

Synchronizing Adaptive LPI Control Mechanism for Improving Energy Efficiency in Ethernet Switch

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Abstract

Ethernet is one of the most widely-deployed and utilized local-loop networking technology across the world, and IEEE 802.3az working group has confirmed EEE(Energy Efficient Ethernet) standard proposal based on LPI (Low Power Idle) mode. This paper suggests Synchronizing Adaptive LPI Control Mechanism in a bid to improve the energy efficiency between interfacing terminals on Ethernet network and the Ethernet switches. This mechanism determines ON and OFF durations of consecutive cycles based on the measured incoming traffic quantities from the terminals. It keeps transferring cycle information which is the most proximate to the traffic bursting cycles while resting in idle is left to LPI mode by conveying the corresponding information to the switch. This paper conducts the performance evaluations with simulations on Poisson distribution traffic and burst traffic. The result has shown that the suggested mechanism in this paper improves the overall performance by reducing the energy consumption rate compared to the existing mechanism, keeping the average packet delay to the similar state as before.

Keywords: Synchronizing Adaptive LPI mechanism, Energy Efficient Ethernet, Packet coalescing, IEEE 802.3az, Small Ethernet switch

1. Introduction

Internet technology has enjoyed the rapid growth for the past three decades. The number of connected users to internet has jumped from virtually none in the early days of 1980s to 6.8 billions on July 2009. It has naturally led to the explosion of power consumption caused by internet users. With electronic gadgets hooked up with internet marking 150THw of power consumption which is almost four percent of the total consumable power of the United States in 2006, almost 13.5% of power consumption of electronic devices are picked up by network devices like switches or routers [1].

Therefore, greatly increased are the interests of governments and industry organizations on the effective use of energy in Internet and design of energy effective telecommunication system [2]. While Ethernet is one of the most widely- deployed and utilized local-loop networking technology across the world, it is expected that developing energy effective Ethernet protocol can cut 3 TWh in maximum from the yearly energy consumption, which leads to the cost reduction of yearly 400 million US dollars in the Unites States alone and over one billion US dollars of energy costs across the world [3]. IEEE 802.3az working group confirmed EEE (Energy Efficient Ethernet) standard proposal based on LPI (Low Power Idle)

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mode on September 2010, having poured the accumulated efforts toward standardization works in order to enhance the energy efficiency on internet [4]. LPI is a mechanism to protect the energy from unnecessarily being wasted by switching the corresponding Ethernet link status to idle mode when it has no frames to transfer [7, 8]. EEE can reduce the unnecessary energy wastes at the access network environment which represents low load of traffic characteristic, applying not only for Ethernet network interface card, but also for Ethernet switch [5, 6]. This paper suggests Synchronizing Adaptive LPI Control Mechanism in a bid to improve the energy efficiency between interfacing terminals on Ethernet network and the Ethernet switches. This mechanism determines ON and OFF periods of consecutive cycles based on the measured incoming traffic quantities from the terminals within a certain period. It offers adaptive LPI control mechanism in proportional to the traffic load by conducting synchronous data transfer to the switch, upon conveying ON, OFF period information to the switch.

The remainder of the paper is structured as follows. The second chapter discusses the related studies with energy control mechanism of Ethernet switch. The third chapter suggests Synchronizing Adaptive LPI Control Mechanism based on the analysis which addresses the issues of Adaptive PPSE mechanism. This is followed by performance evaluation with simulations at Chapter 4 and finalized with Chapter 5.

2. Related Work

Periodically paused switched Ethernet (PPSE) was previously proposed to enhance energy efficiency in small-sized Ethernet switch [7]. In this mechanism, port of switch enters either ON state or OFF state. When the port goes to ON state, the switch can send packet normally. When OFF state, power of link turns off, so that packet transmission is stopped. Switch is changing state ON and OFF alternatively while operating. Duty cycle is a value that indicates percentage of time the switch spends in ON state. It can be obtained from (equation 1). T_{on} denotes the time that switch spends in ON states during one interval, which is tightly related to energy consumption rate of switch. T_{off} is the time that switch spends in OFF states.

