Calculation method of time allocation for control, management and maintenance on remote-operated optical-fiber switching nodes system

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***Abstract*—We formulate a method to calculate time allocation for the control and management maintenance function and the time needed to complete the function for system design of remote-operated optical-fiber switching nodes.**

***Keywords*—Remote-operated optical-fiber switching nodes, control, management and maintenance function, time allocation**

I. Introduction

An optical access network design theory based on the concatenated loop topology [1], which is the next generation optical access network to support beyond 5G, is proposed. This topology is based on a loop-type configuration that consists of an upper loop connected to a communication building and a lower loop connected to the upper loop, which makes it easy to realize redundant paths. It is also robust to demand variation because of its support of fiber reassignment to meet unexpected demands. For this theory, we propose the installation of an optical fiber switching function that flexibly switches optical paths at remote-operated optical-fiber switching nodes (nodes) installed at the contact point between the upper and lower loops. This proposed node can switch the optical paths by use of the power-over-fiber technology [2].

To deploy a node as a network device, the controller in central office must have the management and maintenance functions. Firmware (FW) updates to fix bugs is one of the functions [3,4]. However, it is not clear how to calculate the system maintenance time (T_{SM}) that can be allocated to management and maintenance functions. Furthermore, it is necessary to simulate how the value of T_{SM} changes with the distance and number of nodes, and which parameters determine the value of T_{SM} must be considered.

In this paper, focusing on FW updates for management and maintenance functions, which is expected to take a long time to execute due to the low communication speed available, we

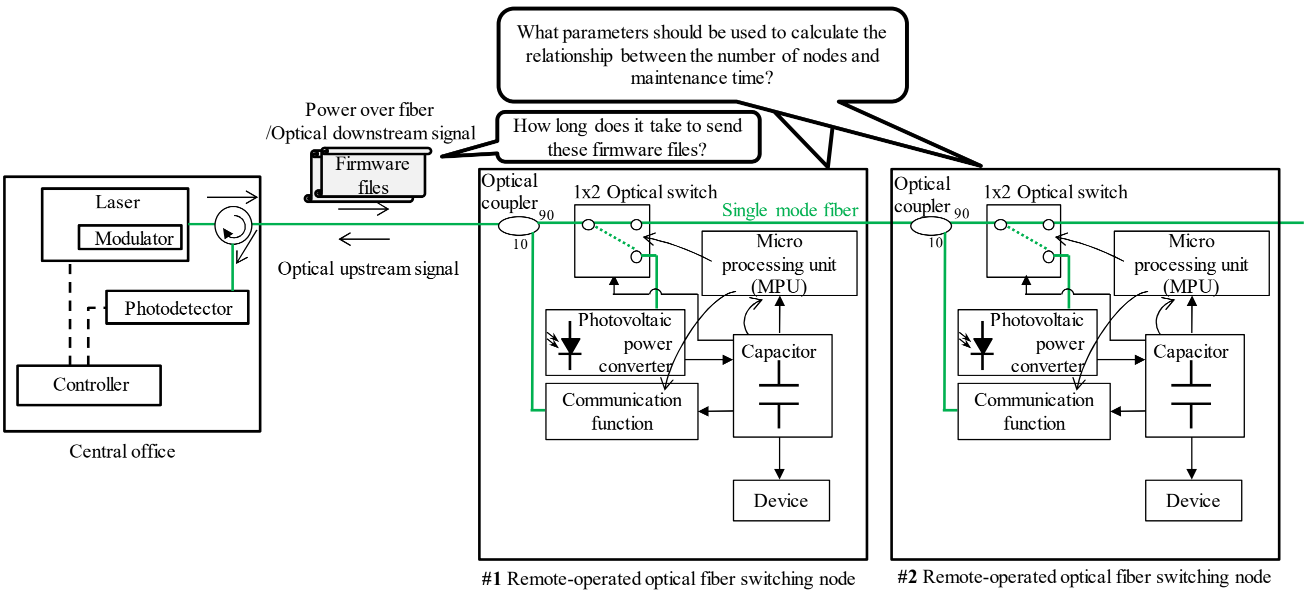

Fig. 1. System model of remote-operated optical-fiber switching nodes.

clarify how to calculate the T_{SM}. We also clarify how to calculate the file size that can be transmitted in T_{SM} and the time required for FW updates for a certain file size sent from the controller.

