Wiring the Physical Network of the Next Generation Home Network

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Abstract The next generation home network needs an infrastructure that can handle the large volumes of data yielded by the transfer of high definition images and data streams from different kinds of terminals. Optical fiber cable is the most promising candidate for the next generation home network; such cable offers extremely large capacity.

This paper examines the network topology or the wiring course from ONU (Optical Network Unit) to the optical wall socket and introduces a formula that allows us to calculate the total wiring length (of optical fiber cable) in a home for different network topologies. Moreover, the longest transmission distance needed to configure the home network is calculated.

I. Introduction

A home network is a communication network that connects all terminals and a variety of sensor groups in a home. It has recently become possible to create a home network that can interconnect consumer electronic devices such as televisions, videos, telephones, refrigerators, microwave ovens, and air conditioners as well as personal computers and their peripherals. Therefore, the next generation home network needs an infrastructure that can transfer the extremely large data streams generated by high definition image services and many different types of terminals and sensors.

A lot of studies have differentiated the wired and wireless transmission media for use in the home. The wireless LAN (Local Area Network) suffers from electromagnetic interference [1] and has relatively poor security. As for the metallic cable generally used in current home networks, the bandwidth – distance product is insufficient, and it will make it difficult to transmit and receive streams of ultra-high-density images, a key goal of the next generation home network. Optical fiber cable, on the other hand, offers much higher capacity than either metallic cable or wireless. Moreover, it eases the issues posed by installing cable in actual houses since it offers a smaller diameter than metallic cable as well as being lighter. Therefore, it is thought that optical fiber cable is the strongest candidate for the transmission medium of the next generation home network.

One barrier to implementing the next generation home network is that the wiring of optical fiber cables has not been studied sufficiently. The authors have presented the basic considerations raised by wiring a house by introducing the general house model [2]; they also compared, at a basic level, physical network topologies as well as the WDM technology [3].

This paper further elucidates the wiring configurations that could be used to realize the next generation home network. It starts by summarizing the network topologies suitable for home use and then describes wiring routes in an actual house for each network topology. It also introduces several equations that yield the total cable length for each topology. Optical power budgets for each network topology are then estimated.

Experiments conducted to verify the estimated power budgets will be presented at the conference.

II. Features of Network Topologies

The network topologies examined here for the next generation home network are a) single star, b) double star, and c) ring. Each house accommodates an ONU (Optical Network Unit) and a router. The router is connected to the optical wall sockets located on the walls of all rooms. Several wall sockets exist in a room. Each terminal/ home appliance is connected to the router through its nearest optical wall sockets. The features of each topology are described below:

A. *Single star*

Figure 1 shows the network configuration of the single star. All connections can use the same wavelength because this topology uses dedicated optical fiber cable to each optical wall socket to establish point-to-point connections.

However, increasing the number of optical outlets directly increases the number of wires. One solution is to employ multiplexing technologies just as in the access network.

TDM (Time Division Multiplexing) or WDM (Wavelength Division Multiplexing) can reduce the number of optical fiber cables needed. Another approach is to use double star topology or the ring topology.

B. *Double star*

Figure 2 shows the double star type network topology considered here. As shown, in a double star the router connects to several branching filters in a star, and each branching filter connects to several optical wall sockets in another star. The number of optical fiber cable can be reduced compared to the single star. However, more than one wavelength is needed to create multiple connections between the router and each wall sockets simultaneously.

C. *Ring*

Figure 3 shows the ring network topology examined here. As shown in Fig. 3, a ring is formed that connects the router to several ADMs (Add/Drop Multiplexers). Here, passive ADM like an AWG (Arrayed Waveguide Grating) is considered in the ring. The key feature of this topology is that it can reduce the number of cables because it uses WDM. Total wiring might also be less than is true for the other two topologies. However, because the ring type allocates one wavelength to each optical wall socket of each room, the number of wavelengths required equals the number of wall sockets.

