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# MA : Multiple Acknowledgement Mechanism for UWSN (UnderWater Sensor Network)

Soo-Young Shin[†], Seung-Joo, Lee[††], Soo-Hyun Park[†††]

## ABSTRACT

With the advent of the ubiquitous technology age, the progress of network technology has enabled a robust sensor communication, not just in cities, but also in poor surroundings such as deserts, polar regions, or underwater environments. In this paper, we propose a Multiple Acknowledgement (MA) technique to replace the conventional Automatic Repeat reQuest (ARQ) technique. The MA mechanism is to send an Ack to many receivers simultaneously. The CH (master, coordinator) of the unit cluster broadcasts a Beacon frame where Ack information of the previously transmitted data is included. This technique can reduce the number of transmissions and overhead significantly. The proposed technique is a scheme improving the efficiency of an underwater sensor network where the uplink data transmission is the mainstream. The Performance of the ARQ, Block Ack, Pervasive Block Ack and the proposed method were compared with one another and analyzed. The proposed method showed significant performance improvement as compared with the ARQ, BA, and PBA in its channel efficiency.

**Key words:** UnderWater Sensor Network (UWSN), Medium Access Control (MAC), ARQ, Multiple Acknowledgement (MA)

## 1. INTRODUCTION

In the last couple of years, worldwide research and development on an UnderWater Sensor Network (UWSN) has been conducted. Various methods for overcoming its inferior transmission environment have been attempted. Studies on modems, filters, and multiple communication protocols for acoustic communication have been started [1]. The majority of underwater acoustic channels are characterized by a poor quality physical link caused by time-varying multi-path propagation and motion-induced Doppler distortion. As a result, the Bit Error Rate (BER) of an acoustic link is often high. Moreover, the BER can vary with time as the propagation conditions change. Errors in the received bit stream are thus inevitable. To establish reliable communication over such a channel, an ARQ procedure must be in place where erroneously received data packets are retransmitted [2].

The ARQ is a technique for reliable transmission. With the ARQ, if there is a transmission failure, the failure information is generated for the failed frame retransmission. In the case of the TCP/IP network protocol, this technique can be applied to end-to-end retransmission and in the case of Medium Access Control (MAC) of the lower layer (data link layer of OSI Model), it can be

※ Corresponding Author : Soo-Hyun Park, Address : (136-702) 861-1, Jeongneung-dong, Seongbuk-gu, Seoul, Korea, TEL : +82-2-910-4559, FAX : +82-2-910-4017, E-mail : shpark21@kookmin.ac.kr
Receipt date : Sep. 22, 2009, Revision date : Nov. 30, 2009
Approval date : Dec. 30, 2009
[†] School of Business IT, Kookmin University
(E-mail : sy-shin@kookmin.ac.kr)
[††] Department of Information and Communication Engineering of Seoil University
(E-mail : aventino@seoil.ac.kr)
[†††] School of Business IT, Kookmin University
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applied to retransmission in a link-by-link and one hop. Since the portion of overhead of the MAC stage, such as Beacon, Sync, Contention period, Request to Send (RTS),Clear to Send (CTS), Ack, etc., is rather large, we know that a high percentage of network performance is wasted in a MAC [3]. Among the sources of waste in MAC, Acknowledgement (Ack), or No-Acknowledgement (Nack), which is generated whenever data transmission has occurred. This Ack or Nack is the main source of overhead. Especially, in a cluster-based sensor network containing a large number of nodes, the information collected by each sensor node is collected by Cluster Head (CH) or Master and the collected information is transmitted to an external network through a GateWay (GW). Therefore, we require a study on the energy-efficient retransmission technique [4,5].

In this paper, we propose a new technique for transmitting Ack or Nack at once all together, not transmitting it every time. CH, which manages data collection and scheduling in a cluster, collects data through uplink transmission and broadcasts Ack/Nack, which is the information whether there are data errors or not, within a Beacon frame. Since Ack/Nack has information of the existence of errors only, it is not necessary to worry about security problems. In addition, the complexity of a network caused by frequent data transmission and reception can be very much simplified.

