Power-saving performance evaluation of the adaptive deep sleep enabled PON based on applications and PON management system linkage operation

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SUMMARY The increase in power consumption of network equipment due to the growth of traffic has become an issue. The access network accounts for about 80% of the total network power consumption and reducing the power consumption of the access network is an effective way to save power in the network. Deep sleep is a method for achieving significant power savings in Passive Optical Network (PON), which are widely used as one form of access network. However, during the period when the Optical Network Unit (ONU) is in deep sleep, the application is unable to communicate, thus creating a problem of immediate communication.

We have proposed a method for determining the suitable sleep mode and sleep time for PON connected to Internet of Things (IoT) applications that perform periodic communication, in which the IoT application and the PON system cooperate. In this paper, we evaluate the power-saving performance of a PON system in which a sleep time-adaptive deep sleep mechanism based on the linkage between the application and the PON management system can be applied to simulations. In addition, we propose an improved version of the previously proposed method that adaptively adjusts the sleep time using information from linkage IoT applications based on the characteristics of the system to which it is applied.

keywords: PON, IoT, deep sleep, Energy efficient, Application and network cooperation

1. Introduction

The increasing power consumption of network devices due to the growth in traffic has become a problem, and there is a demand for power efficiency in networks. As approximately 80% of the total network power consumption occurs in the access network [1], achieving power reduction in the access network is an effective approach.

Figure 1 shows the power consumption ratio among various components of an optical access system [2], revealing that ONU consume 60% of the power. Therefore, reducing the power consumption of ONU is an effective method for power efficiency in PON. One technique for power reduction in ONU is ONU sleep, which temporarily suspends certain unused functions such as optical signal transmitter (Tx) and receiver (Rx) to decrease power consumption [3]. However, the power-saving effect of existing ONU sleep techniques (Tx sleep and TRx sleep) is limited. This is because most current PON systems are developed for Fiber To The Home (FTTH) applications, ONU installed in typical households have various connected devices, some with strict latency constraints, which restricts the extent to which sleep mode can be implemented.

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PON is expected to be used as a network to support future smart cities [4]. In smart cities, a new PON system will be required to communicate with many IoT devices, which will further increase PON power consumption. The communication requirements of IoT are different from those of existing FTTH. Therefore, it is necessary to study power-saving methods based on the communication requirements of the IoT.

Therefore, we have proposed an IoT PON System linked to IoT applications [5]. The IoT application notifies the IoT PON Manager via ONU, Optical Line Terminal (OLT) of the transmission interval. Based on this information, the IoT PON Manager determines the sleep mode and sleep time of the ONU.

In this paper, we evaluate the power-saving performance of a PON system in which a sleep time-adaptive deep sleep mechanism based on the linkage between the application and the PON management system can be applied to simulations. In addition, we propose an improved version of the previously proposed method that adaptively adjusts the sleep time using information from linkage IoT applications based on the characteristics of the system to which it is applied.

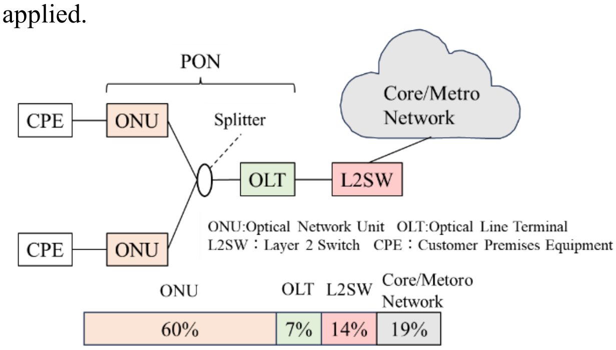

Fig. 1 Power consumption of optical access systems.

2. Conventional Methods and Issues

2.1 Power consumption reduced by TRx sleep

The power-saving techniques in PON are standardized in IEEE P1904.1 Service Interoperability in EPON (SIEPON) [3]. It defines Tx sleep, where the ONU Tx is periodically halted, and TRx sleep, where both the Tx and Rx are periodically halted. TRx sleep is a technique in which the OLT instructs the ONU to temporarily stop supplying power to the TRx when the OLT confirms that no traffic is flowing in the PON section. Figure 2 shows a 100 Gbps-class PON ONU power consumption diagram of TRx sleep. 100 Gbps class PON is assumed because the higher the transmission speed, the more branches can be realized and the possibility of extending T_{sleep} by reducing the transmission time (T_{active}) per ONU is higher. Figure 2 shows that power consumption during sleep is about 60% of active. This power consumption is estimated based on 1G-EPON and 10G-EPON since 100 Gbps class PON ONUs do not yet exist.