III. WIRING ROUTE IN A HOME

This section examines, for each network topology, the wiring route between the optical wall sockets in each room and the router. The number of optical wall sockets needed for each room is also examined.

Wiring routes are considered using the housing model shown in Fig. 4 and Fig. 5. The house consists of multiple boxes stacked together; each has size of *a* x *b* x *c* [2]. The router is located at the origin of the x-y-z axes and ONU location is arbitrary.

When the cable is wired into an actual house, the wiring must pass through wall and ceiling cavities.

It is assumed that each room will have four optical wall sockets, one in each corner.

In all network topologies it wires under the roof or in the wall in each room and it wires along each axis.

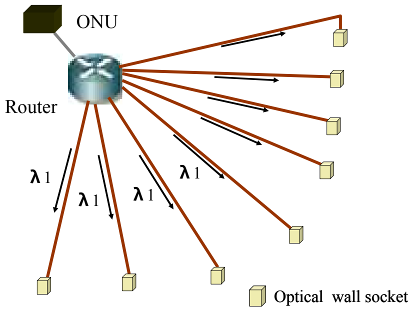

Fig. 1 Single star type

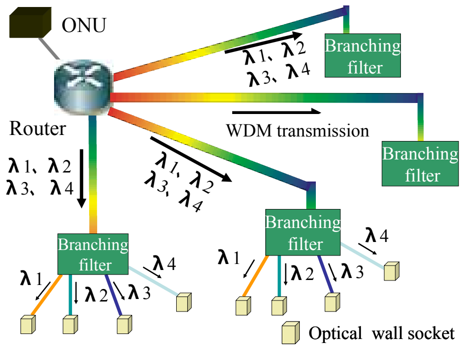

Fig. 2 Double star type

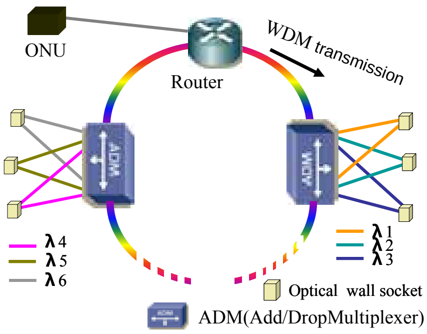

Fig. 3 Ring type

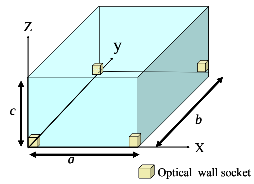

Fig. 4 Room model and location of optical wall sockets

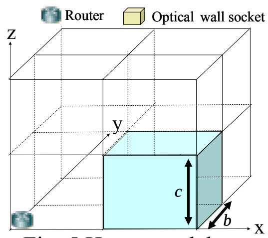

Fig. 5 House model

A. *Single star*

As described in Section II. A, all optical wall sockets are directly connected to the router in a star as shown in Fig. 6.

B. Double star

The double star places the router at the origin of the x, y, z axes and a branching filter in the corner ceiling of each room (at the nearest corner to the origin as in Fig. 7). The first stage star, router to branching filters, uses WDM so each connection is realized by one optical fiber cable. The second stage stars connect branching filters to optical wall sockets as shown in Fig. 7.

C. Ring

The ring locates the router at the origin and the ADM in the left corner ceiling of each room. WDM connections are made between the router and ADM and between ADM and ADM. The ring type forms one ring each floor that connects directly to the router. Each ADM is connected to the four optical wall sockets in that room. Figure 8 shows the wiring route.

With the ring network, the shortest wiring route depends on the number of rooms on each floor. There shot categorized into three cases when the number of rooms N_x in x-axis and N_y in y-axis.

i) $N_x \leq 3$: Fig. 9 (a) and (b) show the wiring route. In the figure, (m, n) denotes the number of rooms N_x on x-axis and N_y on y-axis.
ii) $N_x \geq 4$ and even: Fig. 9 (c) shows the wiring route.
iii) $N_x \geq 4$ and odd: Fig. 9 (d) shows the wiring route.