In Section 2, we describe the concepts of underwater sensor network and MAC configuration. In Section 3, we discuss conventional ARQ technique and the proposed multiple acknowledgement (MA) technique. Mathematical model and numerical simulation results are presented Section 4 and conclusions in Section 5.

## 2. UNDERWATER SENSOR NETWORK AND MAC

In an underwater sensor network, the measured data, such as temperature, salinity, dissolved oxygen, various chemical concentrations etc, are transmitted periodically. In addition, an underwater acoustic sensor network has obstructions such as a narrow bandwidth resulting from low-frequency channels, propagation delay, various noise, multi-path, and so on. As long as any epoch-making transmission media and bandwidth improvement are not provided, an underwater sensor network shall be Low Rate Low Power (LRLP) oriented [6].

Figure 1 shows a unit cluster and CH. In the figure, the CH makes synchronization of its network and gathers information transmitted by sensor nodes (S1~S5) using an effective scheduling method. After gathering the information, the CH transmits the information to the gateway or Base Station (BS). In addition, the CH can conduct a re-configuration of the network, confusion control, downlink transmission and communication with other CHs. GW and BS can be an Autonomous Underwater Vehicle (AUV). We assume that the GW, CH, and sensor nodes are all in a heterogeneous condition [4].

In an underwater sensor network environment, there are many obstructions of communication such as long transmission delays, high error rates, narrow bandwidth, attenuation, multi-paths caused by media characteristics, artificial noise sources,

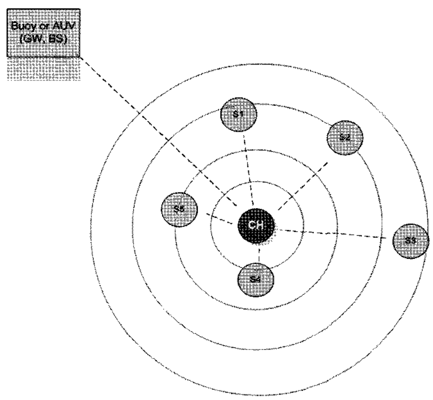


Fig. 1. The Clustered Topology of an Underwater Sensor Network

distortions caused by movement of underwater creatures, tidal currents ,and so on. Therefore, a communication protocol coping with those obstructions and making communication efficient is necessary. The following are conditions we established for our underwater MAC protocol study [6].

- Minimization of the transmission overhead: RTS, CTS, Carrier Sensing(CS), Ack, initiation process(configuring), periodic Beacon broadcasting procedure, and Guard time are overhead that should be minimized.

- Minimization of the frame overhead: A minimized and suitable MAC header and footer should be configured and utilized.

- Optimization of the number of transmissions: This is closely related to transmission overhead. In addition, the number of transmissions should be optimized using an aggregation technique while maintaining the frame length at a suitable level.

- Minimization of the number of retransmission: Retransmission should be minimized by correcting the errors without retransmission as much as possible by analyzing the transmitted data using self error detection and a correction technique such as Cyclic Redundancy Check (CRC).

- Maintenance of the frame length in an optimum status: If the frame length is reduced then the effectiveness of transmission is decreased and vice versa. However, as the length of the frame increases, the error rate increases also. In connection with the channel status and transmission environments, the technique is required to maintain the length of the frame payload in an optimum state.

# 3. MULTIPLE ACKNOWLEDGEMENT MECHANISM

## 3.1 Conventional ARQ and BA

The ARQ mechanism was developed for retransmission in case of a transmission error [3]. The Stop-and-Wait (S&W) ARQ technique is a basic ARQ. With the ARQ, after the sender transmits its data frame, the sender waits an Ack which is a notifying signal of successful reception by the receiver. If there is no Ack message during the pre-defined Ack reception section, or if a Nack is received, the sender will start the procedure of retransmission of the frame (Figure 2). If an Ack is received, the sender will start to transmit the next frame. In this way, the S&W ARQ technique has advantages of simplicity and reliability of data transmission however it has disadvantages of lower effective links in the case of larger packets resulting from a high transmission delay rate as well. In addition, the next data frame cannot be transmitted until receiving an Ack/Nack or a time-out reached. Go-Back-N, Selective Repeat technique, Hybrid ARQ and other techniques have been introduced [7].