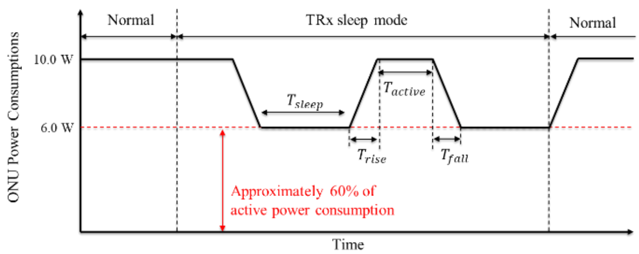

Fig. 2 Power consumption of TRx sleep by 100 Gbps class PON ONU.

The power-saving techniques defined in SIEPON have a limitation on the sleep duration, which is set to be less than 1 second to prevent link disconnection due to timeouts. Consequently, even when setting the sleep duration to the maximum value allowed by the standard, the achievable power reduction is limited to around 40% because power supply cannot be interrupted for components that cannot resume operation within a certain time frame.

2.2 Power consumption reduced by deep sleep and packet loss

In [6], which classifies ONU power-saving methods in PON, deep sleep is classified as a method that sleeps for a longer period than TRx sleep and has a significant impact on traffic such as link disconnections. Figure 3 shows the power consumption transition of deep sleep with a 100 Gbps-class PON ONU. Deep sleep is classified into the following four periods based on ONU power consumption:

1. Diagnostic period during which the Operating System (OS) is restarted and memory is checked
2. Initialization period during which the link is re-established.
3. Active period for sending/receiving data.
4. Sleep period during which power supply to almost all components of the ONU, except the timer, is stopped.

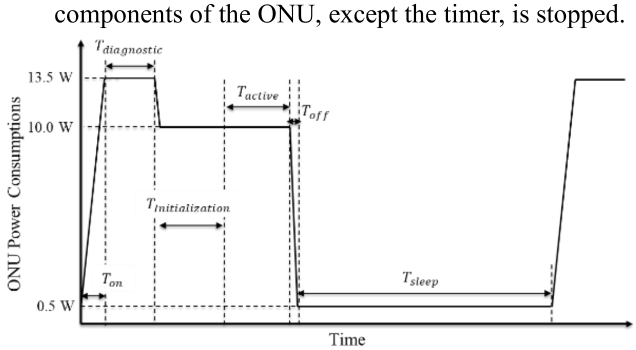

Fig. 3 Power consumption of deep sleep by 100 Gbps class PON ONU.

In deep sleep, the ONU periodically sleeps using a timer in the ONU. When the ONU is in deep sleep, if an IoT application sends a transmission, packet loss occurs. In addition, power is completely interrupted, requiring transition, diagnostics, and initialization as shown in Fig. 3, which takes 7 seconds to boot up.

3. Proposed Method

Deep sleep, which provides significant power savings, has the problem that packet loss occurs when an application starts transmitting outside of the active period. To solve this problem, it is necessary to wake the ONU from deep sleep in accordance with the timing of application transmission. However, in conventional PONs for FTTH, a wide variety of applications are connected to the ONU, each of which transmits data independently, making it difficult to match the timing of each application.

Therefore, we have proposed a solution to the deep sleep problem for PONs connected only to IoT applications that perform periodic communication by determining the suitable sleep mode and sleep time in cooperation between the IoT applications and the PON system [5].

3.1 IoT PON System linked to IoT applications

In this section, we present the IoT application linkage IoT PON system we have proposed in [5], in which the IoT application and the PON system link in order for the ONU to come back from sleep mode according to the timing of the transmission of the IoT application. The purpose of this system is to determine the sleep mode and sleep time that satisfies the application under the ONU, in cooperation with the IoT application and the PON system. First, the IoT application informs the ONU about its transmission cycle. Then, the ONU notifies the IoT PON manager through the OLT about the transmission cycle that was informed by the IoT application. The IoT PON manager then calculates the proper sleep time, selects sleep mode (TRx sleep or deep sleep) that matches that sleep time, and notifies the ONU of this information. The ONU then performs sleep operation according to the notified schedule. The above operation prevents IoT applications from sending data while the ONU is in sleep mode, thereby preventing packet loss. Figure 4 shows an example of adaptive sleep time setting by the proposed method.

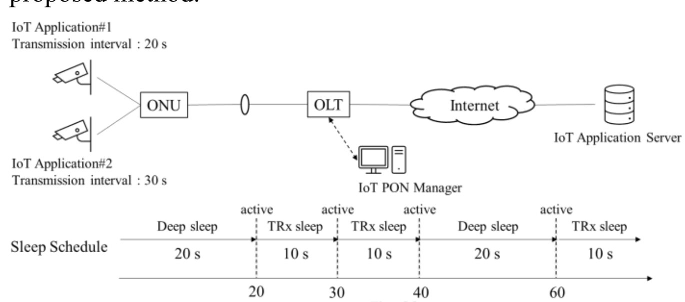

Fig. 4 IoT PON System linked to IoT applications and Example of an adaptive sleep schedule.