$$D = T_{on} / (T_{on} + T_{off}) \quad (\text{equation 1})$$

This mechanism is a solution to achieve significant energy saving at the expense of a acceptable level of packet delay, only if duty cycle, T_{on} , and T_{off} are set to be proper value, and incoming traffic load is maintained not exceeding certain level. On the other hand, if traffic load increases over certain level, average packet delay also grows substantially high. For this reason, this mechanism is not suitable for transmitting real-time multimedia data properly. To overcome this challenge, adaptive PPSE mechanism was suggested. While the traditional mechanism has a fixed time interval staying in ON or OFF state, the adaptive PPSE considers past traffic load to determine whether to put the switch in ON or OFF state [7]. If pktCount , which denotes the number of packets received while ON state, exceeds threshold, the switch does not enter OFF state, that is, it keeps sending data without going to sleep. Therefore, average packet delay could be maintained under certain value even when there is high traffic load. If the pktCount is under threshold value, it indicates that traffic load is relatively low. In this case, the state of switch would enter OFF state, so that it can save power consumption.

3. Synchronizing Adaptive LPI Control Mechanism

This chapter suggests Synchronizing Adaptive LPI Control Mechanism in a bid to improve the energy efficiency of compact Ethernet switch based on the analysis which addresses the issues of Adaptive PPSE mechanism.

The analysis of the simulated result in previous study [7] on Adaptive PPSE mechanism finds the issues and considerations as follows.

First, Adaptive PPSE determines if all the ports should make the state transition to ON or OFF, based on the status of specific port with the highest traffic load among all the ports dangled from the switch. If the number of received packets(pktCount) at the port of highest traffic load staying at ON state, exceeds the threshold, all the ports would keep ON state although traffic loads of other ports are all very low. It has, therefore, been pointed out that this mechanism has the problem being unable to correctly reflect the characteristics of all the traffics incoming to the switch [8].

Second, energy consumption rate sparks sharp increase when the incoming traffic load in the event of applying the fixed duty cycle exceeds the duty cycle. In particular, the number of transferred packets during most of ON period surpasses the threshold when applying low threshold value such as 1000 bytes. It therefore represents 100% of energy consumption rate because it continues to keep maintaining ON state without transition to OFF state.

The energy reduction effects can be hardly expected in this case although the average packet delay is sharply reduced owing to the packets' swift transfer while all the ports stay at ON state. The energy efficiency increasingly grows when the traffic load exceeds the duty cycle even in the event of applying high threshold value such as 5000 bytes. However, the average packet delay has shown to slightly increase without decreasing despite the prolonged ON state. The energy consumption rate for the ideal case is supposed to linearly increase in proportion to the traffic load.

The average traffic load of access network appears to mark no less than 10% of link capacity, which is relatively lower than the one of core network, but the traffic flow is very changeable and has the burst characteristic [8]. Therefore, it should ensure the energy efficiency, keeping proper average packet delay for each case because traffic load has both higher and lower duration than average.

To alleviate the problems of adaptive PPSE as mentioned above, this study proposes Synchronizing Adaptive LPI Control Mechanism. This mechanism segregates every individual port status of Ethernet switch and network interface card by ON or OFF state. Transmission and reception of packets are called off at OFF state owing to power blocking of most components, whereas normal transmitting and receiving are possible at ON state. The switch leads operation with a certain type of recursive cycle, and this paper defines this operation as a default cycle. The default cycle comprises of duration time (T_{cycle}) with certain constant value (e.g., 100msec). T_{cycle} defines as sum of variables T_{on} , T_{off} as in (equation 2).

$$T_{\text{cycle}} = T_{\text{on}} + T_{\text{off}} \quad (\text{equation 2})$$

T_{off} means a time which a port stays at OFF state while T_{on} represents a time which continues to operate as ON. The switch has n ports comprising of $(n-1)$ interface ports to the access network and one core network interface port. The start time of default cycle is synchronized to correctly coincide with all the links, and T_{on} , T_{off} durations of individual links have distinct values depending upon traffic quantities which come to corresponding links. That is, it resolves the issues of adaptive synchronous coupling mechanism by independently managing ON, OFF state transitions by links based on analysis of traffic characteristic of each link. It can improve energy efficiency due to its more concrete capability to correctly judge

packet quantities to transmit at consecutive default cycles by performing forecasts on incoming traffic characteristic at the terminal node.

If links of switch are activated, LPI control module of access network device (*e.g.*, PC) sets default parameters for a down-link through initialization process. It sets default parameters for an up-link through initialization process of core network device (*e.g.*, router) as the same as above. Here are default parameters, T_{cycle} , T_{on_def} , T_{off_def} and, T_{on_def} means default value of T_{on} , T_{off_def} means default value of T_{off} , respectively. This paper sets T_{cycle} , T_{on_def} , T_{off_def} with 100msec, 5msec, 95msec, respectively.