A study for increasing transmission effectiveness of an ARQ and its practical implementation has been conducted simultaneously. In the IEEE 802.11x standard, the Block Ack (BA) technique was proposed to reduce the waste of channels that resulted from Ack transmission. In the proposed technique, MAC Protocol Data Units (MPDUs) are transmitted at an interval of a Short Inter Frame

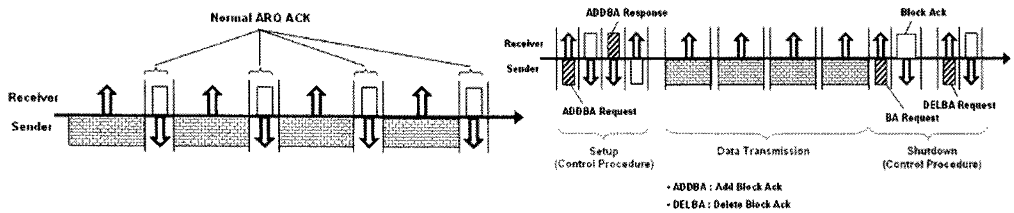


Fig. 2. ARQ(left) and BA of IEEE 802.11x(right)

Space (SIFS) period and the Block Ack (BA) is transmitted at once after the last data is received [8-11].

There are several big differences between underwater data transmission technology and the Wireless LAN IEEE 802.11x technology, which makes it possible to transmit data at high speed, in wireless radio communication environment and requirements. Since the BA technique of IEEE 802.11x standard has been implemented based on the assumption of wideband, the frequency of control frame transmission does not cause difficulty during the procedure of setup and message sequencing for exchanging a BA [8,9]. In an underwater environment, however, the BA technique will cause excessive overhead and the problem of transmission delay underwater cannot be overcome.

The Pervasive Block Ack (PBA) technique has smaller transmission overhead by simplifying the transmission procedures of the BA technique. Channel efficiency and the number of transmissions are significantly improved by the skipping of the transmission of control information notifying the starting and ending of a BA [10]. Further study is necessary to apply BA technology to under water sensor networking (UWSN).

### 3.2 The MA Mechanism

The MA mechanism is to send an Ack to many receivers simultaneously. The CH (master, coordinator) of the unit cluster broadcasts a Beacon frame where Ack information of the previously transmitted data is included. Figure 3 shows an example of a normal ARQ and MA technique in a situation of multiple accesses. S1 ~ S3 are sensor nodes (sender) and CH is a cluster header (receiver). In the case of MA, the frame containing control frames within the super-frame transmitted 4 times (*1 beacon + 3 data*) compared with 7 times of transmission (*1 beacon + 3 data + 3 Acks*) by using ARQ. Red dotted lines in Figure 3 show the

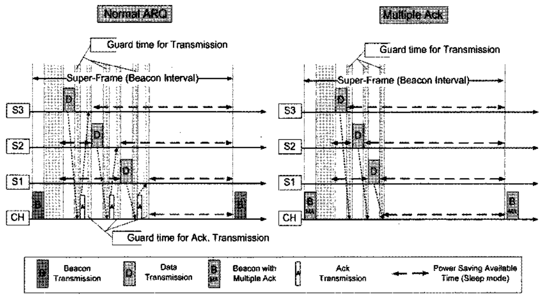


Fig. 3. Multiple Access Examples for ARQ(left) and MA(right)

margin which can be saved by reduced Ack transmission time and marginally guaranteed Guard time. With the MA technique, the network lifetime can be increased by managing energy consumption. For example, the total number of frame transmissions, the transmission time, and the Guard time can be reduced and energy consumption also can be reduced as much as the reduced duty rate. In addition, the technique can be an efficient method in case of an inferior media environment, such as in underwater.

