# Dynamic Acknowledgement for the Energy Efficiency of the High-rate Wireless PAN

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## ABSTRACT

The emerging high-rate wireless personal area network (WPAN) technology, currently being developed by IEEE 802.15.3 task group, will provide a very high-speed and short-range transmission capability with QoS provisions. Its standard defines three acknowledgement (ACK) types at the MAC layer: no ACK, immediate ACK, and delayed ACK. Those ACK policies, however, do not consider the status of the transmission link, and it may cause overhead by unnecessary ACK frames or fail to maintain the MAC error control. In this paper, we propose an efficient way of MAC acknowledgement which dynamically adjusts the ACK policy according to the link status: A poor link quality causes frequent ACK frames and a good link reduces the number of ACKs. Extensive simulation results show that our method significantly improves the energy efficiency of the WPAN than the standard way of acknowledgement.

***Keywords—****WPAN, MAC, ACK, Energy-efficient, link qulity*

## 1. INTRODUCTION

Recently, extensive research efforts have been devoted to improve the performance of wireless personal area networks, which enable short-range wireless ad-hoc connectivity. As the short-range applications in the near future are expected to require high-quality video and audio streaming and multi-MByte file transfers, a high-rate WPAN standard has been developed by the IEEE 802.15.3 task group in 2003[1]. The standard, commonly referred to as *high-rate WPAN*, provides the data rate currently up to 55 Mbps, and the rate will be increased to several hundreds Mbps shortly. Such a rate is suitable for the wireless transfer of huge multimedia files, streaming video and audio in a very short time.

IEEE 802.15.3 High-rate WPAN consists of several devices (DEVs), and one DEV among them is required to assume the role of the piconet coordinator (PNC) of the piconet. If a DEV needs channel time on a regular basis, it asks the PNC for isochronous channel time. The PNC, upon receiving the channel time request command, allocates channel time for the DEV if the requested channel time is available[6].

WPAN will be used for portable devices such as PDA, notebook, and home appliances, which in most cases require a significant processing power. Most portable devices of WPAN are likely to be battery powered, and its capacity is limited due to the size of wireless stations. Thus, the energy-efficiency is one of the most important aspects to be considered. Recently, many researchers have studied efficient way of power management for the mobile devices, developing energy-efficient communication protocols while maintaining their performances. Especially, the power control and management mechanisms for the IEEE 802.11 WLAN are extensively studied and suggested[2-5]. The problem of enhancing energy-efficiency of the high-rate WPAN, however, has rarely been studied so far, since the main concern with the WPAN has been not the energy but providing QoS.

In this paper, we propose a simple ACK policy for the high-rate WPAN in order to achieve energy efficiency while maintaining its QoS. Peer DEVs control the frequency of acknowledgement according to the status of communication link. When the link is poor, they increase the number of ACK frames in order to maintain the service quality and retransmit the error frames. On the other hand, they reduce the control overhead by lowering the frequency of ACK when the link quality is good. This paper is organized as follows: In the next chapter, we briefly describe the functionality, ACK policies, and the pattern of energy consumption in the high-rate WPAN. In chapter 3, we proposed our Dynamic ACK policy for the high-rate WPAN. Chapter 4 describes the simulation model and presents how our approach outperforms the standard method, and finally chapter 5 concludes this paper.

## 2. PRELIMINARIES

### 2.1 MAC Functionality of the High-rate WPAN

The IEEE 802.15.3 is a standard for high-rate (55Mbps or standard will provide for low power, low cost solutions

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addressing the needs of portable consumer digital images and multimedia applications[7]. Figure 1 shows several components of an IEEE 802.15.3 piconet. The piconet is a wireless ad hoc network that is distinguished from other types of networks by it short range and centralized form. The WPAN is based on a centralized and connection-oriented networking topology. At initialization, one node (DEV) will be required to assume the role of the coordinator or scheduler of the WPAN. It calls the PNC (piconet coordinator). In addition, the PNC will also allocate network resource, perform admission control, synchronize timing in the piconet, according to a pre-defined set of QoS policies and manage power save mode.