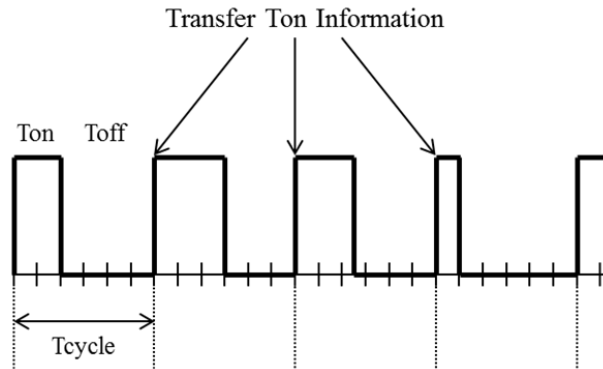


Figure 1. Operational process of default cycle

This mechanism recursively conducts default cycle which is synchronized between switch and terminal device as Figure 1. This study takes an example of up-link traffic to explain the delivery of packets from terminal device to internet core network, even though Ethernet is of full-duplex communication. The first default cycle comprises of T_{on_def} and T_{off_def} , and it then operates every cycle in accordance with value T_{on} , T_{off} which have reflected the traffic status. Figure 2 and 3 have shown the detailed operations between switch and terminal nodes in order to improve the energy efficiency on Ethernet.

Each terminal node evaluates the values T_{on} , T_{off} of default cycle, measuring packet quantities which have been received from application layer during OFF period of previous default cycle and stored at transmission queue. It figures out T_{on} value through calculating the estimated time to transfer the corresponding packets to the switch, considering total quantities of packets, capacity of transmission links and its overhead, and T_{on} value has the value of T_{on_def} multiplied by integer and should not exceed half of default cycle. It derives T_{off} using Eq. 1. The terminal node delivers T_{on} value to switch at the instant the default cycle begins. The switch decides T_{on} period of up-link transmitter at the internet core network based on T_{on} value of total links, once it receives T_{on} value from link.

The terminal node cuts back on energy consumption by stopping transmitting packets and letting corresponding link to switch to LPI mode once it reaches the expiration of T_{on} period, while transmitting the packets loaded on transmission queue to the switch only for T_{on} period. The switch also reduces energy consumption by stopping packet reception and letting corresponding link to switch to LPI mode during T_{off} period once it reaches the expiration of T_{on} period, transmitting the received packets to the internet core network for T_{on} period.