II. Characteristics and Control, Management and Maintenance Functions of Remote-operated Optical-Fiber Switching Nodes

Fig. 1 shows the system model of the node. The central office consists of a controller for controlling and communicating with the nodes, a laser that can be externally modulated as a light source for supplying power, a photodetector for receiving upstream signals from the nodes, and a circulator for controlling the direction of upstream and downstream signals. The central office and the nodes are connected by single mode fiber. The nodes are connected in series and share the fiber. When the 1x2 optical switch direction of each node is up, the central office and the rear nodes are connected, and when the 1x2 optical switch direction is down, the central office is connected to the node so that power supply, communication and control can be realized. When the 1x2 optical switch direction of node #1 is up and node #2 is down, only communication the central office with node #1 is possible because 10/100 of the light is input by the optical coupler of node #1. In Fig. 1, "Device" consists of the optical cross connect device including optical switches [5] and an optical fiber power monitoring device [6]. This system has three characteristics as shown in *A*, *B* and *C* below.

A. Power over Fiber

- To ensure communication between the controller and the MPUs of all nodes, the voltage value of the capacitors supplying power to the MPUs must at least equal the minimum driving voltage V_0.
- The receiving power of a node depends on the laser emission intensity, the distance of the node from the central office, and the number of nodes. The maximum voltage that can be stored in the capacitor and the time it takes to charge to the maximum voltage depend on the received power. However, in discharging, the relationship of voltage drop to time is constant regardless of the distance and number of nodes.

B. Control, Communication and Power over Fiber (PoF)

- To implement PoF, the central office intensity-modulates the feeding light and control communication signal (downstream signal) and transmits to a node.

C. Control and Communication

- The communication speed is low (110 bps) but constant.

To deploy a node as a network device, the controller must have the following management and maintenance functions: optical cross connect device operation and optical fiber power monitoring device operation (light intensity measurement and measurement data transfer), confirmation of capacitor voltage, communication confirmation to check the health of each device in the node, remote reset to restart the MPU (Micro processing unit) in an abnormal situation, and FW updates to improve the functional operation of the MPU such as fixing bugs. FW updates require data to be transmitted from the central office to each node. Since the communication speed is low as described in Section *C*, if large files are sent, the voltage at each node will decrease and may fall below the lower limit, V_0, and communication between the controller and the MPUs of all nodes will be lost. However, it is not clear how to calculate the T_{SM} that can be allocated to management and maintenance functions. Furthermore, since the nodes are arranged in series, it is necessary to simulate how the value of T_{SM} changes with the distance and number of nodes, and which parameters determine the value of T_{SM} must be considered.

It is necessary to clarify how to calculate the T_{SM} and also clarify how to calculate the file size that can be transmitted in T_{SM} and the time required for FW updates for a certain file size sent from the controller.

III. Proposed Calculation method

Fig. 2 shows the flow of the calculation method of T_{SM} and the time required for FW update, T_{all}.

(i) The number of nodes N and the distance from central office L_x are set. P_{FWx} (mW) is the power balance during the FW update of node #x and is given by equation (1).

$$P_{FWx} = P_{rx} \cdot r_L \cdot r_V - P_{fwm} > 0 \quad (x = 1, 2, 3, \ldots, N) \tag{1}$$

Here, P_{rx} (mW) is the light receiving power when node #x charging, as determined by N and L_x, r_L is the ratio of the feeding light in intensity modulated signal, r_V is photoelectric conversion efficiency, and P_{fwm} (mW) is the power consumption of the MPU during the FW update. "$P_{rx} \cdot r_L \cdot r_V$" indicates that the light receiving power is reduced by intensity-modulating the FW file into the feeding light and photoelectric conversion, as described in Section *B*. The required condition is that P_{FWx} is greater than 0. This relation can be used to calculate an estimate of the minimum light receiving power during the FW update, making system design more efficient.

(ii) Determine maximum voltage V_{max} corresponding to P_{rx} of all nodes. These values depend on the characteristics of the photoelectric conversion elements.

(iii) The values of the charging time T_{cx} (s) from V_0 (V) to V_{max} and the discharge time T_{dx} (s) from V_{max} to V_0 are measured and determined for all nodes.