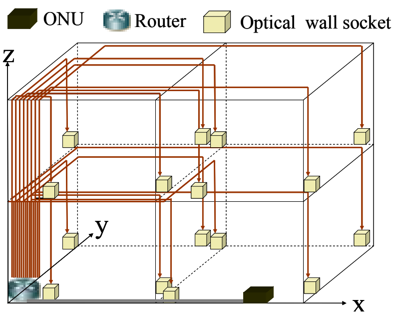

Fig. 6 Wiring route of single star configuration

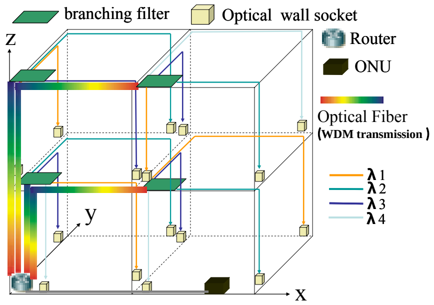

Fig. 7 Wiring route of double star configuration

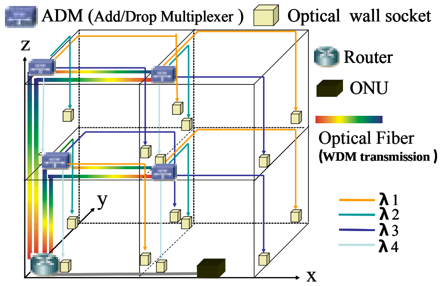

Fig. 8 Wiring route of ring configuration (all sockets needed)

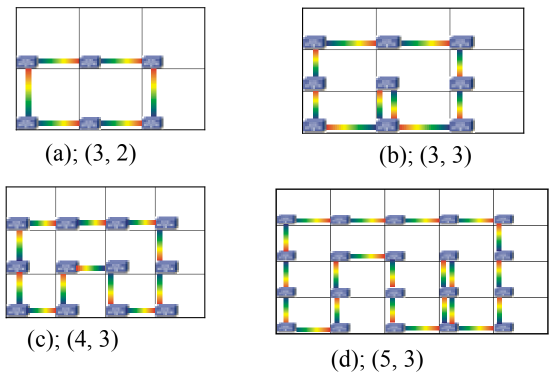

Fig. 9 Ring route

IV. Total Wiring Length Formula for Calculation

This section introduces our formula to calculate the total wiring length. The size of one room is assumed to be as shown in Fig. 4, *a* in x-axis, *b* in y-axis, and *c* in z-axis. The house has *F* floors. Other parameters are as follows:

- Total wiring length; L ($L=L1+L2+\ldots+Lf$)
- Floor; f
- Total wiring length on the f-th floor; Lf
- The total number of rooms on the f th floor; Nf
- The number of rooms on the x-axis on the f -th floor; Nfx
- The number of rooms on the y-axis on the f -th floor; Nfy
- Length between each branching filter or ADM and its optical outlets; l ($l=2a+2b+4c$)

A. Single star

L_f for the single star is given by $L_f=L_{fx}+L_{fy}+L_{fz}$,
Where L_{fx}, L_{fy},and L_{fz}, are given as (1),(2), and (3);
Therefore, L_f is given as (4);

$$L_{fx} = \sum_{i=1}^{N_{fx}} \{2a + 4a(i-1)\} \times N_{fy} \quad (1)$$

$$L_{fy} = \sum_{j=1}^{N_{fy}} \{2b + 4b(j-1)\} \times N_{fx} \quad (2)$$

$$L_{fz} = \{8N_f + 4(f-1)\} \times c \quad (3)$$

$$L_f = \sum_{i=1}^{N_{fx}} \{2a+4a(i-1)\} \times N_{fy} + \sum_{j=1}^{N_{fy}} \{2b+4b(j-1)\} \times N_{fx} + \{8N_f + 4(f-1)N_f\} \times c \quad (4)$$