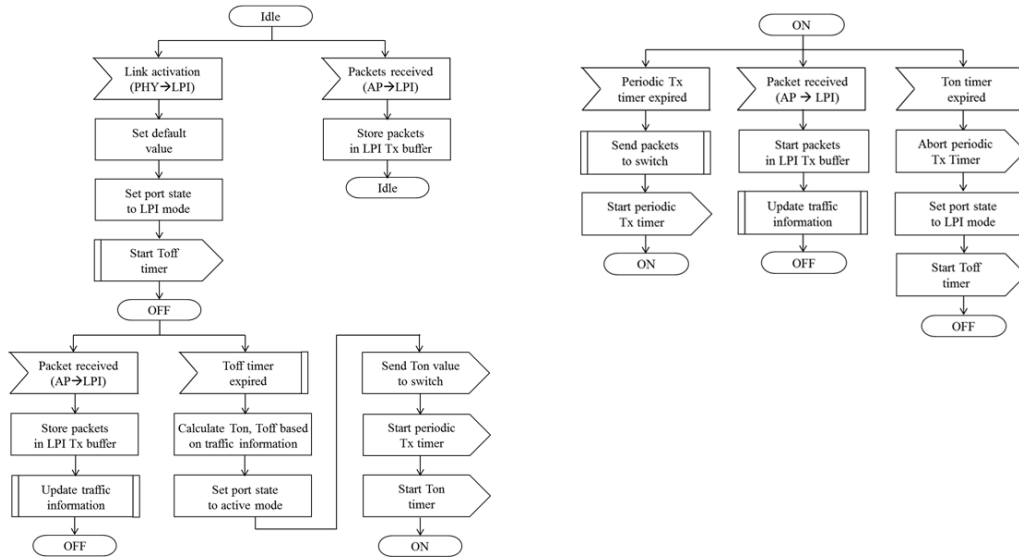


Figure 2. State transition diagram for NIC

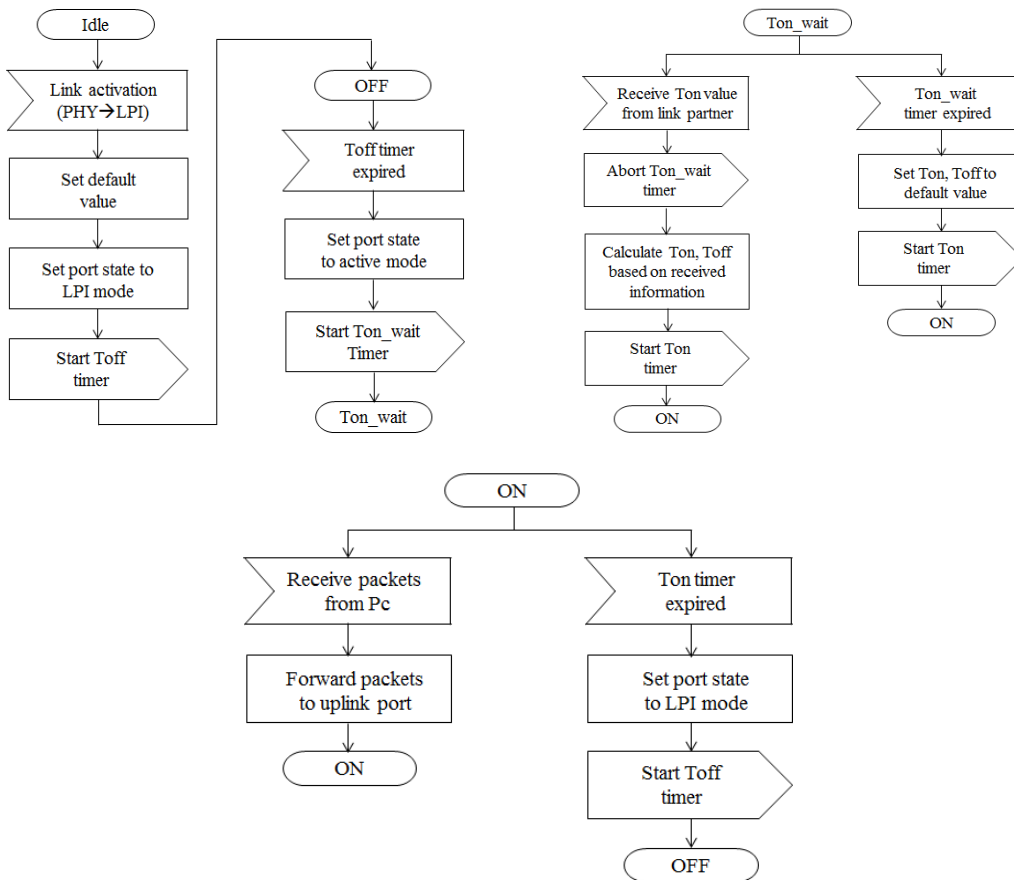


Figure 3. State transition diagram for Switch

4. Performance Evaluation

4.1. Simulation Environment

This study has conducted the performance analysis of suggested mechanism with simulations, using CSIM 20 simulator as a simulation tool [9]. It has performed modeling on traffic gathering from all links connected with switch as a link, applying the same network architecture as the previous study [7]. It has implemented the script determining ON, OFF state transition based on the estimated transmission rate of traffic through checking packet size of gathered link. 10 Gbps has been given to Ethernet link capacity and 100msec for T_{cycle} for performance analysis.

The incoming traffic pattern has been checked for two cases. First, it has implemented the script to determine the average arrival rate according to the set load, assuming that this traffic pattern follows Poisson distribution which has fixed packet with 1500 bytes. Second, it has conducted the performance analysis using traffic trace file created by synthetic traffic generator [10] in order to evaluate the burst characteristic of Ethernet traffic.

This study has measured the energy consumption rate and average packet delay by moving between interval with 1 ~ 30% of its traffic load for the suggested mechanism and Adaptive PPSE mechanism with two threshold, 1000 and 5000 packets.

The energy consumption rate is derived from (equation 3), and it has been assumed to consume 10% of energy at OFF state because minimum level of components are activated, and 100% at ON state because all the components work. A_{on} represents totally operated period at ON state while A_{off} means totally operated period at OFF state while they are being simulated.

$$P_a = 100 \times (A_{on} + 0.1 \times A_{off}) / (A_{on} + A_{off}) \quad (\%) \quad (\text{equation 3})$$

Packet delay means a time needed for packets to come into the switch and be transmitted to destination link. That is, packet delay means a time required to deliver the packets from network interface card of host terminal device to the destination link through switch.

