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An Acceleration-based Packet Transmission Mechanism for Wireless Sensor Systems

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Abstract

A wireless body sensor system (WBSS) provides diverse healthcare services by attaching sensors to the arms, abdomen, and feet of a user and by swiftly obtaining the user's movement and health-related information. In order to overcome the battery limitations of sensors and the variations in wireless channels in such WBSSs, much research is being conducted. This paper aims to propose a new packet transmission power control (TPC) mechanism that judges wireless channel conditions using acceleration values and inhibits packet transmission when the channel is unstable, thereby reducing energy consumption. The TPC mechanism proposed in this paper was able to save energy efficiently while not increasing the delay time much when the channel condition changed.

Keywords: *Wireless body sensor system, acceleration, packet delay, energy saving*

1. Introduction

Wireless senor systems are at present applied to our actual lives and provide much convenience to society as a whole in smart city areas, including air pollution measurement and parking space monitoring, or in smart agricultural areas, such as measurements of moisture, light, or temperature, which are growth elements of agricultural produces. Among them, wireless body sensor systems (WBSSs) provide diverse healthcare services by attaching sensors to humans and quickly identifying the users' exercise amount, health, and location information.

One of the major characteristics of a WBSS is its small battery. The sensor is attached to the human body and therefore, the size and weight of the battery are restricted. Accordingly, there has been much research to reduce battery consumption. Another characteristic of a WBSS is that the condition of a wireless channel is very changeable from moment to moment. This is due to the locations of the sensors attached to a user, such as at the wrists, waist, and chest, the space where the user is located, such as indoor and outdoor spaces, and changes in the user's movements, such as standing, walking, and running.

To overcome such characteristics of a WBSS, research on low power energy and adaptation to a wireless channel as fast as possible is being conducted. Among such research, a representative area of low power research in the software sector includes data packet compression technology, a low power media access control protocol, and a transmission power control (TPC). In addition, research aimed at swiftly adapting to diverse wireless

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channels includes research that quickly judges and adapts to wireless channel conditions using TPC algorithms and an accelerometer.

Such existing research enabled efforts to adapt to unstable situations while transmitting packets, despite the wireless condition being unstable. Nonetheless, excessive packet transmission in an unstable wireless situation leads to packet loss and increases in control packet transmission rates, as shown in Figure 1, resultantly increasing total energy consumption.

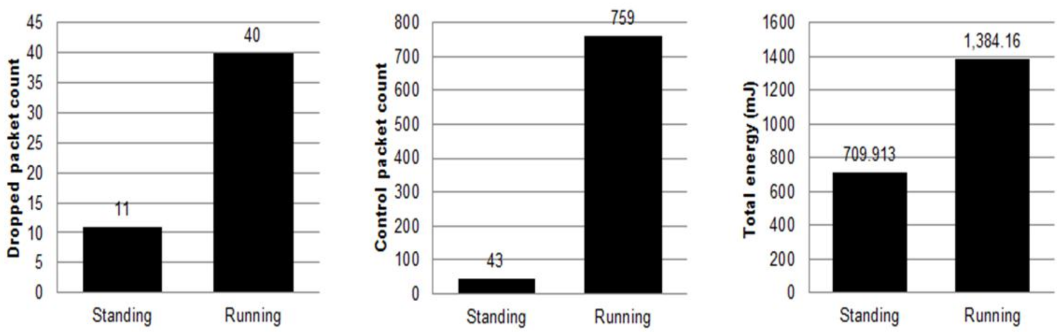

Figure 1. Differences in Packet Loss, Transmission Amount of Control Packet, and Total Energy according to Movements

Accordingly, this paper will judge the wireless situation in the process of packet transmission with acceleration values and will inhibit packet transmission if it is judged that the wireless environment is unstable, thereby proposing a method to heighten total energy by reducing packet loss and controlling packet transmission.