4. Evaluation of power-saving effects of application linkage

We apply the proposed method to a human flow analysis system using surveillance cameras whose frame rate varies with the human flow, as proposed in [7], and evaluate the power consumption of the ONU when applied to this system. The following situations are assumed in the simulation as shown in Fig. 5:

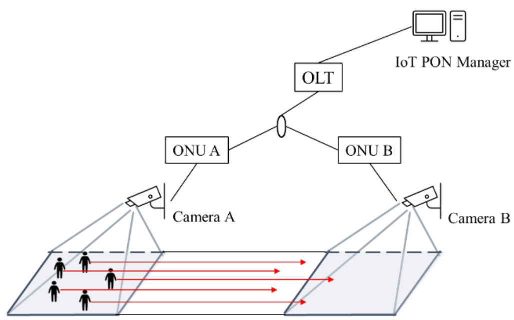

Fig. 5 . Image of the envisioned system.

At the entrance to the passageway where people pass, there is Camera A, which is always active and capable of detecting people. During the times when no people appear in the shooting area of Camera A, the IoT PON Manager puts downstream ONU B in sleep mode. When a person appears in the shooting area of Camera A, the IoT PON Manager sends an unsleep message at the time when ONU B wakes up. For simplicity, assume that there are two cameras and two ONUs, and that the direction and speed of human movement is constant.

4.1 Sleep Algorithm

For simplicity, the number of cameras and ONUs is assumed to be two, and the direction and speed of people moving are assumed to be constant. In addition, Person captured by Camera A must also be captured by Camera B. Based on the condition, the sleep duration and sleep mode are determined by the following sleep algorithm. Figure 6 shows the flow of the sleep algorithm.

1. Camera A records the time when the group of people appeared ($t_0 - \delta$) and disappeared ($t_0 + \delta$) in the shooting area.
2. Camera A notifies the IoT PON Manager of the recorded time via ONU, OLT.
3. IoT PON Manager records the time.
4. Camera A records the time when the new group of people appeared ($t_1 - \delta$) and disappeared ($t_1 + \delta$) in the shooting area.
5. Camera A notifies the IoT PON Manager of the recorded time via ONU, OLT.
6. IoT PON Manager records the time and determines the sleep time ($t_1 - t_0 - 2\delta - t_{rise}$) and sleep mode (If sleep time is less than threshold, then TRx sleep is indicated. If not, then deep sleep is indicated).
7. At the time when no one is left in the area of camera B, the IoT PON Manager notifies ONU B of the determined sleep time and sleep mode.
8. ONU B sleeps according to the notified sleep time and sleep mode.
9. If no one appears after ΔT from $t_1 + \delta$, the IoT PON Manager notifies ONU B of the sleep time ($\Delta T - t_{rise}$) and sleep mode.
10. ONU B sleeps according to the notified sleep time and sleep mode.
11. Camera A records the time when the group of people appeared ($t_2 - \delta$) and disappeared ($t_2 + \delta$) in the shooting area.
12. Camera A notifies the IoT PON Manager of the recorded time via ONU, OLT.
13. IoT PON Manager records the time and determines the sleep time ($t_2 - t_1 - 2\delta - \Delta T - t_{rise}$) and sleep mode.
14. At the time the ONU wakes up from sleep, the IoT PON Manager notifies ONU B of the determined sleep time and sleep mode.
15. ONU B sleeps according to the notified sleep time and sleep mode.

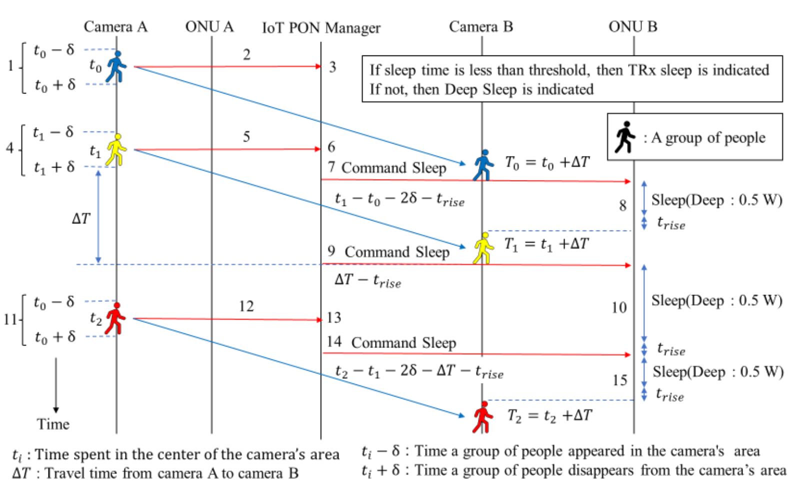

Fig. 6 Sequence diagram of the sleep algorithm

Table 1 Simulation parameters.

