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Adaptive Transmission Range Based on Event Detection for WSNs

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Abstract*— Wireless sensor networks usually pay attention to energy efficiency by reducing the data transmission rate or using data aggregation techniques. However, in an urgent situation of a disaster monitoring application, sensing data become very important. The sensing data are required to be at the base station quickly so that the administrators can evaluate the situation and issue the early warning message. This paper focuses on the adaptive operations of sensor nodes. The sensor nodes can automatically adjust its transmission range based on the degree of importance of sensing data. In the urgent situation, the transmission range is increased to reduce the number of hops to reduce the latency. In the normal situation, the transmission range is decreased to reduce the battery consumption of sensor nodes. The proposed mechanism, called *A-TRED*, evaluates the degree of importance of sensing data and adjusts the transmission range of sensor nodes accordingly. *A-TRED* consists of three processes which are 1) data checking process, 2) packet formation process , and 3) packet forwarding process. The simulation results show that *A-TRED* can automatically adapt WSN key performance factors (e.g., latency, battery consumption) by adjusting the transmission range against the environmental changes.

Keywords*–*WSN, Transmission Range, Adaptive, Event Routing

I. Introduction

A wireless sensor network (WSNs) is a group of small sensor nodes, which is used to evaluate the environmental situations. The wireless sensor network are widely used in a environmental changes monitoring and natural disaster warning systems [3]. The sensing data from a wireless sensor node are transmitted toward a base station via intermediate nodes in multi-hop manner. After the sensing data arrived at the base station, the sensing data is processed and analyzed for evaluating the environments. [13].

Since the size of a sensor node is small, its battery power is limited. Practically, a sensor node mostly consumes battery energy for communication process (i.e., path routing, receiving and transmitting packets) [5]. The power consumption of a sensor node is also varied to its communication range. Using the long communication range consumes more energy than the short communication range [8] [7].

Generally, wireless sensor networks focus on battery energy saving at all times. For example, the multi-hop data transmission technique is used to reduce the energy consumption of sensor nodes and extend the network lifetime [2] [11]. Howvever, the multi-hop data transmission leads to a time delay of data transmission and data losing [12]. Consequently, it is not proper for urgent events that data must be reported immediately. For example, the event of the conflagration in forests, the sensor nodes need to consume more energy than the normal state to increase the strength of data transmission of the transmitter.

This paper proposes *A-TRED* (Adaptive Transmission Range Based on Event Detection) technique, which can adapt the strength of data transmission in order to consume battery energy efficiently. The proposed mechanism, *A-TRED*, evaluates the degree of importance of sensing data and adjusts the transmission range of sensor nodes accordingly. *A-TRED* consists of three processes which are 1) data checking process, 2) packet formation process , and 3) packet forwarding process. The simulation results show that *A-TRED* can automatically adapt WSN key performance factors (e.g., latency, battery consumption) by adjusting the transmission range against the environmental changes.

II. WSNs Characteristics

In multi-hop data transmission, each sensor node keeps forwarding packets to its neighbor nodes until the packets arrive to a base station. A sensor node broadcasts packets to its neighbor nodes in its transmission range. Usually, the sensor node transmits packets by using a low-range data transmission in order to limitedly consume its battery energy. Figure 1 shows how a sensor node sends the sensing data to the base station in multihop manner; where (r) represents the transmission range of the sensor nodes. However, each sensor node can consume more energy to increase the transmission range (R).

When a sensor node receives or transmits a data packet, it consumes battery energy. Equation 1 describes how the battery energy is reduced. When E_T represents a total energy consumption of the energy for receiving (E_{rx}) and transmitting (E_{tx}) a data packet.

$$E_T = E_{tx} + E_{rx} \tag{1}$$

$$E_{tx} = (E_{elec} + E_{amp}) * k * d^2 \tag{2}$$

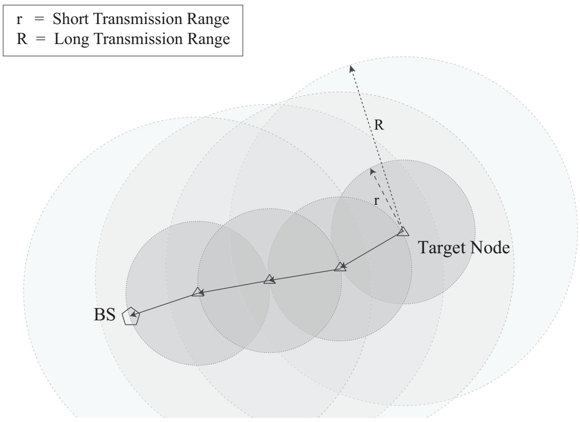

Fig. 1: Transmission Range of Sensor Nodes.

