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（研究装置設備の紹介・成果報告）

Wavelength Routing Network Test-bed for Large Contents Distribution Applications in a Campus

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ABSTRACT : The design and demonstration results for a campus-scale wavelength routing network test-bed are described. 4K digital cinema contents are successfully transmitted over the test-bed network via 8 λ and GbE interfaces to verify the feasibility of the network.

Keywords : wavelength routing, WDM, content transfer, 4K

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1. Introduction

WDM (Wavelength Division Multiplexing) technologies have been advanced in several networks; Core networks now offer several tens of wavelengths resulting in enhanced capacity. Recently, they also use the wavelength routing functionality in e.g. GMPLS (Generalized Multi-Protocol Label Switching) network. The access network is expected to adopt the WDM PON (Passive Optical Network) approach for future enhancement via service multiplexing or capacity enhancement after the rapid deployment of FTTH (Fiber To The home).

Relatively smaller networks such as LANs (Local Area Networks) have not really benefited of WDM technology. This is mainly due to the cost issue as the bit rate and network size are rather small and the network facilities are only lightly shared. However, new applications such as medical, scientific research, and education all with high-resolution visual services require higher LAN performance [1].

This paper first discusses general requirements for designing campus-scale networks, and then describes the wavelength based full-mesh network test-bed, together with some experimental results and lessons learned.

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2. General requirements of the campus scale network

Major goals of the network are to support educational and scientific applications in a campus. General requirements for the network are summarized in Table 1 [2, 3]. Recent video applications with high resolution need a lot of bandwidth; strong bandwidth compression is not favored due to the increase in latency. Traffic patterns are bursty with very high peaks [4]. Therefore, bit rates should be over 1 Gb/s. Distance is set by the campus size of about 400 x 600 m. The campus core is used for building to building connections. The distance for campus edge is set 100 m for inside building connections. This value was calculated by using the generalized house model with parameters of 30 x 10 x 3 m

Table 1 General requirements.

Item	Value/attribute
- bit rate	: > 1 Gb/s
- distance for core	: < 2 km
for edge	: < 100m
- # of connecting points	: around 10 (at present)
- type of connection	: center-to-end, end-to-end
- functionality	: bit rate independent, scalability, signal format independent

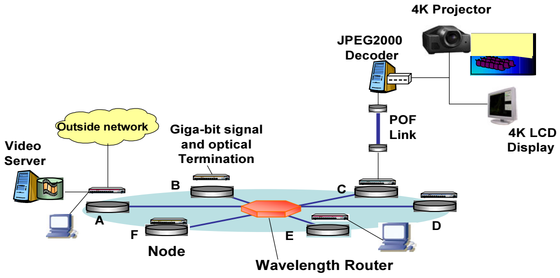

Fig. 1. Network configuration.

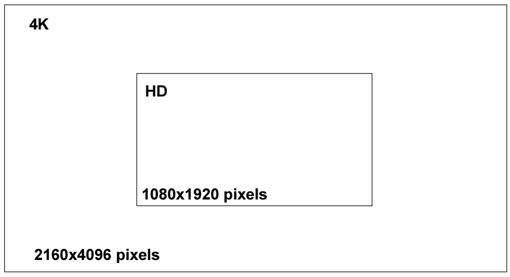

Fig. 2. Comparison of 4K and HD in terms of pixels.

with 5 floors [5]. The number of connecting points corresponds to the number of buildings to be connected with increases for multiple floors in each building. Connection types are center to end (C-E) for content distribution applications and end to end (E-E) for normal communication. Functionality is an important issue. Terminals and their attributes vary widely and rapid evolution is expected. Therefore, bit rate independency, scalability, and signal format independency are of importance.

3. Wavelength based full-mesh network test-bed

In order to realize a network that meets the requirements mentioned above, we have developed a passive star network with a wavelength router as the center node.

Figure 1 shows the configuration of the network. The wavelength router connects the nodes in a star [6]. Each node performs giga-bit signal termination and optical signal termination. Node A connects to a video server with 4K content. Node C connects to a 4K projector or 4K LCD (Liquid Crystal Display), both via a JPEG 2000 Decoder. Connections between nodes A to C simulate center to end connections. In this experiment, however, only point-to-point links are used. Other nodes connect either PCs or nothing. The 4K digital cinema content is the highest resolution commercial content currently standardized by the DCI (Digital Cinema Initiatives) [7]. Figure 2 compares the pixel-size for 4K and the most widely used high definition (HD) television format. Each 4K frame holds 2160 x 4096 pixels, about 4 times higher resolution than HD content. Therefore, scientific or educational applications that offer high reality can be implemented. The original uncompressed content occupies about 6.4 Gbit/s.

Figure 3 shows the layered functions of the network. Three layers, optical, IP, and application, form the network. The optical layer functions include WDM on a fiber between the wavelength router and any node with bi-directional transmission, wavelength routing at the router, and the creation of a wavelength-based VPN (Virtual Private Network) through the addition of fiber connections via loop-backs and a cyclic AWG (Arrayed Waveguide Grating) [8]. The IP layer functions full-mesh connections. The application layer offers both E-E and C-E connections.