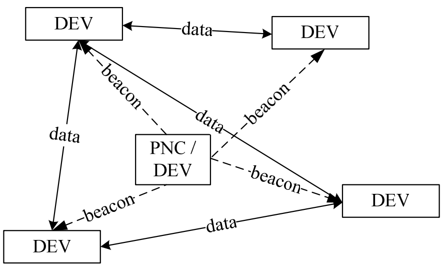


Figure 1 : DEVs and PNCs of a high-rate WPAN

The high-rate WPAN time-slotted superframe structure is comprised of three main sections. In the first period, the PNC transmits a beacon frame and DEVs receives the beacon frame and synchronize their timer with PNC's timer in piconet. The beacon frame is used to carry control information to the entire piconet and the allocation of channel time. In the second period, optional CAP (contention access period) is mainly used to association request/response, channel time request/response and also possible exchanging of asynchronous traffic using CSMA/CA (carrier sense multiple access / collision avoidance). In the third period, CTAP (channel time allocation period) is composed of Management CTAs and CTAs, and this period is used for isochronous streams and asynchronous data transfer. The CTAP adopts a standard TDMA, and allocated guaranteed time slots each DEV. All transmission opportunities during the CTAP begin at predefined times, is relative to the actual beacon transmission time, and extends for predefined maximum durations, is communicated in advance from the PNC to the respective devices using the traffic mapping information element conveyed by the beacon. During its scheduled CTA, a DEV may send a number of arbitrary data frames with the restriction that aggregate duration of these transmissions which are not exceed the scheduled duration limit.

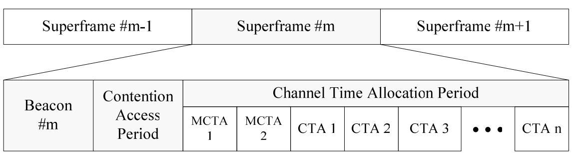


Figure 2 : IEEE 802.15.3 piconet superframe

## 2.2 ACK policies of the IEEE 802.15.3

There are three kinds of ACK policies in the IEEE 802.15.3 WPAN. Each ACK policy has a different characteristic. According to ACK policy, energy efficiency and guarantee of QoS are difference. Generally, there are trade off energy efficiency and guarantee of QoS. In this subsection, we describe the ACK policies in the IEEE 802.15.3 WPAN standard.

The first, Immediate-ACK (Imm-ACK) policy acknowledges every data frame. This policy has a feature which is guarantees QoS of traffic. The receiver DEV send an ACK packet to the sender DEV when a data frame had received and after a short interframe space (SIFS). The sender DEV received this ACK frame; it will be transmitting the next data frame. If sender DEV did not received this ACK frame, than it retransmit a data frame after ACK timeout. The interframe space of retransmission is about 28us. This ACK policy has good property for the QoS of traffic and poor performance for energy efficiency. DEVs would frequently transit their status between TX and RX. So DEV would consume their battery resource. Immediate-ACK policy is suitable in poor wireless link.

The second ACK policy is No-ACK policy which has no retransmission, DEV status transition and ACK timeout in No-ACK policy. Generally, this ACK policy used real time traffic like a video and audio stream. Sender DEV transmits irrelevantly data frames after a SIFS whether receiver DEV received correctly pervious data frames or error occurred. Even if this No-ACK policy saving energy resource owing to no ACK frame, the QoS of traffic does not guarantee.

