# CWDM Networks with Dual Sub-channel Interface for Mobile Fronthaul and Backhaul Deployment


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***Abstract*— This paper describes the SK Telecom's mobile fronthaul deployment via CWDM networks with dual sub-channel interface. It also describes requirements for the next generation optical fronthaul and backhaul CWDM network evolution to support next generation fixed, mobile, and converged network services.**



***Keywords*— CWDM, mobile fronthaul, mobile backhaul**


## I. INTRODUCTION

Global mobile broadband subscriptions reached around 1.7 billion Q1 2013, are predicted to reach 7 billion in 2013, and are expected to consume around 14 Exabytes monthly in 2018 with a CAGR of around 50 percent (2012-2018) driven mainly by video [1]. Korea has been the most advanced market in mobile network that deployed long term evolution (LTE) system nationwide already in 2012 and has started to launch LTE-advanced (LTE-A) in 2013. The high bandwidth of LTE and LTE-A has driven mobile network efficiency to co-locate base band units (BBUs) in central office (CO) to provide cloud computing capability and locate remote radio heads (RRHs) in distributed area. And there has also been generated a need to connect a large number of BBUs in CO and RRHs with optical fiber efficiently.

The coarse wavelength division multiplexing (CWDM) technology [2] is one of the most cost effective ways to provide connectivity between BBUs and RRHs through common public radio interface (CPRI) or open radio interface (ORI) with 1.25G to 10G capacity per wavelength channel. The CWDM, however, has one limitation due to low wavelength channel count. It can only provide 8 bidirectional wavelength channels from 1271 nm to 1611 nm excluding two wavelength channels 1371 nm and 1391 nm to avoid near water peak of G.652 fiber. The nominal channel spacing specification of 20 nm and spectral excursion specification of +/- 6.5 nm, which were determined considering effective realization of uncooled laser and wide pass-band filters [3], made the said 8 bidirectional wavelength channel capacities.

Recently, newly developed low cost cooled package solved the low channel count limitation of the CWDM. With keeping the existing CWDM filters compatible to G.694.2 wavelength grid in the field, one can locate more than two sub-channel wavelengths within the CWDM wavelength slot. As an example, one can design the CWDM with dual sub-channel whose wavelengths are bound within +/6.5 nm of the existing CWDM filter with further confining the sub-channel wavelengths to have 4 nm guard-band within the CWDM filter as illustrated in Figure 1(a). Then one can increase the bidirectional channel capacity twice from 8 to 16, as demonstrated with measurements shown in Figure 1(b).

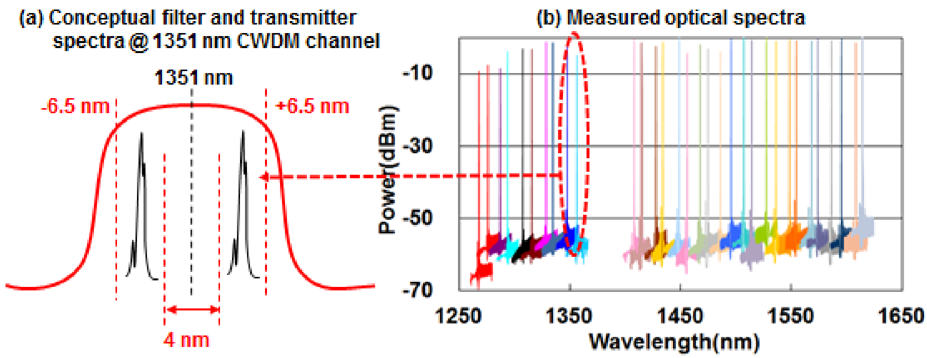



**Figure 1.** Optical transmitter spectra of 2 x 16 channel wavelengths for the CWDM with dual sub-channel interface system. (a) conceptual filter and transmitter spectra @ 1351 nm CWDM channel (b) measured 2 x 16 CWDM optical spectra

Besides, SK Telecom has been expanding the new CWDM architecture to become hybrid CWDM and dense wavelength division multiplexing (DWDM) system to increase wavelength channel capacity by more than 100 wavelength channels, which is 84 CWDM sub-channels within 14 CWDM wavelength slots and 16 DWDM wavelength channels within 2 CWDM wavelength slots.

## II. MOBILE FRONTHAUL NETWORK USING CWDM WITH DUAL SUB-CHANNEL INTERFACE FOR 4G (LTE) SERVICE

SK Telecom has been building the CWDM network with dual sub-channel for the cost effective 4G mobile fronthaul networks with CPRI connection, in which several tens of thousands of optical transceivers have been deployed since 2012. Depending on situation site by site, some CWDM networks with dual sub-channel interface were deployed with point-to-point architecture and others were deployed with ring architecture as shown in Figure 2, respectively. In both cases, the mobile base stations consist of BBUs located in a CO and RRHs in distributed remote area. The LTE RRHs and the BBUs are connected using CPRI line bite rate option 3 (2457.6 Mbit/s) or OBSAI (Open Base Station Architecture Initiative) line bit rate (3072 Mbit/s) through a bidirectional CWDM wavelength channel with two sub-channel interfaces.