2. Related Work

Diverse studies aimed at overcoming changes to wireless channel signals due to the location of sensors and users' movements in a WBSS have been conducted [1-2]. Among them, research on a TPC mechanism is a representative research on increasing energy efficiency. In order to understand the existing TPC mechanism, the packet flow in a WBSS should be understood. Figure 2 shows a TPC model [3] used in a WBSS TPC mechanism. In a TPC model, the sensor node attached to the body senses data and transmits this data to the sink node in the form of a data packet, and the sink node measures the received signal strength indicator (RSSI) of the data packet received from the sensor node. When the measured RSSI is within the target RSSI margin range set in the sink node, the sink node waits for the next data packet from the sensor node without other motions. Here, if the RSSI value is not within the target RSSI margin, the sink node calculates a new transmission power level (TPL) value using a TPC algorithm to revise the TPL of the sensor node. The TPL value calculated is delivered to the sensor node through the control packet by the sink node, and the sensor node, which receives it, carries out the packet transmission using the new TPL updated from the next data packet.

Representative TPC algorithms include a linear algorithm [4], a binary algorithm [5], and a dynamic algorithm [6]. A linear algorithm [4] heightens or lowers the set TPL by a level when the RSSI fails to enter the target RSSI margin. On the other hand, a binary algorithm [5] sets the TPL at the middle value between the current TPL and the maximal TPL when the measured RSSI value is smaller than the target RSSI margin, and it sets the TPL as half the current TPL value when the measured RSSI value is larger than the target RSSI margin. Lastly, a dynamic algorithm is a method of estimating an optimal TPL value by creating a linear equation using the RSSI value of two previously received data packets.

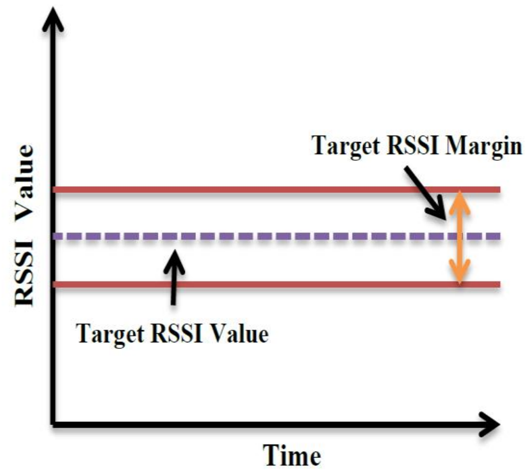

Figure 2. Transmission Power Control Model [3]

[7] studied this method to perceive a fall using an acceleration-based self-constructing classifier. This algorithm is used to provide information on positive and negative cases and produce classifications using the educated information. [8] proposed a method to estimate users' poses based on acceleration-based wearable sensor systems. The paper captured motions based on markers and utilized a partial least squares regression analysis. However, [7] and [8] did not judge the current wireless situation using an accelerator.

3. Proposed TPC Mechanism

The ultimate goal of the TPC algorithm we intend to propose lies in improving the total energy efficiency by inhibiting packet transmission when it is judged that the wireless channel condition is unstable. Therefore, when the waiting time of the data packet is shorter than the deadline dynamically set by the algorithm, the data packet transmission is inhibited. In addition, the Ack packet, whose length is shorter than that of the data packet, is transmitted, and when the waiting time of the data packet is longer than that of the deadline, all packets that stood by longer than the deadline are transmitted. The reason for Ack packet transmission is to inform that packet transmission is inhibited because the current wireless situation is not good, not because data loss occurred in the sink node.

Figure 3 shows a flowchart of the proposed TPC algorithm. First, the sensor node measures the current acceleration value after sensing the data. Then, using the measured acceleration value and the pre-set MaxDeadline value, the deadline value under the current channel condition is calculated. The sensor node identifies the waiting time of the data it has, and if there is data that stood by longer than the deadline, it puts all the data together in a data packet and transmits it to a sink node. In case there is no data to transmit because there is only data with a waiting time shorter than the currently set deadline, the sensor node transmits the Ack packet instead of the data packet, notifying the sink node that data delivery was delayed. Here, the Ack packet is not transmitted at the TPL value set in the current sensor node to prevent a loss, but it is transmitted at three levels higher than the average transmitted TPL. When the sink node receives the packet, it first measures the RSSI and identifies the type of packet. If the packet type is Ack, it means the transmission of the data packet was inhibited; therefore, the sink node stands by waiting for the next packet. If the received packet type is a data packet, the measured RSSI is checked for whether it is within the target RSSI margin. If the measured RSSI is within the target RSSI margin, the sink node stands by waiting for the next packet. However, if the measured RSSI is not within the target RSSI margin, a new TPL is calculated using the TPC algorithm. The calculated TPL is delivered to the sensor node through the control packet. The sensor node receiving it updates and uses its TPL.