## 4. NUMERICAL RESULTS

### 4.1 Analytical Model

In this section, an analytical model of the proposed MA technique is defined. Table 1 is the list of used terms. Equations in this section will use dot (".") or suffix to indicate 4 different types of acknowledgement techniques based on the contents of Table 1. For example, $N_{ack.ARQ}$ means the number of Ack transmissions in the ARQ technique.

The usability of the channel can be expressed by $R/C$ where $R$ is the Frame transmission rate and $C$ is the Bandwidth. In addition, the efficiency of the operating channel means the ratio of the data length to the total frame length. It can be expressed by $\frac{L_{payload}}{L_{total}} = \frac{L_{total} - L_{control}}{L_{total}}$. The total length of the frame is the sum of the length of the payload and the length of the other control information. $L_{control}$ , the

Table 1. List of used terms

| Term | Definition |
|---|---|
| $C$ | Maximum network bandwidth |
| $R$ | Frame transmission rate |
| $B$ | Blocked Ack number (in the case of a BA and PBA) |
| $DATA$ | Data Frame containing control information |
| $SET$ | Frame for processing the start and end of Block Ack |
| $BEACON$ | Frame, where control information is included, transmitted by the CH periodically |
| $ACK$ | Ack Frame |
| $L_{total}$ | Sum of the Frame length transmitted for one successful data transmission (Data frame + Control frame) |
| $L_{data}$ | Data Frame length containing a MAC header |
| $L_{payload}$ | Payload length |
| $L_{control}$ | Total length of the control information of successful data transmission |
| $L_{ack}$ | Ack frame length |
| $L_{beacon}$ | Beacon frame length |
| $\Sigma L_{control}$ | Sum of the control frames' length generated from the corresponding link |
| $N_{total}$ | Total number of transmission |
| $N_{data}$ | Number of transmissions of Data Frame |
| $N_{ack}$ | Number of Transmissions of Ack Frame |
| $N_{beacon}$ | Number of transmissions of Beacon frame |
| $N_{control}$ | Number of control Frames containing Ack and Beacon frames |
| $Len()$ | Function to calculate Frame length |
| $int()$ | Integer function |
| $BEACON()$ | Function calculating the Beacon frame's corresponding field |

length of the control information, is the sum of the length of the Data Frame, Beacon, and the Ack minus the Payload. (Equation *(1)~(2)*).

$$L_{total} = L_{payload} + L_{control} \tag{1}$$

$$L_{control} = (L_{data} - L_{payload}) + L_{ack} + L_{beacon} \tag{2}$$

The following equations show the definition of the number of transmissions of Ack and Beacon and the total length of the control information. Equations *(3) and (4)* are about the ARQ technique, *(5) and (6)* are about the BA technique, *(7) and (8)* are about PBA, and *(9)and (10)* are about the MA technique.

$$N_{ack.ARQ} = N_{data} \tag{3}$$

$$\Sigma L_{control.ARQ} = Len(DATA_{ARQ} - DATA_{payload}) \times N_{data} + Len(ACK_{ARQ}) \times N_{ack.ARQ} + Len(BEACON_{ARQ}) \times N_{beacon} \tag{4}$$

$N_{data}/B$ is a ratio of the number of transmissions over the number of blocked Ack transmissions. It is used for calculation of the number of transmissions of BA or PBA. Since the number of transmissions of BA and PBA cannot be a real value, it is converted to an integer value using *int()*. The reason for 3 times the transmission number is the two more frames required for starting a BA and ending a BA, that are added to the transmission.

$$N_{ack.BA} = 3 \cdot \text{int}(\frac{N_{data}}{B}) \tag{5}$$

$$\Sigma L_{control.BA} = Len(DATA_{BA} - DATA_{payload}) \times N_{data} + Len(ACK_{BA}) \times \text{int}(\frac{N_{data}}{B}) + 2 \cdot Len(SET_{BA}) \cdot \text{int}(\frac{N_{data}}{B}) + Len(BEACON_{BA}) \times N_{beacon} \tag{6}$$