In the third method, sender DEV requests the ACK frame to receiver DEV occasionally. This Delayed-ACK (Dly-ACK) policy shall be used only for directed stream data frame, i.e. isochronous connections, where the Dly-ACK policy has been set up with negotiation between the sender and receiver DEVs. The use of Dly-ACK policy is confined method to real time traffic that request the channel time

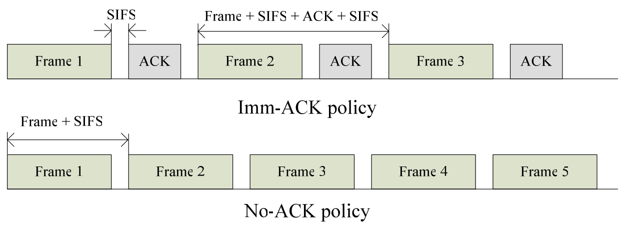


Figure 3 : Imm-ACK and No-ACK policy

There are merits and demerits to each ACK policy. In this paper, we propose the Dynamic-ACK policy which combine QoS guarantee and energy efficiency that is advantage of Imm-ACK and No-ACK policy. Dynamic-ACK policy dynamically adjusts the ACK according to the link quality. A poor wireless link quality causes frequent ACK frames and good link reduces the number of ACK frames.

## 2.3 Energy consumption in the WPAN

In this subsection we describe the energy consumption in the IEEE 802.15.3 WPAN and consider to the method that reduce the number of MAC frames in order to save energy resource. We explain about type of MAC frames. There are 4 kinds of MAC frames in the WPAN. The first, beacon frame is generated by the PNC station and it broadcasted all of DEV that appertain to PNC's transmission range. This MAC frame has many functions that are piconet management, DEV synchronization, channel time allocation information, DEV association and disassociation. This beacon frame contains the important information and transmitted when the superframe starting. The second MAC frame is MAC control frame that is used for piconet management such channel time assignment, association, authentication, security, channel probe and PNC handover. This control frame has important information for the piconet management like a beacon frame too. The third frame type is data frame that has information for receiver DEV. The last frame type is ACK frame. This ACK frame is used for confirmation of reliable transmission. If wireless channel quality is good, it is applied by overhead.

We measured the energy consumption each MAC frame in IEEE 802.15.3 WPAN. We construct simple topology and transmit regular traffic. There are two stations in the piconet. One is PNC another is DEV station. DEV send data traffic to PNC and PNC send ACK frame and beacon frame frequently. And we used to the Imm-ACK policy. But we except the control MAC frame because it is not regular transmission and transmit occasionally. Below table 1 shows the results of simulation.

Table 1 : Consumed energy in the piconet

| | PNC | DEV | Total | Percentage |
|---|---|---|---|---|
| Beacon | 0.281417 J | 0.140708 J | 0.422125 J | 6.514464 % |
| Data | 1.731797 J | 3.463536 J | 5.195333 J | 80.17722 % |
| ACK | 0.574906 J | 0.287448 J | 0.862354 J | 13.30832 % |
| Total | 2.58812 J | 3.891692 J | 6.479812 J | 100 % |

We observe energy consumption that is used for ACK frame transmission. It is about 13.3% of whole consumption energy in the piconet. The beacon frame in these MAC frames is certainly necessary frame for piconet management and DEV synchronization. Data frames that include information for receiver are important similarly. We could not reduce the number of these frames. So we take an interest in economization of the number of ACK frames for energy saving in this environment. If it reduces the number of ACK frames, DEV not only save its energy resource but also to transmit a data take a place of transmission of ACK frame. So DEVs may gain the aggregate throughput using the channel time efficiently. If DEVs reduce the number of ACK frames simply, problem may happen which it do not retransmission in well-timed. This situation is connected that do not ensure the QoS of traffic. We need to the ACK policy that is possible both the QoS guarantee and energy saving. In the next section, we propose the Dynamic-ACK policy that is suitable for these conditions.