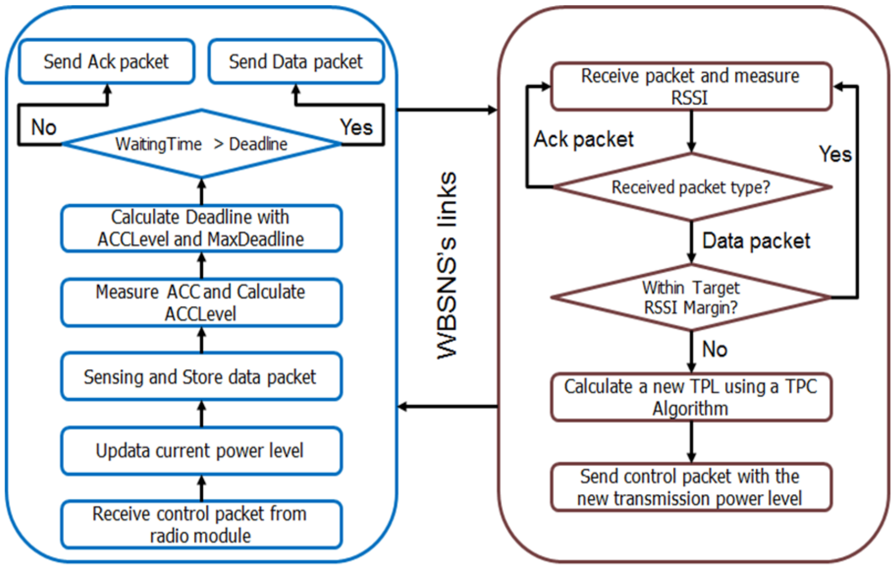

Figure 2. Flowchart of the Proposed Algorithm

The TPC mechanism proposed in this paper dynamically calculates and uses deadline values with acceleration values and MaxDeadline values. The deadline is correlated to the following formula.

$$\text{Deadline} \propto \text{ACCLevel} * \text{MaxDeadline}$$

In this formula, the MaxDeadline is the preset maximal delay time and it refers to the value of the maximal increase in the deadline when the ACCLevel increased maximally. When the ACCLevel is calculated, the deadline increases proportionate to the MaxDeadline. Next, the ACCLevel in this formula represents the values expressed by each level after grouping the measured acceleration values. To determine the ACCLevel, the distribution of the acceleration values should be known first. Figure 4 presents the distribution of acceleration values measured in the states of standing, walking, and running through an actual experiment.

As shown in Figure 4, the acceleration values are not grouped, but each value is considered one ACCLevel. An ACCLevel from 0 to 155 is defined as an ACCLevel MAX. Next, the measured acceleration values are grouped in the direction of the small deviation in the number of accelerations by each ACCLevel, and Figure 5 shows examples of ACCLevel 4, ACCLevel 8, ACCLevel 16, and ACCLevel 32, which divided the ACCLevels into 4, 8, 16, and 32 groups using such a method. Table 1 displays the range of acceleration values by each ACCLevel.