Equation 2 describes the energy consumption for transmitting a data packet (E_{tx}). The number of bits in a packet is represented as k. d is the distance between the transmitting node and the receiving node. E_{elec} is the energy consumption constant to carry out the data transmission, and E_{amp} is the energy consumption constant to expand the transmission range.

$$E_{rx} = E_{elec} * k \tag{3}$$

Equation 3 describes the energy consumption for recieving a data packet (E_{rx}), which is equal to the size of data packet (k) times with the energy consumption constant to receive the packet (E_{elec}).

Generally, a WSN is applied to query the environmental data in the interested area by using a large number of sensor nodes. However, data packets sent through sensor nodes in multi-hop manner face with some occurrences such as data loss, long latency, data duplications, and data errors [6]. These issues become more complicated in urgent situations, (E.g., disaster monitoring, battle field sensor). In an urgent situation, sensing data become very necessity and need to be arrived at the base station immediately. The data packet route should be adaptive to the environmental changes.

Mostly, a sensor node can adjust its transmission range. For example Xbee [14] can change the transmission strength from 0 *dbm* to 10 *dbm*. An Xbee sensor node consumes more energy to forward a packet with high transmission strength. This example is showed in Figure 2.

This paper proposed to automatically adjust the transmission range of each sensor node based on the environmental sensing data. When an urgent situation occurs; environmental sensing data changes dramatically, the sensor nodes should forward the data packet with high transmission range. In this case, the sensor nodes consume more energy to transmit the data packet in long range but the data packet may arrive at the base station (i.e., packet latency) earlier compared to the normal situation with normal transmission range. After the urgent situation, the sensor nodes should return to their normal state for energy saving.

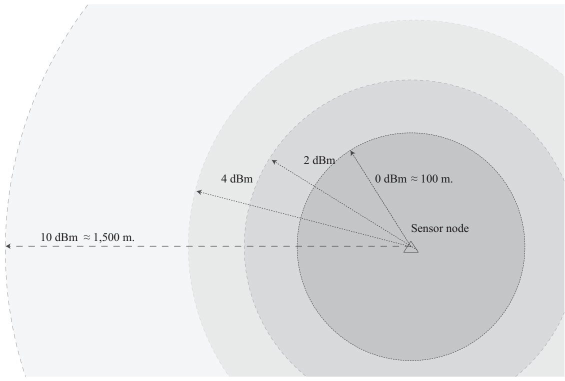

Fig. 2: Transmission Range of an Xbee Sensor Node.

III. The Design of *A-TRED*

This paper proposes *A-TRED* (Adaptive Transmission Range Based on Event Detection).*A-TRED* is a mechanism to adjust the transmission range of sensor nodes to the sensing environmental data changes. *A-TRED* consists of three procedures: 1) data checking, 2) packet formation, and 3) data forwarding. Data checking procedure is applied to check the importance level of sensing data. If the data changes rapidly, an urgent situation is detected. Then, the sensor nodes are in the long range transmission mode. In order to let intermediate sensor nodes know that they are in the long range transmission mode, the data packet formation procedure is required. In the packet formation procedure, the data packet header is modified to identify the transmission mode. Then, each intermediate sensor nodes forwarding the packets according to the mark bits in the packet header in the data forwarding procedure. Thus, the key mechanism in *A-TRED* is how to identify the importance level of the sensing data and automatically adapt transmission mode.

In *A-TRED*, there are two transmission modes for sensor nodes. The short range transmission mode is applied in normal situations. In the short range transmission mode, sensor nodes transmit the packet in a short range by using low power strength transmission to consume low energy. When the sensing environmental data is detected to be in an urgent situation, the long range transmission mode is applied. In the long range transmission mode, sensor nodes transmit the packet in a long range by using high power strength transmission.