4.2. Simulation Results Analysis for Poisson traffic

Figure 4 has shown the energy consumption rates for cases which encompass ideal case, Adaptive PPSE mechanism, and previously suggested mechanism as a simulation result of traffic with Poisson distribution. The energy consumption rates for the existing switches mark 100% because they always keep ON state regardless of exerting loads. The ideal case in energy efficient Ethernet environment means energy consumption rate varies in linearly proportional to network loads. The result of performance analysis for low and high threshold cases has shown the very similar projection to one of previous study. The reason that this study marks higher energy consumption rate than the previous study was that this study assumed 10% of energy consumption whereas none for the previous study at OFF state.

The suggested mechanism in this study has shown to mark lower energy consumption rate than Adaptive PPSE for most range of traffic loads. In particular, the suggested mechanism has shown to have considerably improved energy efficiency at the range of 6 ~ 10%, average loads of access network, with details that power consumption rate of the suggested mechanism marks 19% whereas the one of the existing mechanism marks 26.5%.

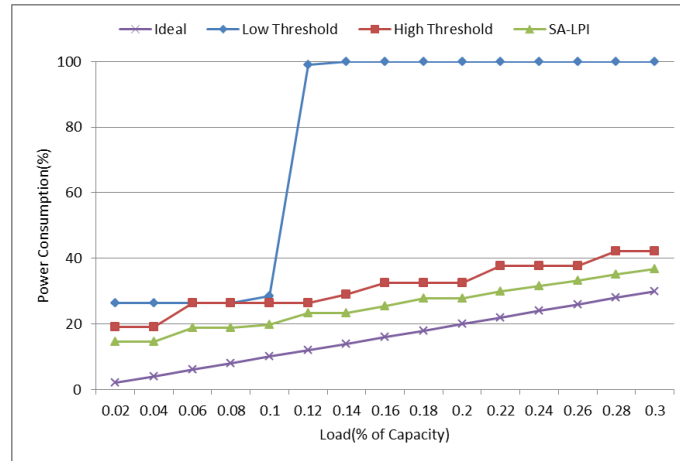


Figure 4. Power Consumption (Poisson Traffic)

Figure 5 illustrates simulation results for average packet delay. In case of low threshold, average delay drops at the lowest level. In particular, in case where traffic load is over 12% of link capacity, link is operated on ON state all the time, which means average delay is almost zero. In case of 6% traffic load, average packet delay of proposed mechanism was recorded 43.1msec, which is lower than that of high threshold case (43.5 msec). Average traffic load of access network is 6-10%. In this range, adaptive threshold mechanism shows higher average packet delay than fixed threshold case. Nevertheless, the difference is not significant. In case over 18%, average delay tends to grow gradually. However, since total packet delay is below 50msec, the delay does not affect service quality even for real-time application.

With the proposed algorithm, average packet delay decreases by tiny amount, compared to traditional algorithm. So, it improves overall performance because it reduces energy consumption rate significantly.

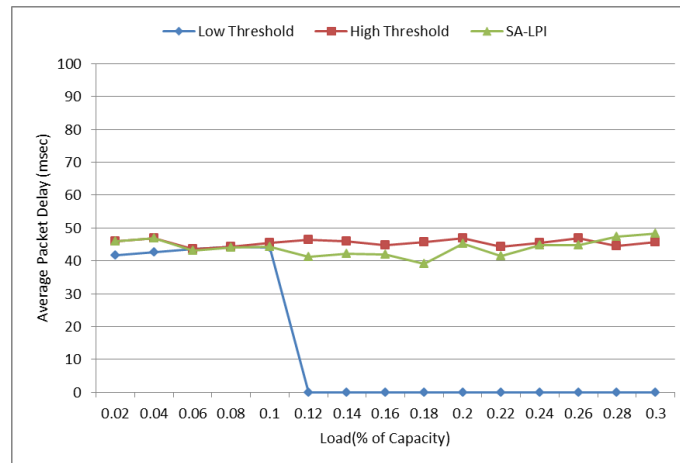


Figure 5. Average Packet Delay (Poisson Traffic)

4.3. Simulation Results Analysis for Burst traffic

The same parameters as the previous study [7] have been set for synthetic packet generator in a bid to create the burst traffic trace. Figure 6 represents the simulated result for burst

traffic. The performance analysis for Adaptive PPSE has shown the very similar result to the one of previous study as the same as Poisson traffic.