## 3. DYNAMIC-ACK POLICY

It was observed in the preceding chapter that DEVs transmit the ACK frames and consume the energy resource in the WPAN. In this chapter, we propose an ACK policy that can transmit with energy efficiency and improvement of performance. The Dynamic-ACK(Dyc-ACK) is the method that economize the battery resource using each DEV reduce the ACK frame depend on wireless link quality. Wireless link quality is measured according to status that is confirmation whether received ACK frame or did not for preceding data frame. If DEV distinguishes that link is good, it send two data frames at once. The receiver DEV is responded by one ACK frame for the transmitted two data frame. After the sender DEV receives this ACK frame, it sends 4 data frames at once. The sender DEV increases the number of data frame that send at once to maximum window size link a TCP transmission. In below figure 4, left figure shows that transmission window increases.

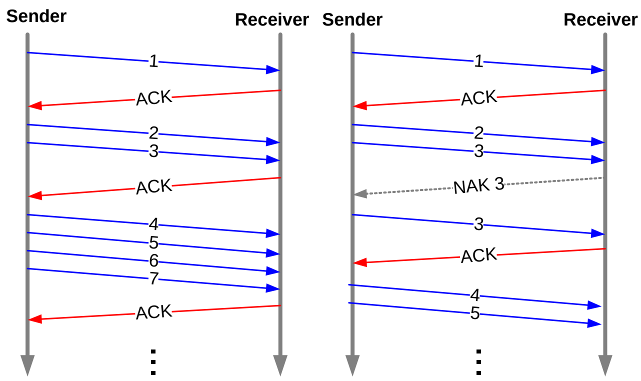


Figure 4 : Increasing of window size in Dynamic-ACK

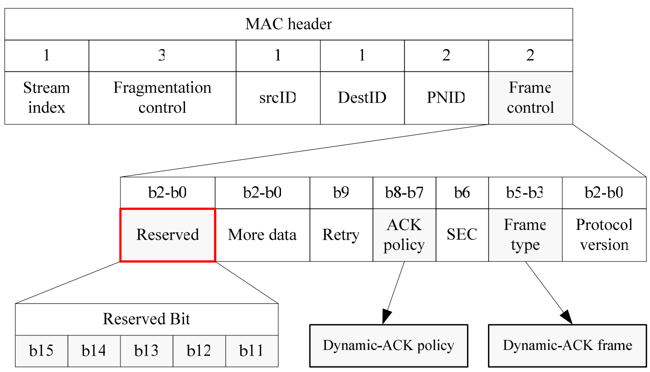


Figure 5 : Modified MAC frame format

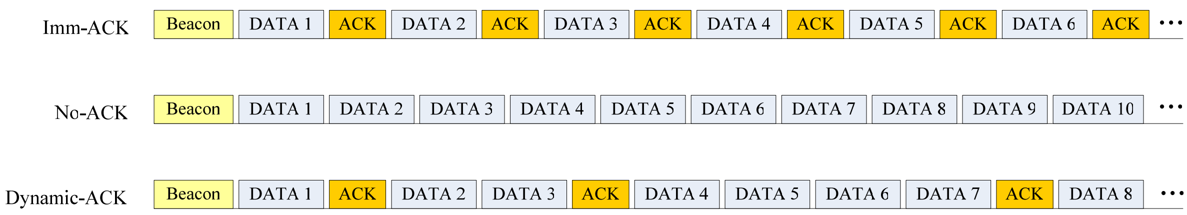


Figure 6 : Operation of three type of ACK policy

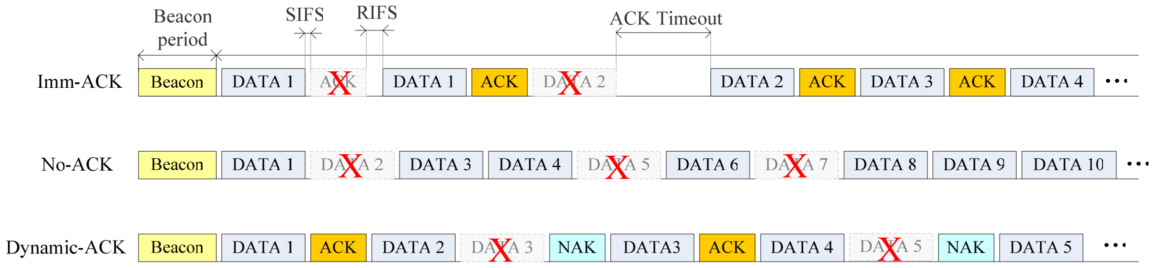


Figure 7 : Operation of three type of ACK policy in error link

If transmission error occurs when DEV sent several data frames. Receiver DEV response by negative acknowledge (NAK) that include the frame sequence number of error data. When sender DEV received NAK frame, it retransmit the data frame such as the sequence number that is included to the NAK frame. When the sender DEV received NAK frame, it discriminates that link quality is bad. And it decreases the window size by half. In below right figure, transmission error is occurs at the third data frame and the receiver DEV sends a NAK frame. Next round sender DEV decreases the window size by half and retransmits the third data frame.

We can reduce the number of ACK frames using this Dynamic-ACK policy. Dynamic-ACK policy can reduce the energy consumption according to that DEV dynamically adjust suitable window size using link quality. We modify the MAC header format that defines the IEEE 802.15.3 standard document. Below figure 5 shows the MAC header format and fields in order to use the Dynamic-ACK policy. Frame control field in MAC header include many control information for favorable transmission. Frame type in Frame control field shows a kind of MAC frame. We additional defined the Dynamic-ACK frame in this field. And we also defined that is Dynamic-ACK