(iv) Maintenance time T_{mx} (s) of each node #x is calculated by the following relation.

$$T_{mx} = T_{dx} - \sum_{k=1}^{N} T_{ck} - T_{cx} \tag{2}$$

This indicates that T_{mx}, the value obtained by subtracting the time to charge all nodes except node #x from the discharge time of node #x, is the time available for executing the management and maintenance function.

(v) Whether all T_{mx} values are positive is determined. This indicates that when T_{mx} becomes negative, a charge cycle that can keep all N capacitors above V_0 is not possible when only the feeding light is transmitted from the controller to N nodes. If it is negative, go back to (i) and correct to a positive value by decreasing N or decreasing L_x.

(vi) The magnitude of the voltage change d_{FWx} of node #x created by the FW update and the voltage change d_{dx} during discharge are compared in all nodes. d_{FWx} and d_{dx} are calculated by the following relations.

$$d_{FWx} = (V_{max\_FWx} - V_0) / T_{c\_FWx} \tag{3}$$

$$d_{dx} = (V_{max} - V_0) / T_{dx} \tag{4}$$

Here, V_{max_FWx} (V) is the maximum voltage at P_{FWx} (mW). T_{c_FWx} is the charging time from V_0 to V_{max_FWx}.

(vii-a) is applied when $d_{FWx} > d_{dx}$, or $d_{FWx} = d_{dx}$. T_{SM} (s) available for the FW update is the smallest T_{mx} in all T_{mx}. This value is common to all nodes. Furthermore, the time T_{all} (s) until completion of the FW update for any one node is calculated by using the following relation.

$$T_{all} = (D_{all} \cdot \sum_{k=1}^{N} T_{ck} + T_{SM}) / (v \cdot T_{SM}) \tag{5}$$

Here, D_{all} (bit) is FW file size. v (bps) is the communication speed. If the file size is too large for FW updating to be completed in one T_{SM}, split the file. When charging all nodes and then performing FW updating on one node is defined as one cycle, the procedure is to repeat the cycle for the number of divided files.

On the other hand, (vii-b) is applied if there is at least one occasion when $d_{FWx} < d_{dx}$. In (vii-b), the time available for the FW update is reduced to (d_{FWx} / d_{dx}) T_{SM}, which is a value common to all nodes, because FW updating consumes more power than normal discharge. Furthermore, it is possible to calculate time T_{all} until FW updating completes for any one node by using the following relation.

$$T_{all} = (D_{all} \cdot \sum_{k=1}^{N} T_{ck} + T_{SM}) / (v \cdot (d_{dx} / d_{FWx})\, T_{SM}) \tag{6}$$

IV. Simulation Results

Based on the flow described in Chapter 3, T_{SM} was calculated and simulated whether FW updating was possible with multiple nodes maintaining V_0 or higher, and T_{all} was calculated.

The feed laser power of the central office was set + 17 dBm [7], which is equivalent to the signal light intensity used for video distribution in the existing transmission system.

(i) $r_L = 0.5$ and $r_V = 0.3$ were set. $P_{fwm} = 0.198$ (mW) and $V_0 = 1.8$ (V) of the MPU were set. Using these values, the following relation was calculated: $P_{rx} > 1.2$ (dBm). As a result of the P_{rx} and the relation of received light power relative to