In the case of the PBA, there are no transmissions of additional control frames such as

$SET_{BA}$ for the Ack. The minimized data and information within Ack makes it possible to improve the efficiency.

$$N_{ack.PBA} = \text{int}(\frac{N_{data}}{B}) \quad (7)$$

$$\Sigma L_{control.PBA} = Len(DATA_{PBA} - DATA_{payload}) \times N_{data} + Len(ACK_{PBA}) \times \text{int}(\frac{N_{data}}{B}) + Len(BEACON_{PBA}) \times N_{beacon} \quad (8)$$

In case of MA, there are no Ack transmissions. The reason for this is that all Ack information is already transmitted with the Beacon. In addition, the sum of the length for Ack is also reduced significantly. Added parts are the *Ack_Flag* and *Multiple_Ack* fields within the Beacon and the total added length is the sum of the *Ack_Flag* (*4 bits*) and the number of Sender bits *Multiple_Ack* (refer Figure 4). For example, when data is received from 20 sensor nodes, the total length of the *Multiple_Ack* field is 24 bits (*=4+20*) (*3 bytes*).

$$N_{ack.MA} = 0 \quad (9)$$

$$\Sigma L_{control.MA} = Len(DATA_{MA} - DATA_{payload}) \times N_{data} + Len(BEACON(Multiple\_Ack\_Field)) \times N_{beacon} \quad (10)$$

Figure 4 shows examples of 4 types of Data, Ack, and Beacon frames.

In Figure 4, the Beacon frame contains control information which is transmitted periodically in a synchronized sensor network system. In the case of the Source Address and Destination Address, they are the short addresses of the general sensor network defined with 2 bytes of short address [11]. Table 2 shows the comparison results for frame length.

The following equations show the comparison results for the lengths of the data transmission frames, the general Ack, and the number of transmissions. According to 4 types of Ack, Equation *(11)* is about the length of Ack. Equation *(12)* concerns the length of Beacon. Equation *(13)* deals with the length of total control information embody Ack, Beacon and etc. Equation *(14)* relates control information for various schemes.

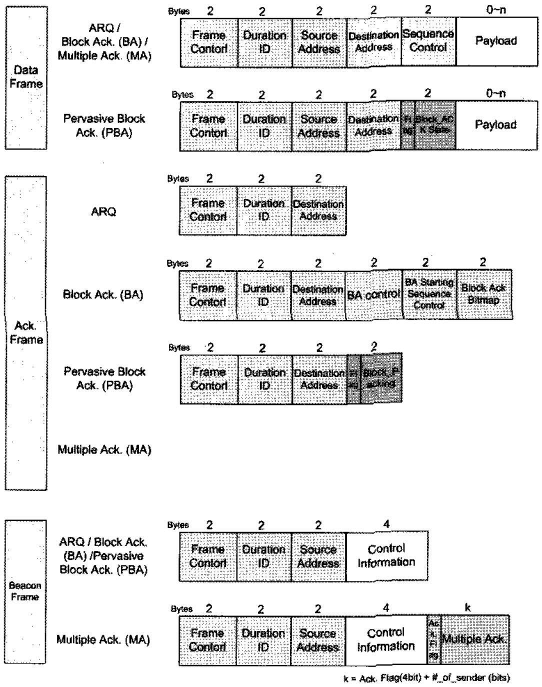


Fig. 4. Frame formats

$$0 = Len(ACK_{MA}) < Len(ACK_{ARQ}) < Len(ACK_{PBA}) < Len(ACK_{BA}) \quad (11)$$

$$Len(BEACON_{ARQ}) = Len(BEACON_{BA}) = Len(BEACON_{PBA}) < Len(ACK_{MA}) \quad (12)$$

$$L_{control.MA} < L_{control.PBA} < L_{control.BA} < L_{control.ARQ} \quad (13)$$

$$N_{control.MA} < N_{control.PBA} <= N_{control.BA} < N_{control.ARQ} \quad (14)$$

The lengths of the transmission data frames of the ARQ, BA, MA, and PBA are all the same. In