policy in ACK policy field. When the DEVs use the proposed ACK policy, DEVs need the field in order to distinguish the ACK frame from the NAK frame. So we used to Reserved field for that inform to sender DEV whether error occurred or not. There are five reserved bits (b11~b15) in the MAC header. The b11 bit shows that whether error occurs or not. The bits that remained from b12 to b15 use to inform the frame sequence number of error frame to sender DEV. When the sender DEV received the NAK frame with this frame sequence number, it would retransmit the frame equivalent to that sequence number. And the pair of DEVs negotiates the maximum window size before the transmission starting.

In the previous chapter, we described the ACK policies that defined the IEEE 802.15.3 WPAN standard. Figure 6 compares the operation of Dynamic-ACK policy with the standard ACK-policies. There is no error in wireless link like a below left figure. If wireless channel was ideal, Imm-ACK policy would have low of efficiency. Whenever a receiver DEV sends an ACK frame, it spends on battery life and channel time. Hence ACK frames are overhead in ideal or good link quality. In case of No-ACK policy, there is no ACK frame, that is, there is no waste energy resource or channel waste. No-ACK policy is more efficient than Imm-ACK policy in fully ideal channel. In case compare with Dynamic-ACK policy, proposed ACK policy shows the performance of middle between Imm-ACK and No-ACK policy in clear link environment.

But there is error frames like a below right figure 6, each ACK policy shows other performance. In case of No-ACK policy, sender DEV can not receive any ACK frames absolutely. So, sender does not retransmission the frame that error occurs, and the QoS and aggregate throughput of traffic might drop. Consumption of energy is fixed regardless of error being. Although Imm-ACK policy could retransmit data frame that error occurs, it is decline of aggregate throughput and many energy consumption for ACK transmission.

Generally, wireless link has different quality according to change of time, neighbor DEVs or other cause. DEVs need the mechanism that dynamically changes the operation in wireless environment. Our Dynamic-ACK policy is the most suitable ACK policy in fluctuating wireless channel. In pour link, this ACK policy transmits the ACK frame similar with Imm-ACK that guaranteed the QoS of traffic. And DEVs save the energy resource in Dynamic-ACK policy due to . In the following chapter, we prove our proposed mechanism's performance that compare with standard ACK policies using simulation.