A-TRED applies the concept of the gradient-based routing protocol [1] for creating the routes for short range transmission mode and long range transmission mode. At the initial state of the WSN application, after deployment of sensor nodes, the base station broadcast hello messages for short range transmission mode and long range transmission mode. Each sensor node updates its two hill values (i.e., HS and HL) to identify how many hop counts to the base station in the short range transmission mode (HS) and the long range transmission mode (HL). Figure 3 shows an example of the HS and HL

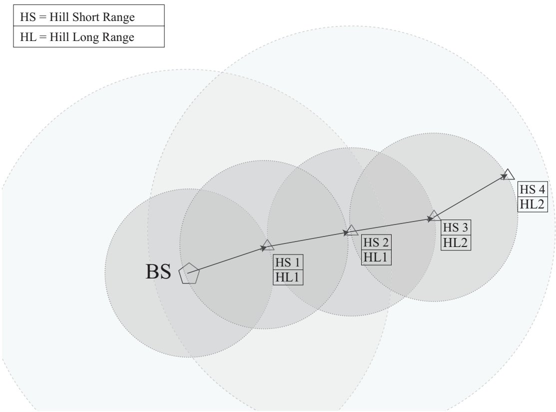

Fig. 3: Sensor Nodes' Hill Values

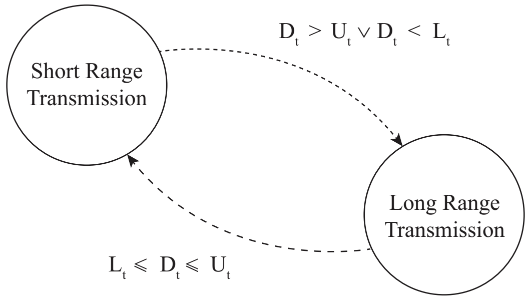

Fig. 4: *A-TRED* Transmission Mode State Diagram

values of each sensor node. For example, the sensor node that contains $HS = 4$ and $HL = 2$ means that its data packet will be forwarded 4 hops in short range transmission mode and 2 hops in long transmission mode to the base station. The data packet also contains the hill value of the current forwarding node in its header as shown in Figure 6. The intermediate nodes forward the packet when its hill value is less than the hill value of the packets. Periodically, HS and HL values at each sensor node keep updated.

After the initial process, *A-TRED* conducts tree procedures to automatically adapt transmission range of the sensor nodes to the importance level of the sensing data.

A. Data Checking Procedure

In this procedure, sensor nodes detect the importance level of the sensing data. The sensor nodes check whether the sensing data changes unusually (i.e., dramatically and rapidly). Normally, to check the sensing data, algorithms apply threshold values to be an upper bound and a lower bound of the sensing data. However, the threshold values cannot adaptive to the environmental data changes. For example, the temperature in winter season in Chiang Mai, Thailand is in 60-85 °F, but the normal temperature in the summer season is in 70-100 °F[1]. In the wildfire application, if the threshold of temperature upper bound is set to 95 °F, the false alarm may occur in the summer season. To over come the static threshold problem, *A-TRED* contributes an adaptive threshold mechanism.

The adaptive threshold mechanism in *A-TRED*, applies an exponential weighted moving average (EWMA) [10] to generate the trend line of the sensing data, the upper bound, and the lower bound threshold.

$$C_t = (1-\alpha)C_{t-1} + \alpha D_t \tag{4}$$

The trend line of the sensing data (C_t) is calculated as shown in Equation 4. C_t is the EWMA of the sensing data at time t. α is the EWMA constant which its value in the range of 0 to 1. D_t is the sensing data at time t. C_{t-1} is the EWMA of the sensing data in the previous time $(t-1)$. The EWMA constant is used as a weight value for the present sensing data. C_t is used to calculate the upper bound and lower bound of the sensing data.

[1] http://www.tmd.go.th

$$U_t = C_t + \beta_t, \tag{5}$$

$$L_t = C_t - \beta_t \tag{6}$$

The upper bound threshold (U_t) and the lower bound threshold (L_t) are calculated as shown in Equation 5 and Equation 6 respectively. β_t indicates the bound size along the trend line (C_t). Sensor nodes change their transmission mode to long range transmission when the sensing data (D_t) is out of the bound ($D_t < L_t$ or $D_t > U_t$). The transmission mode becomes in short range transmission when the sensing data (D_t) is in the bound size ($D_t \geq L_t$ and $D_t \leq U_t$). The transmission mode state diagram is represented in Figure 4.

$$\beta_t = (1-\lambda)\delta_t + \lambda * \beta_{t-1} \tag{7}$$

$$\delta_t = |D_t - D_{t-1}| \tag{8}$$

The bound size (β_t) is the exponential weighted moving average of the difference (δ_t) between the current data (D_t) and the previous data (D_{t-1}). Equation 7 and Equation 8 describe β_t and the δ respectively. λ is the EWMA constant which its value in the range of 0 to 1.