B. Double star

L_f for the double star is given by $L_f=(L_{fx}+L_{fy}+L_{fz})+N_f l$ where l denotes the cable length between each branching filter and its optical wall sockets.
This value is here to $l=2a+2b+4c$.
L_{fx}, L_{fy},and L_{fz}, are given as (5),(6),and (7);
Therefore, L_f is given as (8);

$$L_{fx} = \sum_{i=1}^{N_{fx}} (i-1)a \times N_{fy} \quad (5)$$

$$L_{fy} = \sum_{j=1}^{N_{fy}} (j-1)b \times N_{fx} \quad (6)$$

$$L_{fz} = fN_f c \quad (7)$$

$$L_f = \sum_{i=1}^{N_{fx}} (i-1)a \times N_{fy} + \sum_{j=1}^{N_{fy}} (j-1)b \times N_{fx} + fN_f c + N_f l \quad (8)$$

C. Ring

L_f for the ring is given by $L_f=(L_{fx}+L_{fy}+L_{fz})+N_f l$ where l denotes the cable length between each ADM and its optical wall sockets. This value is fixed to $l=2a+2b+4c$.
L_f is given as follows;

Case i) $N_x<=3$
$N_x=1$, $N_y>1$; $L_f=2(N_y-1)b+2fc+2(f-1)c+N_f l$ (9)
$N_x=2$, $N_y>1$; $L_f=2a+2(N_y-1)b+2fc+2(f-1)c+N_f l$ (10)
$N_x=3$, $N_y>1$; $L_f=4a+(4N_y-6)b+2fc+2(f-1)c+N_f l$ (11)

Case ii) $N_x>=4$ and N_x is an even number
$N_x=4$, $N_y>1$; $L_f=6a+(4Ny-6)b+2fc+2(f-1)c+N_f l$ (12)

Case iii) $N_x>=4$ and N_x is an odd number
$N_x=5$, $N_y>1$; $L_f=8a+(6Ny-10)b+2fc+2(f-1)c+N_f l$ (13)

D. Comparison of total cable length for each network topology

To compare the three topologies in terms of total cable length, several parameters are set as follows; $a=1$, $b=1$, $c=1$, $N_x=3$, $N_y>1$, and $F=2$. A comparison of the total wiring length for each topology is shown in Fig. 10; the parameter is N_y.
It is observed that the ring yields the shortest length and the single star's length is about twice that of the others'.

V. Calculation of Longest Transmission Distance in Each Network Topology

A. The longest transmission distance

The longest transmission distance in each network topology is derived by using the mean values of houses in Japan [4]. These values are;
- size of room (Refer to Fig. 4); a=4.5m, b=4.5m, c=2.4m,
- number of floors: F ; two floors, and
- number of rooms on one floor; four rooms, Nx=2, Ny=2.

The longest distance from the router to any optical wall socket in the single star is calculated to be 25.2m. The route contains six bends and six connectors.
The longest distance from the double star type router to any optical wall socket is also calculated to 25.2m. This value equals that of the single star. The longest route contains four bends and eight connectors. The signal passes through a branching filter in this configuration.
The longest distance from the ring type router to any optical wall socket is calculated to be 29.7m. It contains four bends and fourteen connectors. In this configuration, the signal passes through four ADMs.

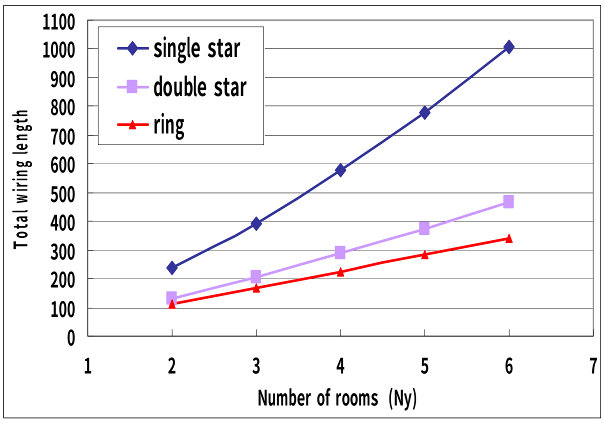

Fig. 10 Total wiring length comparison

B. *The optical level diagram*

In order to realize a network in an actual home, we need to estimate optical power budgets for commercially available devices.