## 4. SIMULATIONS

### 4.1 Simulation Model

Simulations have been carried out to analyze the effect of our proposed ACK policy compared to the standard ACK policies. In the simulation study we focused our attention on the evaluation and comparison of performance of two schemes in consumption of energy, throughput, and energy efficiency. We have used ns-2 with the CMU wireless extensions[9] and 802.15.3 basic MAC modules developed by Intel[10-11].

Table 1 shows the parameters we have used for the simulations. In addition we assume that the DEVs do not move during the simulation and do not consume the energy in idle state. We have chosen the channel bit rate as 100 Mbps in order to provide enough speed of transmission. Note that, although the maximum channel bit rate of current standard of 802.15.3 PHY is 55 Mbps, 802.15 TG3a considers UWB as a strong candidate for the high rate alternative PHY, whose target bit rate is 480 Mbps or above. And TX and RX power set to 1.6W and 1.2W respectively that is based on the data in AT&T Wavelan PCMCIA. We excluded the energy that consume during the idle time of interface card for measurement of actually consumption energy.

Table 2 : Simulation parameters

| | |
|---|---|
| Channel bit rate | 100Mbps |
| Number of flows | 1 flow (2 nodes) |
| CTA duration | 2000 $\mu s$ |
| Initail energy | 10 J |
| TX Power | 1.6 W |
| RX Power | 1.2 W |
| ACK policies | Imm, No, Dynamic |

### 4.2 Results and Discussions

In this sub-chapter, we analyze simulation results and explain the cause. We measured the remainder of energy and aggregate throughput. Also we compute the energy efficiency that based on both consumed energy and throughput.

Below figure 8 shows the results that measurement of consumed energy for each ACK policy. We measured amount of energy every 0.5sec which is sum of sender and receiver. At beginning of simulations, we measured 20J, and it decreases respectively different according as time passes. There are three kinds of ACK policies that are beacon, data and ACK frame. In the result, Imm-ACK policy consumed the most energy because it transmitted more ACK frames than No-ACK and Dynamic-ACK policy. When it is no error in the link, No-ACK policy shows the fewest energy waste. Our proposed ACK policy shows the similar energy waste with No-ACK policy.

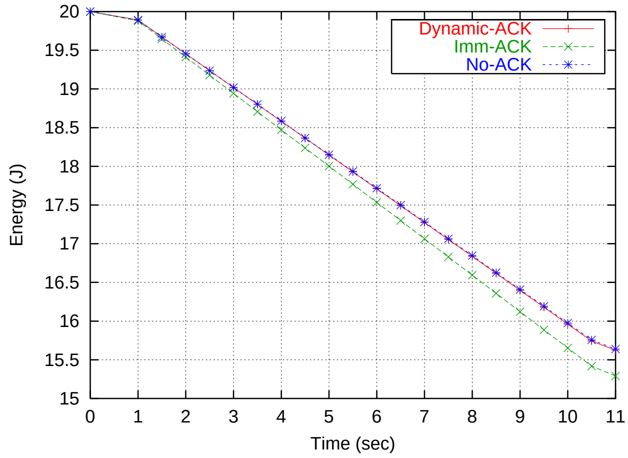


Figure 8 : Energy consumption of each ACK policy

Figure 9 shows the aggregate throughput that measured at the end of simulation. Each ACK policies show the some difference in throughput also. Using Dynamic ACK policy shows better result than Imm-ACK policy. Imm-ACK policy wastes the channel time during the time of ACK frame transmission. Dynamic-ACK policy using this period for data frames transmission in place of ACK frame. So, Dynamic-ACK transmitted more data frame. Dynamic-ACK shows similar performance almost owing to ideal link if compare with No-ACK policy. If we apply error, the performance of No-ACK policy would decrease markedly.