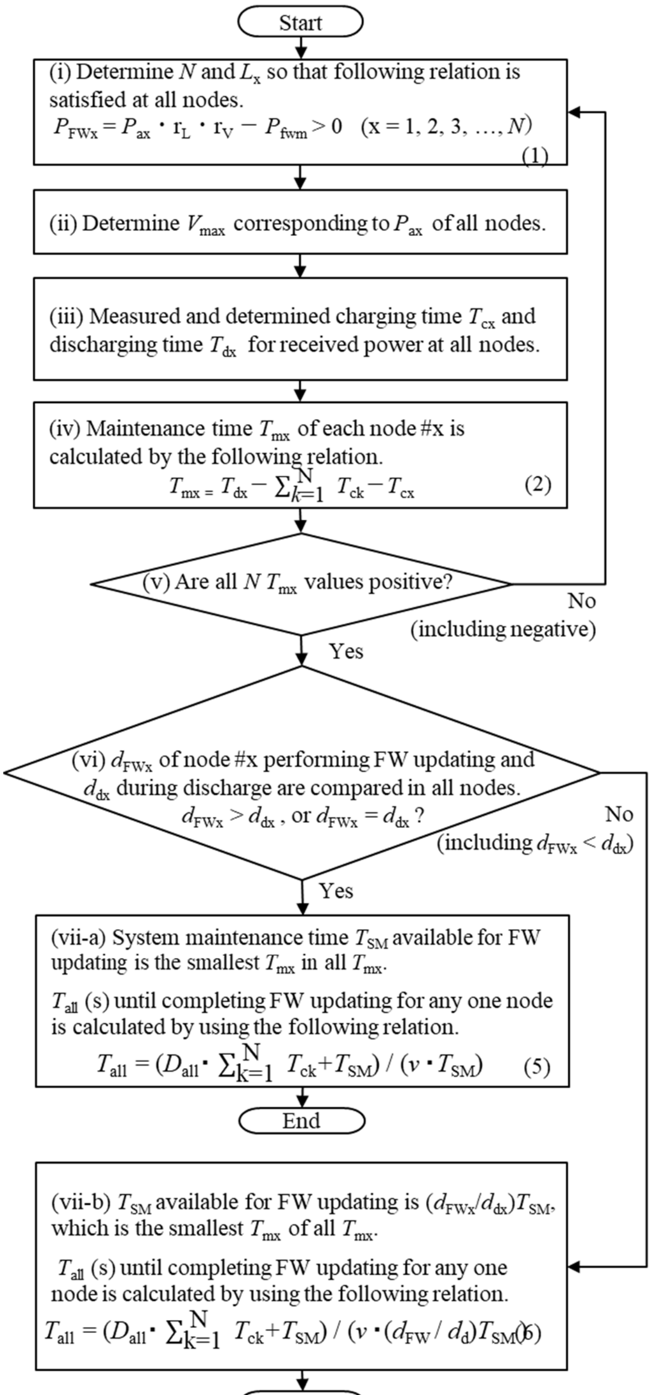

Fig. 2 Flow of the method that calculates system maintenance time T_{SM} and the time required for FW updating T_{all}.

Table 1. Set and calculated values used in determining maintenance time T_{SM}.

Node number #x	Distance from central office L_x	Light receiving power P_{rx}		Maximum voltage V_{max}	Charging time T_{cx}	Discharge time T_{dx}	Maintenance time T_{mx}	System maintenance time T_{SM}
	(km)	(dBm)	(mW)	(v)	(s)	(s)	(s)	(s)
1	0.5	11	12.6	2.9	138	2935	733	326
2	1	8	6.3	2.8	301	2474	434	
3	1.5	5	3.2	2.6	653	2012	326	
4	2	2.5	1.8	2.4	1247	1628	535	

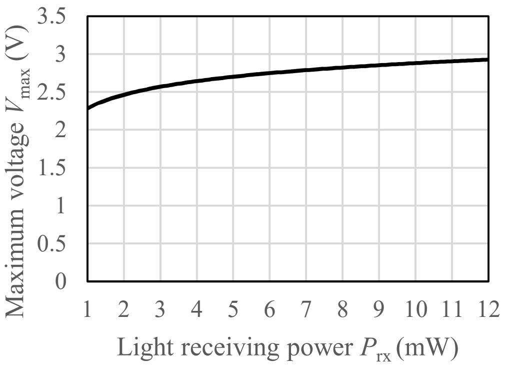

Fig. 3 Relationship between maximum voltage V_{max} and light receiving power P_{rx} from the characteristics of the photoelectric conversion elements [8].

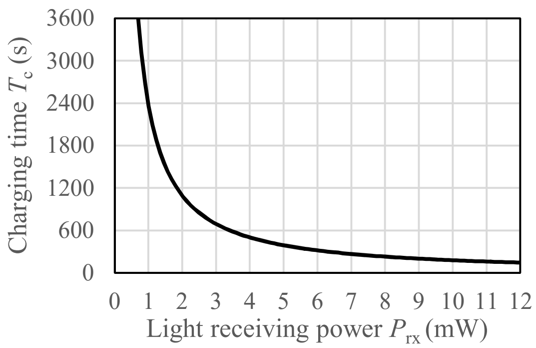

Fig. 4 Relationship between light receiving power P_{rx} and charging time T_c.

the installation distance of the node indicated by Kawano et al. [2], as shown in Table 1, we set $N = 4$ and L_x = 0.5, 1.0, 1.5, 2.0 (km).

(ii) V_{max} was determined from Fig. 3 using the values of the photoelectric conversion elements [8] used in the prototype.