Figure 5 shows an example of the sensing temperature data in 24 hours. The sensing data is represented as the solid line. The trend line of the sensing data (C_t), the upper bound (U_t), and the lower bound (L_t) are calculated as in the Equation 4-8. Figure 5shows that when data fluctuates (at $0-4^{th}$ hour) , the bound size is large. The bound size becomes small when the data slightly changes (at $20^{th}-24^{th}$ hour). When the sensing data rapidly changes beyond the bound size (at 6^{th} hour), the sensor nodes transmit the packets in long range transmission mode. The transmission returns to the short range transmission mode when the sensing data is in between the upper bound and the lower bound (at 15^{th} hour).

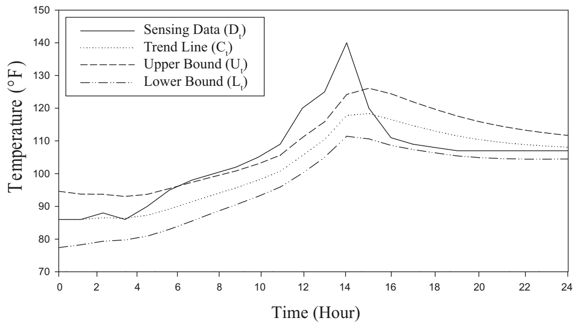

Fig. 5: Sensing Data Example

B. Packet Formation Procedure

After the transmission mode of a sensor node is changed as described in the data checking procedure, the packet formation procedure is performed. Each data packet consists of 6 parts which are 1) packet ID, 2) packet type, 3) data source node ID, 4) current node hill value, 5) data creation time stamp, and 6) sensing data. Figure 6 shows the structure of a packet and the size of each part in the packet. The packet type represents the transmission mode of the packet. The sensor node forwards the packet in the long range transmission mode when the packet type is "1" and forwards the packet in the short range transmission mode when the packet type is "0". This packet formation procedure is represented in Algorithm 1.

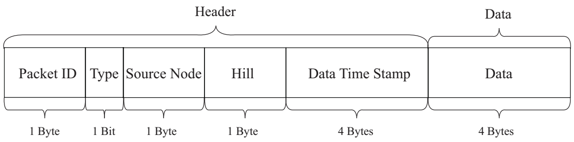

Fig. 6: Packet Structure

Algorithm 1 *A-TRED* Packet Formation Procedure

Read sensing data (D_t)
Update C_t, U_t and L_t
if $L_t \leq D_t \leq U_t$ **then**
  packet type $\leftarrow 0$
  Apply *short range transmission mode*
else
  packet type $\leftarrow 1$
  Apply *long range transmission mode*
end if
Broadcast *packet*

C. Packet Forwarding Procedure

When a sensor node receive a packet from its neighbor, the sensor node checks the packet type. If the packet type is "0", the sensor node will compare the packet hill value with its HS value. The sensor node forwards the incoming

Algorithm 2 *A-TRED* Packet Forwarding Procedure

Receive *packet*
if *packet type* $= 0$ **then**
  if $HS <$ *packet hill* **then**
    Apply *short range transmission mode*
    Broadcast *packet*
  else
    Drop *packet*
  end if
end if
if *packet type* $= 1$ **then**
  if $HL <$ *packet hill* **then**
    Apply *long range transmission mode*
    Broadcast *packet*
  else
    Drop *packet*
  end if
end if

packet with the short range transmission mode if its HS is less than the packet hill value. On the other hand, when the packet type is "1", the sensor node will compare the packet hill value with its HL value. The sensor node forwards the packet with the long range transmission mode if its HL is less than the packet hill value. Algorithm 1 demonstrates how the forwarding procedure is performed. After the sensor node forwards the packet, it returns to listening mode to receive the incoming packets.

IV. Simulation Results

This section shows simulation results to evaluate how *A-TRED* mechanism impacts the latency of the packets and the power consumption of sensor nodes to the changes of sensing data. The latency of a packet is defined as the time interval from the time to create the packet to the time that the packet arrives at the base station. The power consumption of each sensor node is calculated as Equation 1. The configuration parameters are set as shown in Table I.