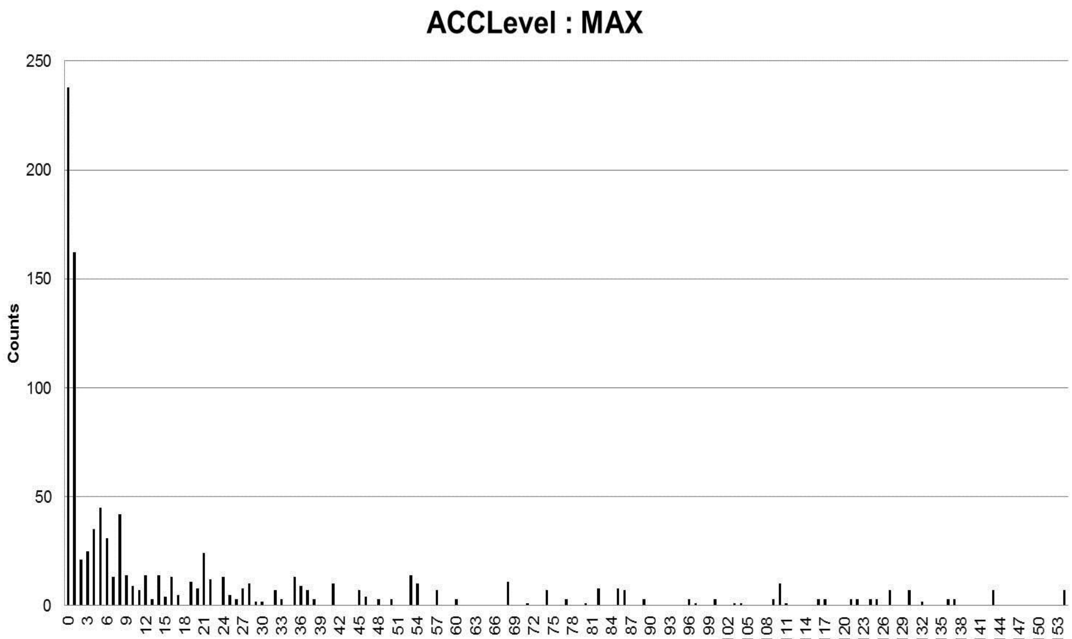

Figure 4. The Number of Each Acceleration Value Measured when Transmitting 1,000

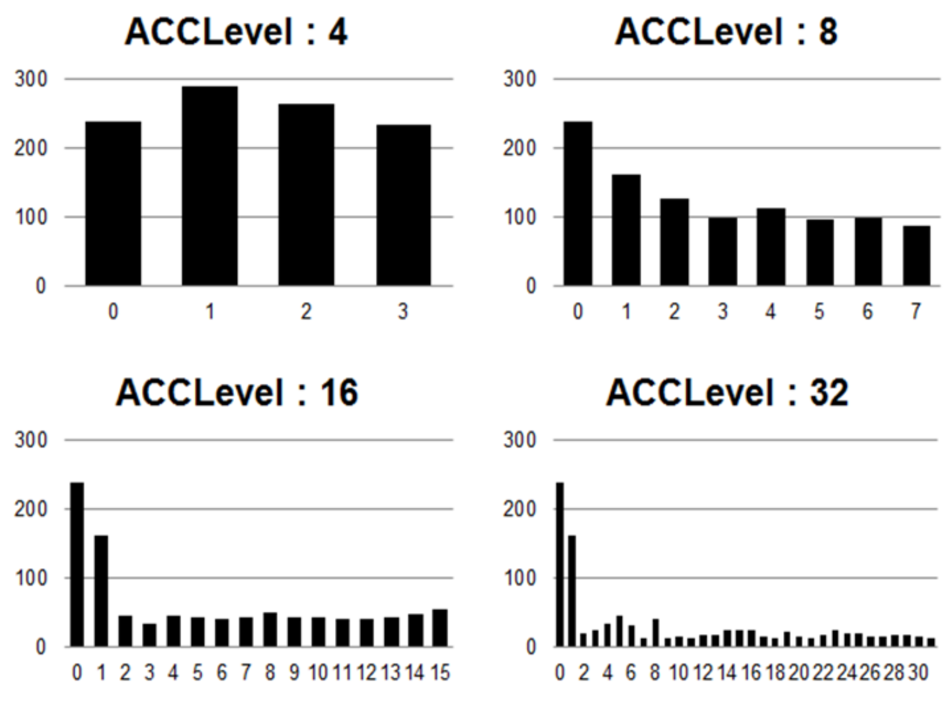

Figure 5. Grouping by Each ACCLevel Classification Level

Table 1. Acceleration Value Range by Each ACCLevel

ACC Level	ACC Level : 4	ACC Level : 8	ACC Level : 16	ACC Level : 32	ACC Level	ACC Level : 32
0 Level	1	1	1	1	16 Level	3
1 Level	5	1	1	1	17 Level	3
2 Level	23	4	2	1	18 Level	4
3 Level	126	4	1	1	19 Level	4
4 Level		12	1	1	20 Level	2
5 Level		19	2	1	21 Level	7
6 Level		45	1	1	22 Level	8
7 Level		69	4	1	23 Level	4
8 Level			7	1	24 Level	14
9 Level			4	1	25 Level	14
10 Level			8	2	26 Level	4
11 Level			9	1	27 Level	21
12 Level			13	2	28 Level	11
13 Level			28	2	29 Level	9
14 Level			34	4	30 Level	13
15 Level			39	1	31 Level	12