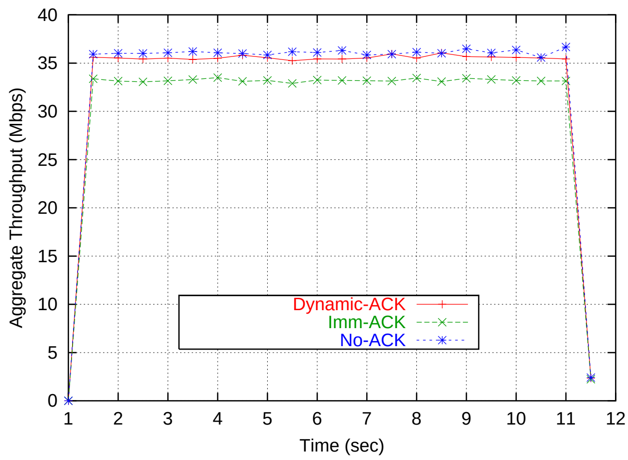


Figure 9 : Aggregate throughput of each ACK policy

We can compute the energy-efficiency from results that is consumed energy and aggregate throughput. The energy-efficiency means degree of efficient energy consumption. This factor is not absolute value but relative value. We can compare each ACK policy according to this factor. This factor is calculated as following. This $\eta$ mean the amount of data frames using same energy. The unit of x-axis is $Mb/s \cdot J$. If there is $1\, Mb/s \cdot J$, DEV transmit 1Mbyte data frame using the battery power of $1\, J$ during 1 second. For example, 160 $Mb/s \cdot J$ mean transmission of 160Mbyte data using 1J during 1second.

$$\eta = \frac{\text{Aggregate Throghtput}}{\text{Consumed Energy}} (Mb/s \cdot J) \qquad (1)$$

In the figure 10, x-axis shows the type of ACK policy and y-axis means the energy-efficiency. The Imm-ACK policy shows the lowest efficiency owing to unnecessary transmission of ACK frames. Transmission of ACK frames waste the assigned channel time and limited battery resource. Although the best result measured In case of No-ACK policy, but it is simulation that executed in impractical environment like an ideal wireless channel. Our proposed method shows similar result almost with No-ACK policy. If it was error in the wireless channel, proposed method might show the best result compare with standard ACK policies.

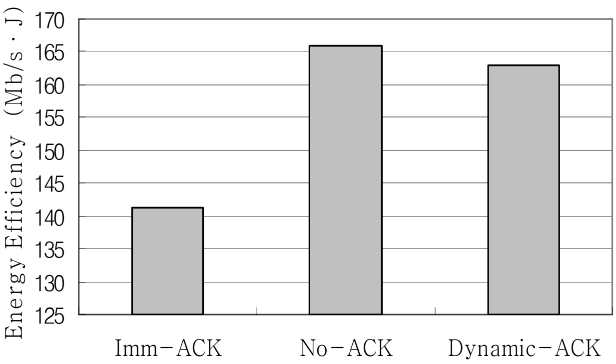


Figure 10 : Energy efficiency of each ACK policy

## 5. CONCLUSION

In this paper, we propose a simple ACK policy scheme for IEEE 802.15.3 WPAN in order to achieve energy saving and maintenance of QoS. Proposed Dynamic-ACK policy enable reductions of the energy consumption according to that DEV dynamically adjust suitable window size using link quality. DEVs confirm the link quality whether they received ACK frame or not. A bad link quality causes frequent ACK frames, namely proposed ACK policy similarly operates to Imm-ACK policy. And a good link reduces the number of ACK frames. In this case, proposed scheme shows the performance similar to the No-ACK policy. So, DEVs could communicate not only guarantee of the QoS but also energy saving. We could prove the improvement of performance according to simulation results.

In our results, we did not simulate that channel error, mobility, and incensement of traffic. Our future works are addition of channel error in the standard ACK policies and our proposed ACK policy. We could confirm the performance of ACK policies using this error model. Each ACK policy has different frequency of ACK transmission and retransmission pattern. We will analyze the performance of proposed ACK policy in various environments. And we are going on additional simulations which are extension of DEV mobility and incensement of the number of flows.

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