TABLE I: Simulation Configuration Parameters

Name	Value
the number of sensor nodes	20
α	0.25
λ	0.9
Transmission range (short,long)	2, 10 dBm
E_{amp}	25 nJ / bit / m^2
E_{elec}	25 nJ / bit
Packet Processing time	20 ms

Figure 7 shows the positions of sensor nodes in the interested area. The interested area size is 1000 * 1000 square meters. The base station is located at the location (0,0). Each cycle represents a sensor node. The number in the circle represents the node ID.

The simulation depicts a wildfire detection application. Figure 8 shows the sensing temperature data at sensor node 17.

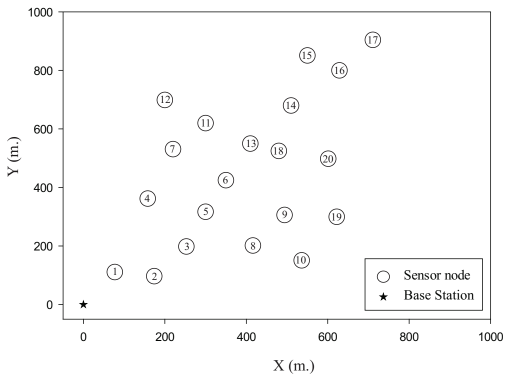

Fig. 7: Sensor Node Locations

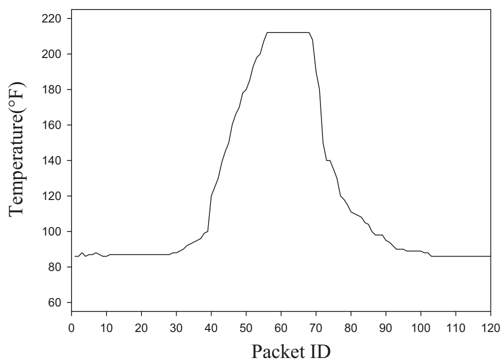

Fig. 8: Sensing Temperature Data

Assume that the wildfire occurs in the middle of simulation. At the end of simulation, the temperature is dropped to the normal temperature.

A. Transmission Mode Adaptation

Figure 9 shows how sensor node 17 adapts its transmission mode to the changes of sensing temperature. At the packet ID 30^{th}, the sensing temperature increases rapidly. The sensing temperature is larger than the upper bound threshold. Thus, the sensor nodes changes its transmission mode from short range to long range transmission mode. When the temperature returns to the normal (the packet ID 110^{th} the sensor nodes changes its transmission mode back to short range transmission mode. Moreover, at the packet ID $60^{th}-70^{th}$, the wildfire still occurs but the temperature is stably high; the transmission mode is in the short range. It is not requires to quickly forward the packet to the base station since the temperature does not change. This cannot happen in the static threshold mechanism.

Figure 10 shows the transmission routes in the short range transmission mode and the long range transmission mode. In the short range transmission mode, the packets for sensor node 17 are forwarded in eight hops. The number of hop counts is reduced to only two hops in the long range transmission mode.

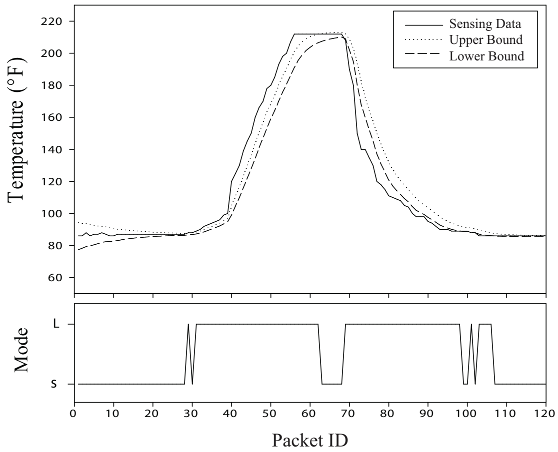

Fig. 9: Tranmission Mode Adaptation in *A-TRED*

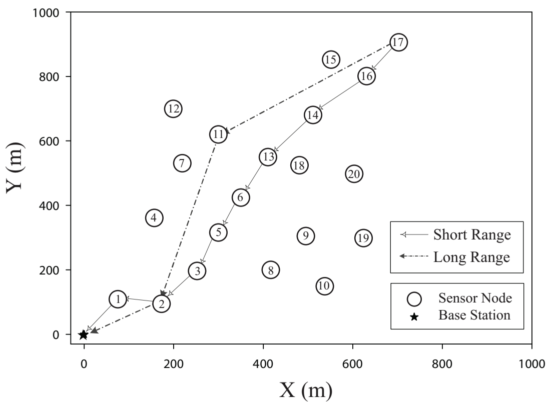

Fig. 10: Packet Transmission Routes

Figures 9 and 10 shows that the *A-TRED* mechanism leads the the transmission mode adaptation to the changes of sensing data.