(iii) The values of T_{cx} and T_{dx} were measured. Fig. 4 shows the relationship between the charging time and the light receiving power of the node. The smaller the light receiving power, the longer charging takes.

(iv) Values of T_{mx} were calculated from equation (2).

(v) Values of T_{mx} were all positive values as shown in Table 1.

(vi) Since $d_{FW4} = -4.4\times10^{-7}$ (V/s), $d_{d4} = -3.9\times10^{-4}$ (V/s) and $d_{FW4} > d_{d4}$, (vii-a) were applied.

(vii-a) T_{SM} is determined to be 326 (s) in #3, which is the smallest of the four T_{mx} values shown in Table 1. Fig. 5 shows the voltage simulation results when charging/discharging and FW updating were performed at each node. FW updating was performed for all four nodes, but it can be seen that FW files can be transmitted to all nodes without falling below V_0.

Next, T_{all} until the FW update is completed for one node is calculated by equation (5). D_{all} = 286,000 (bit), which is the firmware file size of the MPU of the prototype, was set. If the sum of the charging time in all nodes and the transmission times of the FW file, represented by $\sum_{k=1}^{N} T_{ck}+T_{SM}$ was taken as one charge cycle, it was calculated that the charge cycle

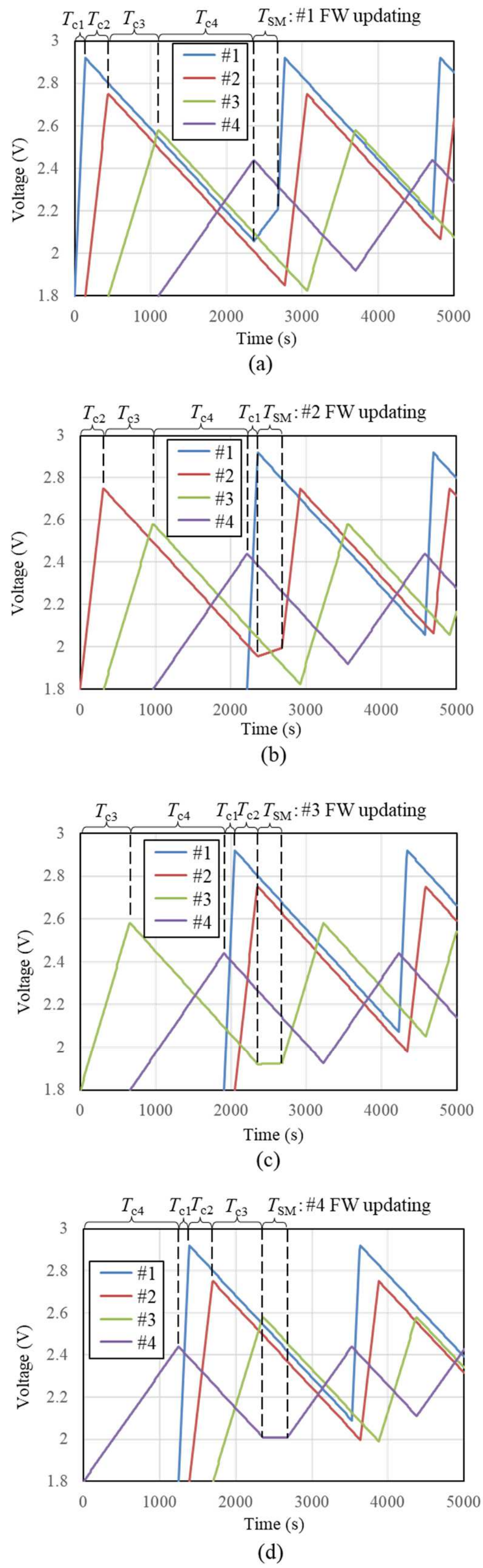

Fig. 5 Simulation results when charging/discharging and FW updating were performed on each node.
FW updates of node (a)#1, (b)#2, (c)#3, and (d)#4.

needed to be repeated 8 times in order to transmit this file, and T_{all} = 5.93 (h) was calculated.

V. Conclusion

We proposed a method for calculating the execution time of FW updating so as to maintain the voltage of the node being updated while keeping other nodes above the minimum driving voltage.

A method for calculating the time required for FW updating based on the size of FW files that can be transmitted at one time was clarified.

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