Lastly, the deadline increase method according to the ACCLevel should be determined, and such a deadline increase method may include a linear increase (LI), an equal increase (EI), and an inverse-linear increase (ILI). Table 2 illustrates a deadline decision equation according to each deadline increase method at ACCLevel 4.

Table 2. Deadline Decision Equation According to Deadline Increase Method at ACCLevel 4

ACCLevel 4	Linear increase (LI)	Equal increase (EI)	Inverse-linear increase (ILI)
0 Level	0	0	0
1 Level	1/6 * MaxDeadline	2/6 * MaxDeadline	3/6 * MaxDeadline
2 Level	3/6 * MaxDeadline	4/6 * MaxDeadline	5/6 * MaxDeadline
3 Level	6/6 * MaxDeadline	6/6 * MaxDeadline	6/6 * MaxDeadline

4. Experiments

4.1. Experimental Setup

Table 3 shows the properties of the experimental environment. In the experiment, CC1000 and SCA3000-D01 were used as accelerator modules, and the setting and explanation of each module may be checked in the datasheet [9-10] of each module. In the experiment, the sizes of the data, control, and Ack packet were set according to the IEEE 801.15.4 standard [11].

The sink node, which receives transmission of the data packet, is located on the chest and the sensor node, which transmits the data packet, is situated on the abdomen, back, and arm. The reason why the sensor node is located on the abdomen, back, and arm is to measure both a case of a good wireless condition and a case of a bad wireless condition.

Table 3. Experimental Environment

Properties	Values
Mote Model	Cricket Mote
Supply Voltage	2.5 V
Radio Module	CC1000
Radio Technology	Zigbee (IEEE 802.15.4)

Figure 6 shows the movement pattern of the body used in the experiment. First, while standing in the beginning position, the subject repeats walking, standing, running, walking, running, and the reason for such a setting is to identify all the changes to the different conditions. Each movement pattern is maintained for 30 seconds, and then the next pattern is applied.

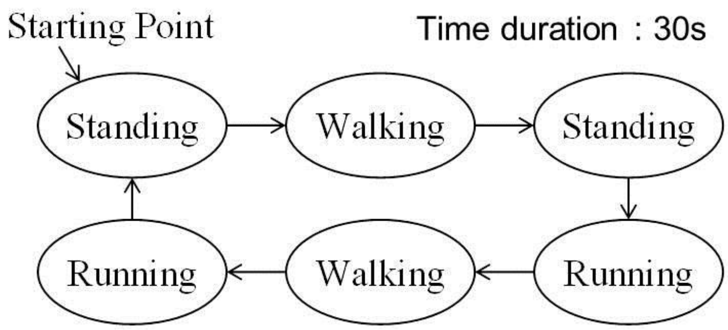

Figure 6. Body Movement Pattern for Experiments

The most important energy measurement in this experiment follows the formula below, as in [1].

$$E = V \times I \times L / C$$

Here, V, I, L, and C refer to volts, transmission power, packet length (bits), and transmission rate, respectively.

4.2. Experiment Results

Figure 7 illustrates a graph that shows the energy consumption and packet delay according to changes in the ACCLevel when the deadline increase methods LI, MaxDeadline 20, and binary TPC algorithm were used. The graph shows that the simpler the ACCLevel, the greater the average delay time and maximal delay time, but the more efficient the total energy become. In addition, in the composition of the graph, the simpler the ACCLevel, the more efficient the Rx and Tx of the data packet and of the control packet become. However, the Ack packet's Rx and Tx gradually increased, resulting from an increase in Ack packets according to the inhibition of packet transmission.