Table 2. Comparison of Frame Length

| Frame type | ARQ | BA | PBA | MA |
|---|---|---|---|---|
| Data Frame (bits) | (10+Payload)*8 | (10+Payload)*8 | (10+Payload)*8 | (10+Payload)*8 |
| Ack. Frame (bits) | 6*8 | 12*8 | 8*8 | 0 |
| Beacon Frame (bits) | 10*8 | 10*8 | 10*8 | 10*8+Multiple_Ack |

the case of the PBA, it is different in that *Flag* and *PBA State* information replace *Sequence Control.* This means that the efficiency of the channel is determined by the process method of the Ack Frame and the control information process rather than the length of the Data Frame. Second, the number of transmissions of control frames and network frames and the duty cycle/rate of the network were analyzed and compared based on the derived equations.

### 4.2 Numerical Results

In this section, we describe our numerical analysis of the analytical model defined above. Figure 5 shows the comparison results of the number of transmissions of control frames. Left one shows the case of 0.5 data per 1 Beacon and right one is for 1.0 data per 1 Beacon.

In the figure, the MA technique shows the smallest number and the ARQ technique shows the largest number. In the case of BA and PBA, when the number of blocks is 1, several control frames were generated resulting from the overhead during the BA setup procedure. If the number of blocks is 2 or more, however, BA and PBA were more efficient compared with the ARQ. The MA shows the most efficient results in all cases. The number of control frame transmission of MA is fixed at 100 and same with the number of transmission of Beacon. The difference between MA and other techniques increases as the number of data transmission increases.

Figure 6 shows the ratio of transmitted data frames over the total frames. The MA was the most efficient and the ARQ was the least efficient. The number of control frame transmission of Figure 6 is inversely proportional to that of Figure 6.

Figure 7 shows the total length of control frames according to various number of data frames. Left one of Figure 7 is the case of block size of one (1) and the length increases in the order of BA>PBA>ARQ>MA. Right one is the case of block size of three (3) and the length increases in the order of ARQ>BA>PBA>MA. From these results, it is verified that if the block size is equal or larger than two (2), the results would be the same with the case of right figure of Figure 7.

Left one of Figure 8 shows the case of block size of one (1). In the figure, it is shown that the maximum processing time begins to be exceeded as the number of data frame becomes over 100. Right one of Figure 8 is the case of block size of