4. Experimental results

In order to confirm the optical characteristics of the system and content distribution functions, and extract

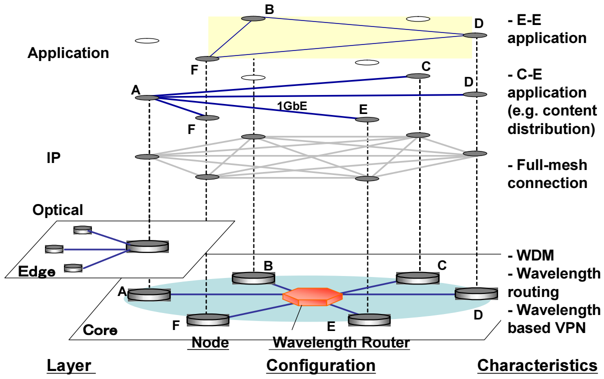

Fig. 3. Layered function.

technical study items, several experiments have been conducted. Figure 4 shows a photograph of the test-bed equipment. The equipment includes two nodes (signal termination), a wavelength router, a video server, a JPEG2000 decoder, a 4K projector, and a 150-inch screen [9].

Core Network

Each node in the core network has SFP (Small Form factor Pluggable) GbE transceiver modules. These modules can be upgraded to 10GbE as the network itself is passive, i.e. bit-rate independent. 8 optical channels ($\lambda 1$ to $\lambda 8$) with 200GHz spacing on the ITU-T grid 37 down to 23 (1547.72 – 1558.98 nm) are used for the wavelength router and nodes.

The wavelength router has wavelength based full mesh characteristics whose input and output relationship is given in Table 2. Figure 5 shows the logical full mesh connection with the center node (Center) and 4 other nodes (N-1 to N-4) with wavelengths. It uses 8 wavelengths for connection as depicted. If future node extension needed, another matrix with additional wavelengths will be created. It uses dielectric multilayer thin-film filters. Measured optical insertion losses of each channel of the wavelength router are 2.5 to 3 dB with 3 dB bandwidth of 1 nm. Total path loss between any nodes is less than 10 dB.

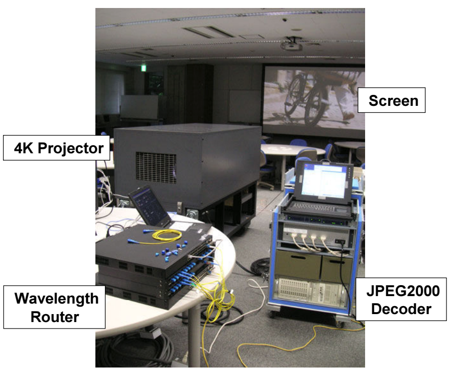

Fig. 4. Test-bed equipment (Video server is not shown).

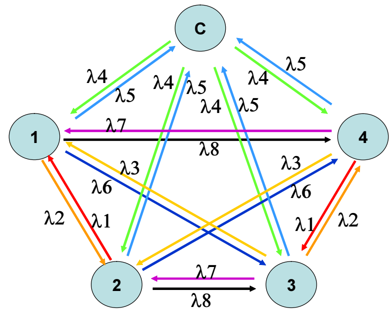

Fig. 5 Full-mesh connections based on the wavelength.

Table 2 Input and output characteristics.

		Output				
		N-1	N-2	N-3	N-4	Center
Input	Node1	-	$\lambda 2$	$\lambda 6$	$\lambda 8$	$\lambda 5$
	Node2	$\lambda 1$	-	$\lambda 8$	$\lambda 6$	$\lambda 5$
	Node3	$\lambda 3$	$\lambda 7$	-	$\lambda 2$	$\lambda 5$
	Node4	$\lambda 7$	$\lambda 3$	$\lambda 1$	-	$\lambda 5$
	Center	$\lambda 4$	$\lambda 4$	$\lambda 4$	$\lambda 4$	-

Edge Network

Output wavelength of the media converter (MC) measured was 791.9 nm where optical power measured was smaller than an actual value because the optical spectrum analyzer has smaller active area at receiver. Its power was 1.8 dBm that was measured with 1 m long GI-POF (Graded Index Plastic Optical Fiber) [10].

Optical loss measured was 9.5 dB for the 50 m POF cable at 791.9 nm.

Connection loss of SMI (Small Multimedia Interface) connecter measured was less than 0.1 dB.

Optical bending loss was smaller negligible for eight 90 degree bends with bend radius of 12 mm.

Transmission Experiment

No packet loss was observed during the 4K content transfer via core and edge networks.

5. Lessons Learned

Several items for future study identified in the experiment are;

- network configuration of the edge network e.g. a simple star, wavelength routed network, a WDM ring,
- wavelength allocation for increased connecting point number,
- transmission medium suitable for shorter distances especially in an edge network e.g. MMF (Multi-Mode Fiber), POF (Plastic Optical Fiber),
- improved network availability especially against fiber break, and
- functional allocation in different layers e.g. Multicast.

6. Conclusions

A campus-scale wavelength routing network test-bed was introduced. The test-bed offers both center-to-end and end-to-end functionality. Results of large capacity content (4K digital cinema content) transfer verified the feasibility of the high speed, but small scale, network with wavelength routing functions. They also imply that this network will be able to support new applications such as medical, scientific research, and education all with high-resolution visual services that require higher performance in a campus area. The test-bed experiments will be further continued to enhance the next phase network.

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