Figure 8 displays how energy consumption and packet delay change according to changes in the deadline method from LI to EI and then to ILI when ACCLevel 32, MaxDeadline 20, and binary TPC algorithm were used. As the graph shows, energy efficiency is good in the order of ILI, EL, and I, and the better the energy efficiency, the greater the packet delay becomes.

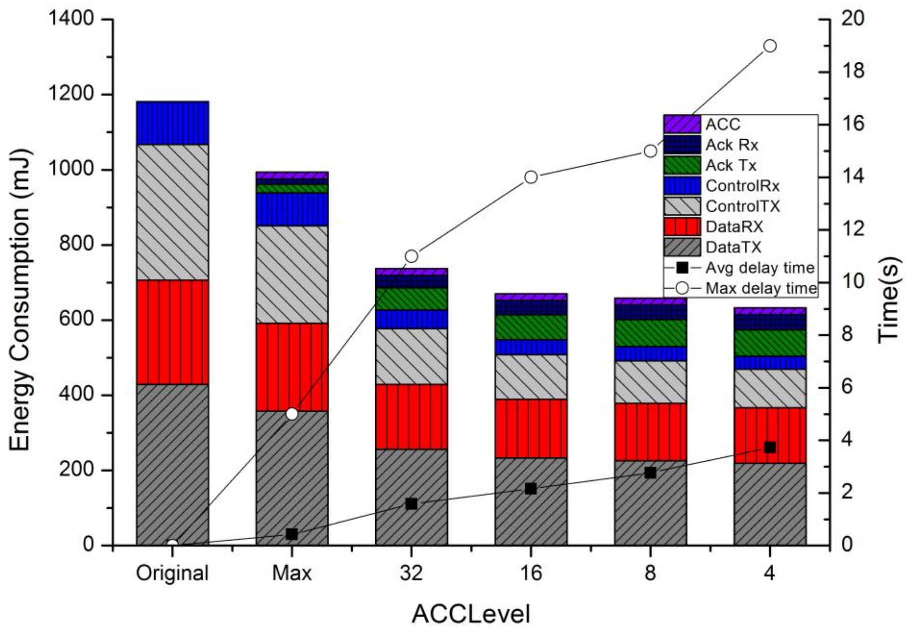

Figure 7. Energy Consumption and Packet Delay according to ACCLevel

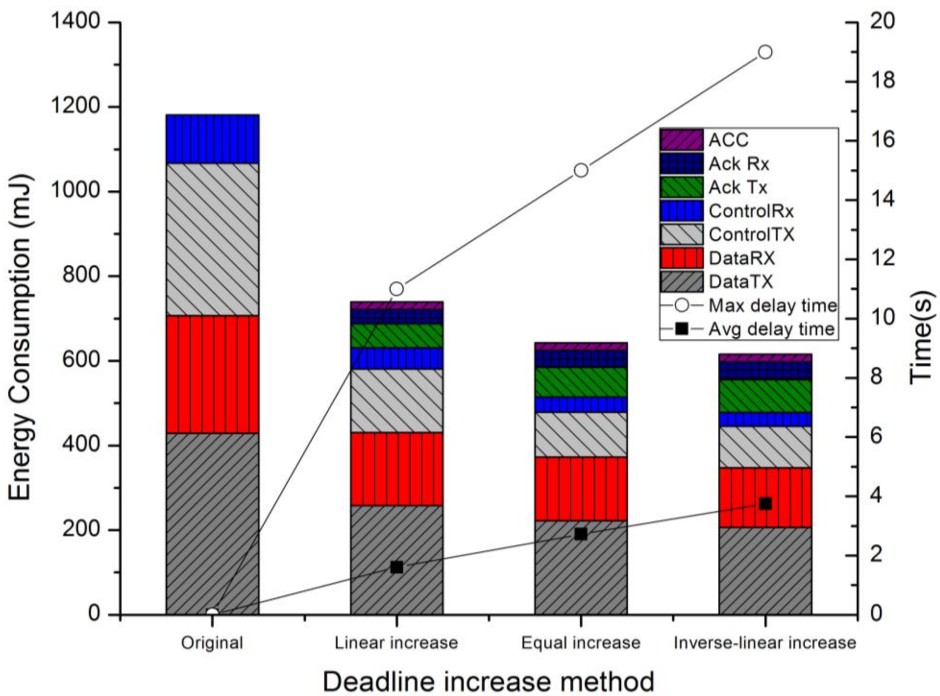

Figure 8. Energy Consumption and Packet Delay according to the Deadline Increase Method

Figure 9 displays the energy consumption and packet delay according to an increase in MaxDeadline when ACCLevel 32, deadline increase method EI, and the binary TPC algorithm were used. As the graph shows, the greater the MaxDeadline, the higher the energy efficiency, but the greater the packet delay become.

