2 OLT channels. The ONUs are colourless and can tune to any NG-PON2 channel. This can also allow channel capacity management by redistributing ONUs across the available NG-PON2 channels.

FSAN Standard Roadmap

Disruptive technologies, innovative R&D

Peak Rates > 10G

2021+

Future Optical Access System (FOAS)

Industry Trends 2016+

SDN
NFV
5G
IoT
Convergence
100G-EPON timeline

IEEE P802.3ca Timeline

- 802.3 interim meeting
- GGF20 working group

100G-EPON

IEEE

100G OLT

Power Splitter

\[ \lambda_0 \]

\[ \lambda_1 \]

\[ \lambda_2 \]

\[ \lambda_3 \]

25G ONU

50G ONU

100G ONU
<table>
<thead>
<tr>
<th></th>
<th>NG-PON2</th>
<th>100G EPON</th>
</tr>
</thead>
<tbody>
<tr>
<td>Standard body</td>
<td>ITU-T SG15</td>
<td>IEEE 802</td>
</tr>
<tr>
<td>Standard</td>
<td>G.989.1,2,3</td>
<td>IEEE802.3ca</td>
</tr>
<tr>
<td>PON capacity</td>
<td>Dn: 4x10G (8x10G)</td>
<td>Dn: 4x25G</td>
</tr>
<tr>
<td></td>
<td>Up: 4x2.5G (8x10G)</td>
<td>Up: 4x25G (or 10G)</td>
</tr>
<tr>
<td>PtP WDM-PON</td>
<td>Included</td>
<td>Maybe not</td>
</tr>
<tr>
<td>Max Capacity of ONU</td>
<td>10G / 2.5G</td>
<td>100G / 100G</td>
</tr>
<tr>
<td>Channel bonding</td>
<td>No</td>
<td>Yes</td>
</tr>
<tr>
<td>Wavelength Plan</td>
<td>Dn: L+band, Up: C-band</td>
<td>Not yet</td>
</tr>
<tr>
<td>Tunable</td>
<td>Yes</td>
<td>No</td>
</tr>
<tr>
<td>Co-existence</td>
<td>G-PON, XG-PON</td>
<td>10G-EPON</td>
</tr>
</tbody>
</table>

**100G EPON Homepage**

**IEEE P802.3ca 100G-EPON Task Force**

**Physical Layer Specifications and Management Parameters**

**Guiding Documents**

- IEEE 802.3ca PAM  
  (Approved on December 5, 2015)
- Criteria for Standards Development (CSG)  
  (Approved on November 10, 2015)
- Objectives  
  (Approved on November 12, 2015)
- IEEE 802.3ca Timeline  
  (Approved on January 21, 2016)
- 802.3 WG Operating Rules

**Standards Development Tools**

- Submit a contribution & request agenda time
- PowerPoint (pptx) template
- 802.3 Tools and Resources
- Baseline Proposal & Technical Matters
- 25 Gbit Channel Model for PON
- Wavelength-induced skew calculator
- 100G Management & Control Parameters

**Meeting Archives**

- May 2016, Whistler, BC, Canada
- March 2016, Naga, China
- January 2016, Atlanta, GA, USA

**Email Reflector**

- Subscribe / Unsubscribe
- View archive

**Study Group Meeting Archives**

- November 2015, Dallas, TX USA
- September 2015, Boston Springs, IL, USA
- July 2015, Waikiki, HI USA - CF3 presentation

**Deadline for requesting time on the agenda: Monday, July 18, 2016 4pm. To request the agenda time, follow these instructions. Please include final draft of PDF file when requesting agenda time.**

**Minutes of the Whistler meeting are now available in the [May 2016 Archives](#).**

**The next face-to-face meeting of this Task Force will occur on July 25-27, 2016. Meeting times during that week are expected to be 1:00 pm to 6:00 pm on July 25, and 8:00 am to 6:00 pm on July 26 and 27, although final times depend on level of contributions. For meeting location and logistics, see the [IEEE 802.3 Ethernet](#) web page.**
25G PON 프로토타입 시험

100G EPON Prototype Research Results

- https://www.aseapublishing.org/ae/abstract?n=ae-24-13-13991

상하향 성능

1Gbpsburst mode upstream

QoS

Contents

5G & C-RAN

전송 용량 저감 기술

광액세스 기술

Indoor Analog RoF 기술
전체 Mobile Traffic의 80%가 Indoor 환경에서 발생
모바일 서비스(SNS 등)은 의사전달 수단에서 개인의 사회적 행동의 도구로 발전
현재는 Data 속도 저하 및 음영지역 해소 필요
Indoor 환경에서 25년 이상 사용되어 검증되고, 급격한 발전이 예상되는 solution은 DAS.
현재 DAS가 적용된 site는 수 만 국소 이상이며, 향후 2023년까지 약 1억 site로 증가 예상

현재의 디지털 DAS 기술 현황

디지털 DAS 구조

디지털 DAS의 광전송 용량 증가

~ 300Gbps
10Gbps
8Gbps
6Gbps
8Gbps
2Gbps
Bandwidth Efficient IFoF based Optical Access

<table>
<thead>
<tr>
<th>Type</th>
<th>Properties</th>
</tr>
</thead>
</table>
| Radio frequency over Fiber (RFoF) | - Transmission of mobile signal on the RF frequency as air interface through fronthaul link  
- Low implementation cost and complexity in RU  
- Requires many wavelength for increasing data-rate |
| Intermediate Frequency over Fiber (IFoF) | - Transmission of mobile signal on intermediate frequency through fronthaul link  
- Bandwidth efficient transmission  
- Flexible bandwidth allocation  
- Increases implementation cost and complexity in RU |

Millimeter wave 5G & Indoor

- 기지국 최대 20Gbps
- 단말 1 Gbps
- 최대 32 FA, 8x8 MIMO 지원
- 최대 전송거리 5km, 최대 8 분기 수용
- 5G 이동통신 서비스 음영지역 해소

밀리미터파 5G 이동통신 시스템

밀리미터파 5G & Indoor DAS

밀리미터파 5G 이동통신시스템 신호 사양

125 MHz x 8FA = 1GHz

Air: 27.5GHz  
125 MHz  
2.7GHz

1.7GHz
5G 프로토타입 성능 시험

Mobile Station Platform (User equipment)
- Terminal Unit
- L1/L2/L3 Board
- L1 FPGA Board
- RF/IF Module

Base Station Platform (BBU)
- Clock Board
- L1/L2/L3 Board
- L1 FPGA Board
- IF Module

Video Streaming
Performance Evaluator

Audio Optical Transceiver

LD Driver
LD
LNA
PD

[Block diagram]

Analog Optical Transceiver

Analog optical transceiver

Frequency response

S21 (dB)

S21

< ±1 dB

[Analog optical transceiver]

[Block diagram]

[Frequency response]
Supporting giga-bit mobile service with 28 GHz mmWave 5G prototype
Achieving peak data-rate up to 1.5 Gb/s per each user
감사합니다