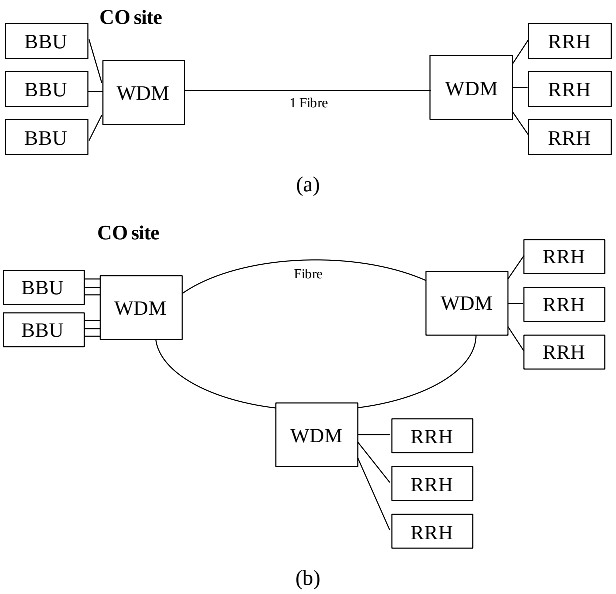



**Figure 2.** Point-to-point and Ring topology applications for 4G mobile fronthaul with CWDM network with dual sub-channel interface

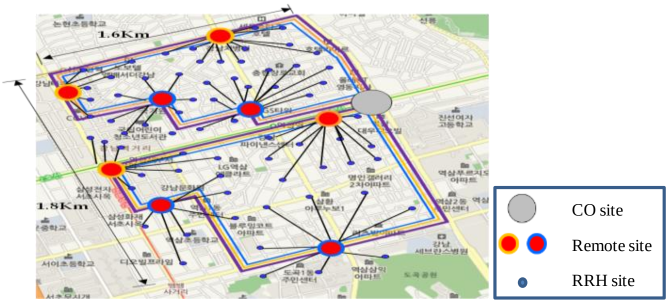
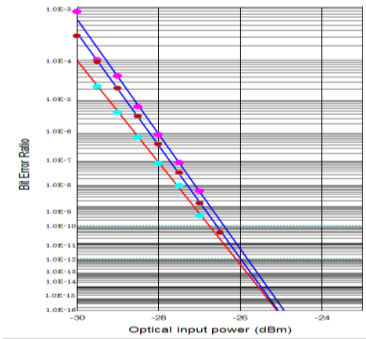



**Figure 3.** An example of 4G Mobile Fronthaul deployment in an area (1.6 km x 1.8 km) in Gangnam distinct with the CWDM ring networks with dual sub-channel interface

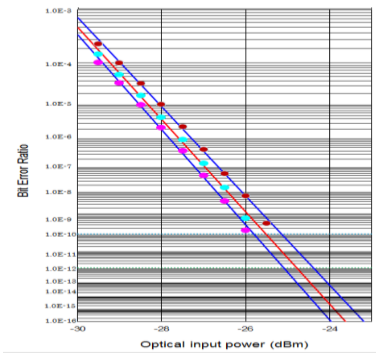
Figure 3 shows an example of actual deployment of SK Telecom's 4G mobile fronthaul networks for LTE service. There are two rings in a part of area (1.6 km x 1.8 km) of Gangnam district of Seoul city. The BBUs centralized to a CO site are connected to the RRHs through two or more existing CWDM filters compatible to G.694.2. In the distributed remote area of these ring networks, bidirectional signals over the CWDM with dual sub-channel interface through a single optical fiber are added and dropped with the existing CWDM filter also compatible to G.694.2.

## III. OPTICAL TRANSCEIVER PERFORMANCE FOR THE CWDM WITH DUAL SUB-CHANNEL INTERFACE ICES

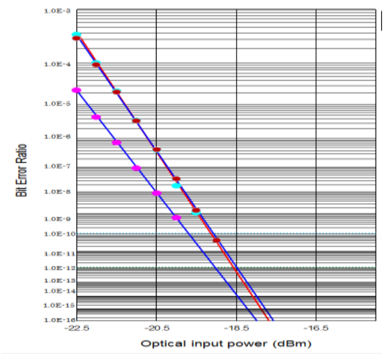
The optical transceiver performance for the CWDM with dual sub-channel interface was investigated in terms of BER over various transmission line rate under standard operating environment conditions. Figure 4 illustrates the said optical transceivers' BER performance for CPRI option 3, 4, and 5, corresponding at 2.5 Gbit/s, 3.1 Gbit/s, and 4.9 Gbit/s, respectively.