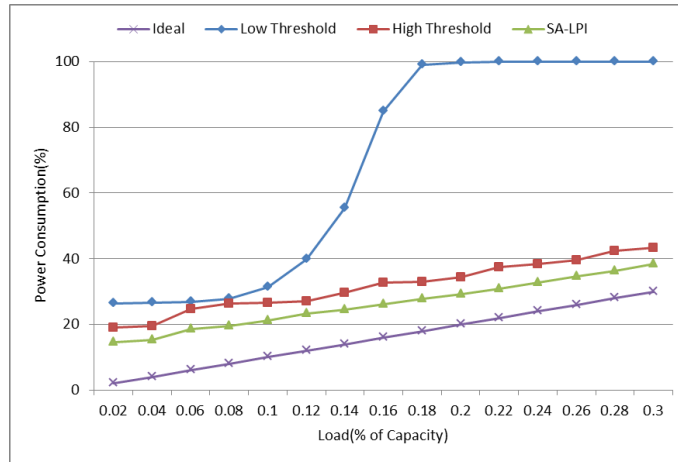


Figure 6. Power Consumption (Burst Traffic)

The suggested mechanism in this study has represented to mark lower energy consumption rate than the operating case with fixed threshold for most range of traffic loads. In particular, the suggested mechanism has shown to have considerably improved energy efficiency at the range of 6 ~ 10%, average loads of access network, with details that power consumption rate of the suggested mechanism marks 19.5% whereas the one of the existing mechanism marks 27.1%.

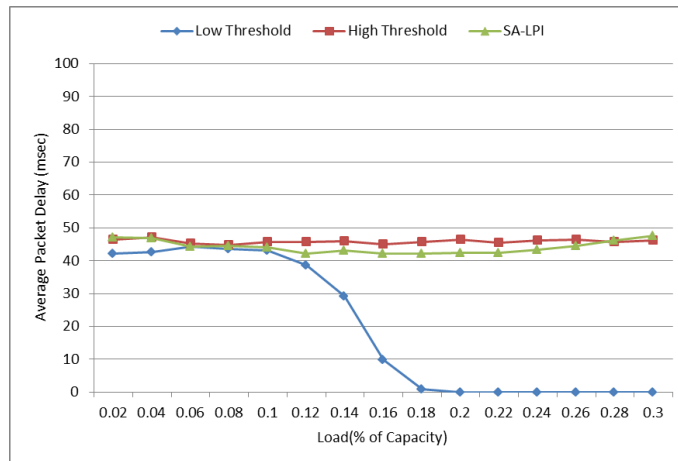


Figure 7. Average Packet Delay (Burst Traffic)

Figure 7 represents the simulated result of average packet delay. The case with low threshold has shown to mark the lowest average packet delay, and especially the case whose traffic load accounts for more than 18% of link capacity has represented to mark nearly zero average packet delay because the links always operate at ON state. With traffic load being no more than 5%, the suggested mechanism has shown to have average packet delay of 44msec which is lower than the case with high threshold having the average packet delay of 45.2msec. The suggested mechanism shows to mark higher average packet delay than the

case with fixed threshold for range of 6 ~ 10%, average load of access network, making its difference so marginal. However, the analysis points out that the total packet delay will not make much impact on ensuring the service quality of real-time applications because it is no more than 45msec.

5. Conclusion

The energy consumption of network equipment marks the trend of high rise with increasing transmission rate of access network devices like Ethernet switch, network interface card, including the recent internet core backbone network equipment. That's why active researches on communication protocols have been going on to reduce the energy consumption of these network equipment. This paper has suggested Synchronizing Adaptive LPI Control Mechanism to improve the energy efficiency between Ethernet network interface devices and Ethernet switches. This study determines the subsequent ON and OFF periods, judging from the traffic quantities incoming from terminal devices within the certain periods. Synchronous data transmission is made between terminal devices and the switch by delivering ON, OFF periods information to the switch. Therefore, this mechanism can address the issues that the existing adaptive synchronous coupling mechanism embraces because the switch performs LPI mode through adapting to the traffic loads. The analysis has shown that the suggested mechanism in this paper enhances the overall performance by reducing the energy consumption rate compared to the existing mechanism, keeping the similar average packet delay to the existing mechanism.

The performance analysis has been going on for the environment that each link has different input traffic characteristic. Moreover, the additional study will be going on with analysis on how suggested mechanism will impact on TCP congestion control.

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