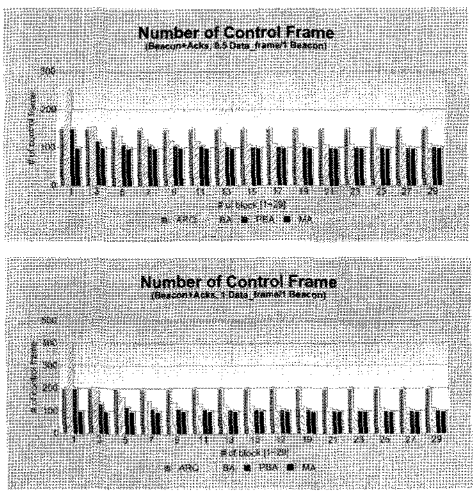


Fig. 5. Number of Control Frames

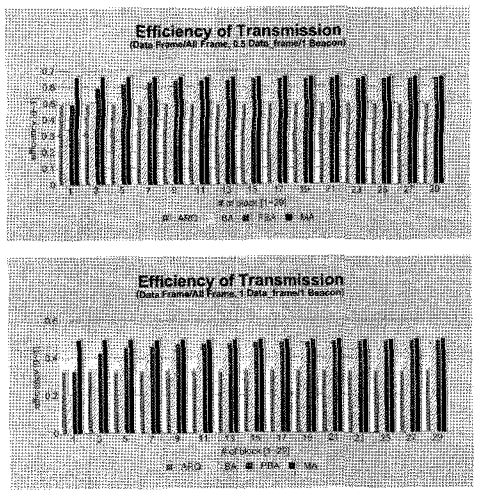


Fig. 6. Efficiency of Transmission

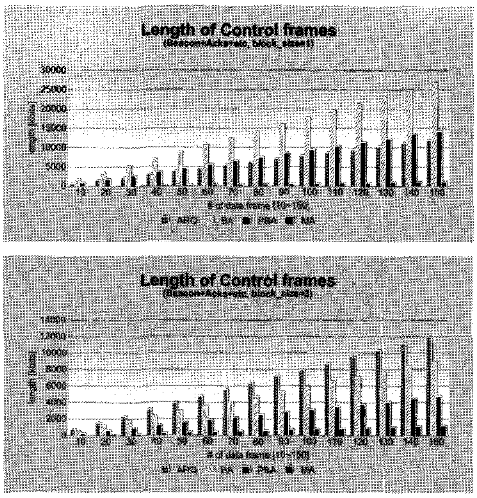


Fig. 7. Total Length of the Control Frames

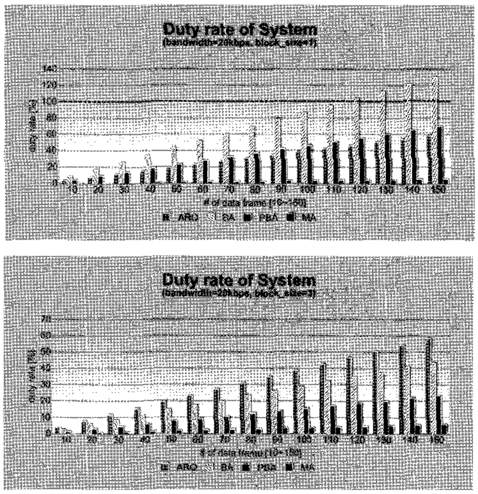


Fig. 8. Duty rates of Systems

three (3) and it is also shown that the duty rate decreased as the number of transmissions of frames increased with a large gap.

## 5. CONCLUSION

In this paper, a new concept of Multiple Ack was proposed. With the proposed method, the efficiency of the conventional Ack method can be improved and overhead can be reduced significantly. A special feature of the Multiple Ack method is that the periodically generated network Beacon has Ack information of all nodes within the unit network range. The Performance of the ARQ, Block Ack, Pervasive Block Ack and the proposed method were compared with one another and analyzed. The proposed method showed significant performance improvement as compared with the ARQ, BA, and PBA in its channel efficiency. With the newly proposed method, time overheads resulted from long propagation time were minimized by reducing the number of transmission. In addition, by reducing the total length of frames, the error rate and the number of retransmission is also reduced. Therefore, the energy consumption is also reduced resulted from lower duty rate and prolonged power saving times.

Future studies to reduce the size of the Ack information of the Multiple Ack are necessary. In addition, studies on schemes to reduce MA information and support Multiple BAs with Aggregation data transmission are also required.

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Soo-Young Shin

Soo-Young Shin has received M.Sc from Duksung Women's University in 2002 and Ph.D degree from Kookmin University in 2006. Now, she get a research prof. position at the University of Kookmin, Seoul, Korea. Her interested fields are USN (Ubiquitous Sensor Network) and wireless sensor MAC scheduling.

Soo-Hyun Park

Soo-Hyun Park has received his B.S., M.S. and Ph.D degrees in computer science engineering from Korea University, Seoul, Korea, in 1988, 1990 and 1998, respectively. He had worked as a senior research engineer of the Central R&D Complex, LG Electronics, Ltd from 1990 to 1999 in Anyang, Korea. Now, He is a professor in School of Business IT, Kookmin University, Seoul, Korea. His current research interests include next generation IP-based routing, sensor network and MAC in Ubiquitous Network.

Seung-Joo, Lee

He has gone the graduate studying in computer networking at the department of computer science of Kwangwoon University(1994-1997) and Ph.D. studying in information system at the department of MIS (Management of Information System) of Kookmin University(2001-2008). Now he is full time instructor professor department of Information and Communication Engineering of Seoil University. His interesting research fields are in ubiquitous sensor network, wireless sensor routing algorithm, MAC protocol.