Table I summarizes the estimated level diagram for each topology.

A multi-mode Graded Index optical fiber (50/125μm) is used. Fiber loss corresponds to the loss for the longest distance for each topology. However, its value is quite small and set to 0.5 dB. The number of connectors and bends are taken into consideration. Even though length of cable is short in a home, the number of connections becomes e.g. up to ten as a single long cable can not be installed throughout an entire connection in a wall. Bending loss is also considered small, but set to 2.0 dB. Loss for a branching filter or ADM is assumed 3.0 dB each regardless its configuration. System margin of 2.0 dB is also considered.

Specification for 1000BASE-SX is considered to the launched power and minimum received power as the next generation home network will use at least Giga bit/s interface [2].

As shown in the bottom row in the table, both single star and double star will be feasible with sufficient power budgets, however, ring needs further estimation in detail.

VI. Conclusion

This paper examined the wiring course of the next generation home network.

It considered the three most likely network topologies. The wiring route of the optical fiber cable in the home was examined based on the features of each topology. A formula was introduced that yields the total wiring length for each of the three topologies.

For the models and parameters considered herein, the ring type offers the shortest total wiring length while the single star's length is about twice that of the others.

The longest transmission distance between the router and any optical wall socket in each network topology was derived by using the mean values of houses in Japan. As a result, the ring type was found to have the longest distance as passive ADMs are used in connection. It may have the greatest transmission loss due to its many connectors and ADMs.

The transmission loss of each network topology was calculated by using an optical diagram. The results show that the ring does indeed have the greatest transmission loss because the longest route passes through four ADMs.

Our results show that the double star topology appears to be the optimal configuration for the next generation home network.

Cable installation trials in actual homes will be conducted to determine real-world optical budgets.

ACKNOWLEDGEMENT

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REFERENCES

[1] S. Terada, Y. Kakishima, S. Yamakawa, K. Tojo, T. Taniguchi, T. Kawakami, and K. Oguchi, "Comparison of Transmission Media for Next Generation Home Network", OECC/IOOC2007, Paper 11P-37, Yokohama, Japan, July, 2007

[2] K. Oguchi, T. Okodo, K. Tojo and K. Okada, "Physical network configuration of next generation home network", OFCNFOEC2006, Anaheim, CA, March 5-10, 2006

[3] Y. Kakishima, K. Okada, and K. Oguchi, "Comparison of Physical Network Configurations for Next Generation Home Network", OECC/IOOC2007, Paper 11P-5, Yokohama, Japan, July, 2007

[4] Ministry of Internal Affairs and Communications, http://www.stat.go.jp/jyutaku/2003/index.htm

TABLE I OPTICAL LEVEL DIAGRAM FOR EACH NETWORK TOPOLOGY

			Single star	Double star	Ring
Launched power (dBm) *1			-9.5		
Loss	Fiber (GI)	0. 5 dB/total	0.5	0.5	0.5
	connector (LC type)	0.5 dB/each	0.5×6=3.0	0.5×4=2.0	0.5×10=5.0
	bending	2.0 dB/total	2.0	2.0	2.0
	branching filter or ADM	3.0 dB/each	0	3.0×1=3.0	3.0×4=12
	Sub-total (dB)		5.5	7.5	19.5
System margin (dB)			2.0		
Received power estimated (dBm)			-17.0	-19.0	-31.0
Received power specification *1 and difference from the estimated power (dB)		-30.0 dBm	13	11	-1

*1 1000BASE-SX