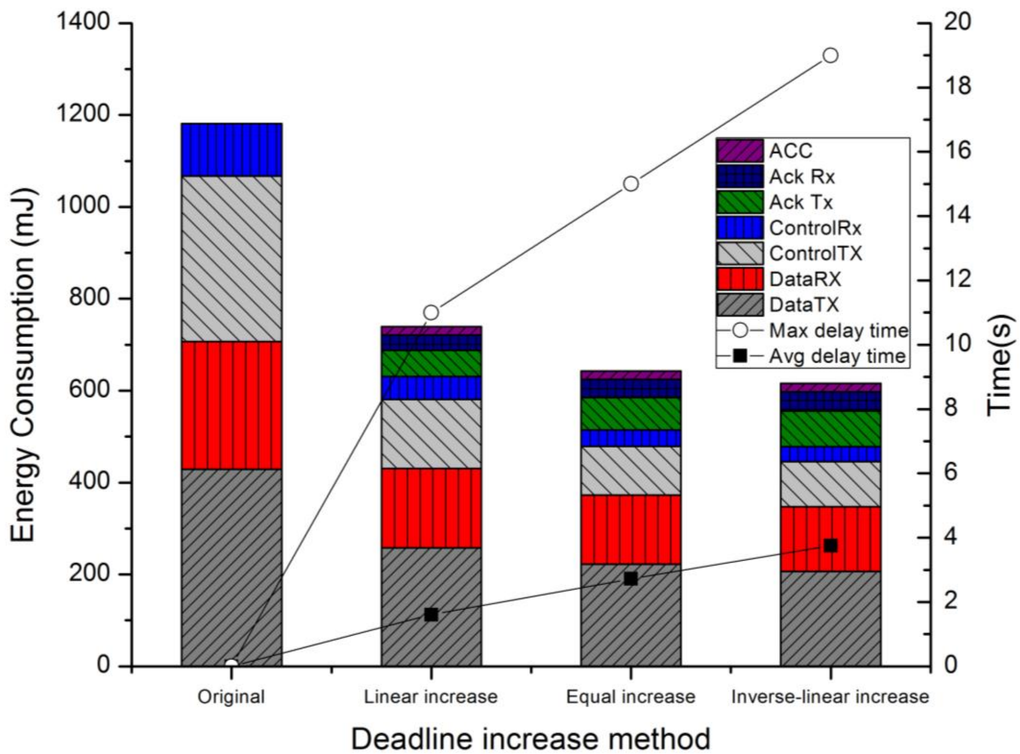

Figure 9. Changes in Energy according to the MaxDeadline

6. Conclusion and Future Research

We proposed a new TPC mechanism where packet transmission was inhibited under unstable wireless channel conditions, and packets were transmitted under stable wireless channel conditions by judging the wireless condition using acceleration values. The proposed TPC mechanism minimizes energy waste through channel variations by transmitting data whose transmission is more delayed than the packet transmission deadline calculated based on the acceleration values measured from a sensor node. Here, the deadline value, which determines the transmission time of the data packet, is linearly correlated with the ACCLevel and MaxDeadline. According to the result of analyzing the TPC mechanism proposed in this paper, through a real sensor experiment, the coarser the ACCLevel used to determine the deadline and the greater the MaxDeadline, the higher the energy efficiency. Under the deadline increase method, the energy efficiency was high in the order of LI, EI, and ILI. The higher the energy efficiency and the lower the efficiency have the shorter the data packet delay time. Future research will examine energy changes by applying the new TPC mechanism to actual exercise and health applications, as well as will determine whether the proposed TPC mechanism exhibits a consistent performance by applying it to different sensor environments.

Acknowledgment

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