(a) CPRI Option 3, BER at 2.5 Gb/s




(b) CPRI Option 4, BER at 3.1 Gb/s




(c) CPRI Option 5, BER at 4.9 Gb/s

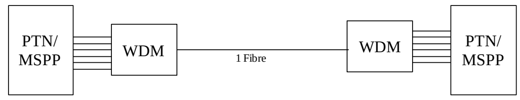
**Figure 4.** BER performance of the optical transceiver for the CWDM with dual sub-cannel interface

The BER performance curves show that the said optical transceiver can operate without FEC upto 5 Gbit/s. Currently, the package of the cooled transmitter optical sub-assemble inside the optical transceiver has been design-optimized for cost to use direct modulation. And thus bandwidth is limited for the 10 Gbit/s operation. 10 Gbit/s optical transceiver is also under development for commercialization sooner or later.

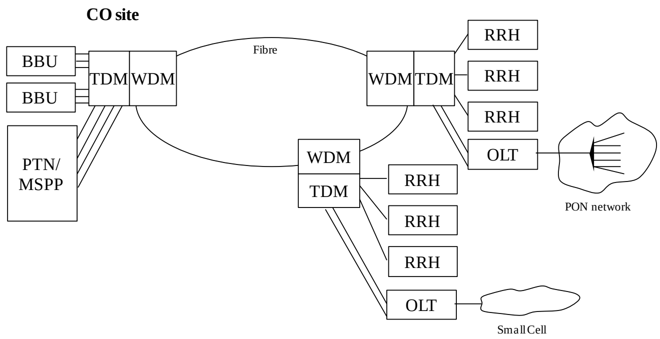
## IV. CWDM NETWORK EVOLUTION FOR NEXT GENERATION FIXED, MOBILE AND CONVERGED NETWORK SERVICES

There exists the need to have cost effective optical network not only to provide the 4G mobile fronthaul but also to provide fixed and mobile convergence. SK Telecom carried out successful trial to use the CWDM network with dual sub-channel interface to connect packet transport network (PTN) equipment and legacy passive optical network (PON) optical line terminal (OLT) equipment, and optical mobile backhaul equipment for small cell applications. The trial CWDM networks with dual sub-channel interface for such fixed and mobile convergence used both point-to-point architecture and ring architecture as illustrated in Figure 5. The trial for the convergence network used optical bandwidth of 2.5 Gbit/s and 10 Gbit/s multiplexing four 2.5 Gbit/s to provide a network flexibility scenario.

On the other hand, LTE/LTE-A has rigid requirements about processing delay in physical layer [5]. CPRI optical transmission delay including the transmission medium may be 100 ~ 200 microseconds at the most, considering that the physical layer processing itself takes 800 ~ 900 microseconds. Therefore, the best thing that we can do to guarantee CPRI optical transmission distance up to 20 km or 40km is to reduce the maximum transmission processing delay as much as possible.




(a)




(b)

**Figure 5.** Application of a point-to-point and ring topology using CWDM network with dual sub-channel for 4G mobile fronthaul overlapped with PTN, optical backhaul for small cell, and legacy PON

After intensive evaluations and deep analysis considering the various applications to be used for current services and for future services related with mobile fronthaul evolution for LTE, LTE-A and beyond 4G, PON evolution from GPON to XG-PON, multiplexing flexibility for PTN, optical backhaul evolution for small cell, SK Telecom came up with the following common requirements

- Channel bandwidth : 1.25 Gbit/s, 2.5 Gbit/s, 5 Gbit/s and 10 Gbit/s per wavelength channel
- Channel count capacity : from 8 (4 wavelength slots with 2 sub-channels) to 96 (16 wavelength slots with 6 sub-channels)
- Link distance support: 20 km and 40 km
- Processing delay : ≤ 3 microsecond (including multiplexing, demultiplexing and forward error correction)
- Topology : point-to-point architecture, linear architecture with add/drop, ring architecture
- Port connectivity : a signal fiber connection for bidirectional communication
- Channel upgradability : each bidirectional channel pair must be independently line-rate upgradable without impacting other wavelength slots
- Hybrid CWDM/DWDM operation : hybrid DWDM over CWDM networks can be configured to support additional channel capacity

Recent investigation on the CWDM optical transceiver using the low cost cooled package showed feasibility to be able to locate 6 sub-channels within a CWDM wavelength slot with G.694.2 wavelength grid. And thus the 96-channel count capacity (16 wavelength slots with 6 sub-channels) is technical feasible. Both 20 km and 40 km link distance are also feasible for 1.25 Gbit/s, 2.5 Gbit/s with PIN-PD or APD devices. 10 Gbit/s operation may need dispersion compensating element to achieve 40 km.

## V. Summary

CWDM networks with dual sub-channel interface have been successfully deploying to fulfill SK Telecom's 4G mobile fronthaul application. Trials to investigate the CWDM with multi sub-channel interface with keeping existing CWDM filter infrastructure compatible to G.694.2 showed feasibility to meet the current and future requirements for the mobile fronthaul evolution, optical backhaul evolution for small cell, PTN multiplexing, and PON evolution. Recently, the CWDM Applications with dual sub-channel optical interface is standardized by Korean standard body TTA for the initial 2.5 Gbit/s short haul application [4].

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