B. Latency of Packets

It can be noted that long range transmission mode can send the data through the intermediate sensor nodes with in the small number of hop counts. This can reduce the latency of packets to arrive at the base station. Figure 11 shows the accumulate latency of a packets forwarding from sensor node 17 to the base station. When the long range transmission mode is applied, the latency of each packet is reduced from 1600 ms to 1200 ms compared to the short range transmission mode. In this case, *A-TRED* reduces the latency by 27.44% per packet.

C. Power Consumption

To show how *A-TRED* adapts the power consumption to the changes of the sensing data, three mechanisms, 1) always in long transmission mode (*ALT*), 2) always in short transmission mode (*AST*), and *A-TRED* are compared. It is showed in Figure 12 that the sensor nodes in *A-Tred* consume the energy in between that in *ALT* and *AST*. This happens

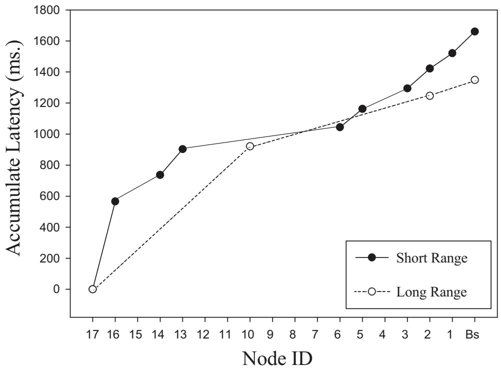

Fig. 11: Packet Latency

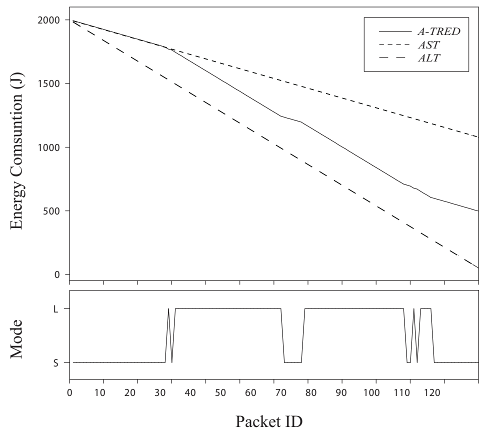

Fig. 12: Power Consumtion

because *A-Tred* can adapt to consume the energy according to the changes of sensing data. When sensor nodes are in the normal circumstances, *A-Tred* consume low energy as the same as *AST* mode does. In addition, when the sensing data changes dramatically, *A-Tred*consume high energy as *ALT* mode. By automatically adjusting the transmission mode, *A-TRED* contributes to keep the energy consumption low and it can consume energy more for increase the transmission range when the importance level of the sensing data becomes high. *A-TRED* mechanism automatically adapts the latency of the packets and the power consumption of sensor nodes to the changes of sensing data.

V. Related work

In [4], the authors proposed algorithm for saving energy of sensor node in WSNs. It uses black bone tree routing to sent data from a target node to the base station. In each times of sending of packet data, all sensor nodes have to insert energy level into data packet. when energy level is low, sensor nodes reroute to preserve sensor node that remains low energy. This paper focuses only energy consumption of sensor nodes but not realizes the importance of data.

In [9], the authors proposed algorithm, called LEACH (Low Energy Adaptive Clustering Hierarchy). LEACH is a hierarchical clustering protocol by beginning from sensor nodes attempt to cluster with nearest neighbor nodes to send data toward base station. LEACH solves the problem for energy consumptions of all sensor nodes and reduce energy in a WSN to prolong network lifetime. However, this paper focuses only energy consumption of sensor nodes but not realizes the importance of data.

VI. Conclusions

This paper proposes a mechanism, called adaptive transmission range based on event detection (*A-TRED*). *A-TRED* mechanism is applied in sensor nodes to adapt the transmission mode correspond with importance level of the sesning data. The simulation results show that *A-TRED* mechanism automatically adapts the latency of the packets and the power consumption of sensor nodes to the changes of sensing data.

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