Items		Value
Simulation time		1 week
ΔT : Travel time from camera A to camera B		10～80 s
Link rate between ONU and OLT		100 Gbps
ONU power consumption	Diagnostic	13.5 W
	Initialization	10.0 W
	Active	10.0 W
	Sleep	TRx : 6.0 W Deep : 0.5 W
Time	rise	TRx : 0.01 s Deep : 7 s
	fall	TRx : 0.01 s Deep : 0.5 s

4.2 Evaluation by computer simulation

The power consumption of ONUs was evaluated by computer simulation for the proposed method and conventional TRx sleep. Table 1 shows the simulation conditions. The human flow data set was measured by the Ministry of Land, Infrastructure, Transport and Tourism in the Otemachi, Marunouchi, and Yurakucho areas of Tokyo over a one-month period from January 15, 2021 (Friday) to February 14, 2021 (Sunday) [8], of which one week data from January 18, 2021 to January 24, 2021 was used.
Figure 7 shows the change in average power consumption of ONU B with ΔT. Figure 7 shows that power consumption is reduced by about 27% when only TRx sleep, and by about 51% when TRx sleep and deep sleep, compared to the case where without sleep.

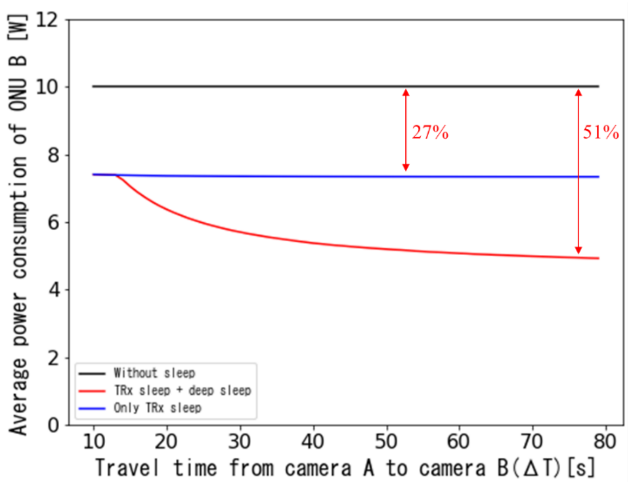

Fig. 7 Change in average power consumption of ONU B due to ΔT.

Figure 8 shows the total energy consumption for a week when #1. both ONUs have no sleep, #2. both ONUs have TRx sleep only, #3. ONU A has TRx sleep, and ONU B has TRx sleep + deep sleep. Figure 8 shows that #2 and #3 reduce energy consumption by 23% and 32%, respectively, compared to #1.

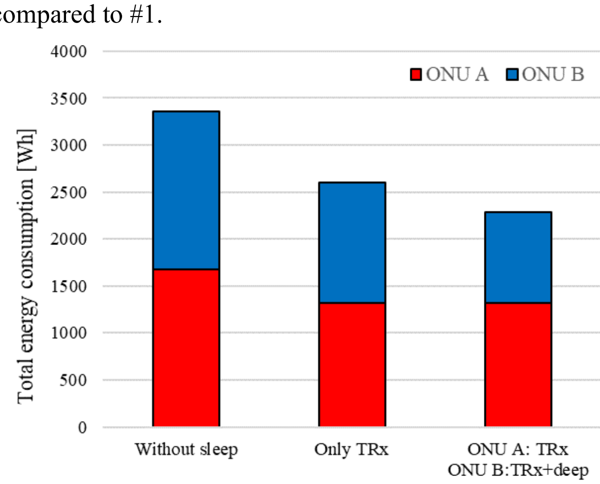

Fig. 8 Total energy consumption per week ($\Delta T = 80$)

5. Conclusion

In order to evaluate the energy consumption by applying the proposed method to a concrete system, which could not be evaluated in [5], the proposed method was applied to a human flow analysis system using surveillance cameras to verify its effectiveness.
Simulation results show that the proposed method reduces the average power consumption of the ONU by up to about 51% compared to the case without sleep. It also reduces total weekly energy consumption by 32%. For simplicity, the simulation was performed with two ONUs, which reduced energy consumption by 32%, but we believe that if the number of ONUs is increased and the size of the network is increased, the proposed method will be even more effective. However, considering the variation in walking speed, the energy consumption reduction effect may be smaller because a larger wake-up time is required.
In the future, we plan to increase the number of ONUs and evaluate the proposed method with more practical parameters.

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