ATTS-DF: Adaptive Tracking Solution to the Target for Data Fusion in Wireless Sensor Networks

Huy Duong-Viet, Viet Nguyen-Dinh

***Abstract*— Wireless sensor networks are composed of many sensor nodes limited to residual energy. The sensor nodes are randomly scattered within in the ranger monitoring and sending - receiving data by radio waves. The measured data often contains the same information, and sending to base station causes the waste of energy of sensor nodes and the risk of congestion. According to the statistics, the energy consumed by transceiver radio signals is many times greater than the energy consumes to process other tasks of sensor node including the calculation on the sensor node. In this paper, we propose algorithms installed on the sensor nodes to monitor non-cyclical target fixed, which base on the fluctuation of the target when it exceeds the threshold. Moreover, algorithm control sensor nodes measures just in time fluctuations exceeded targets need to measure.**

Keywords— adaptive tracking, data fusion, ATTS-DF, WSNs

I. Introduction

Currently, the monitoring systems with sensor networks are developed in sizes (number of sensor nodes, range monitoring, etc.) and qualities (parameter monitoring, the fineness of the measurement, etc.). The sensor nodes are limited to residual energy, thus the energy saving of sensor nodes has been studied seriously and cluster-based network is one of these studies. Clustering solution which splits the wireless sensor networks *(WSNs)* into many networks called cluster, data communication in the cluster can be singlehop or multihop [1]. Cluster head *(CH)* is responsible for data fusion and transferring data of target to base station *(BS).* After each round, the network must setup the new cluster and vote to new CH node to continue operations. In this paper, we consider a sensor node cluster is a miniature sensor networks. The "data fusion" *(DF)* or "data aggregation" are terms to express the concept of data fusion from multi-sensor in clusters of WSNs.

According to articles [2, 3, 4, 5], the energy loss due during the process of sending and receiving radio signals are many times greater than the energy consumption of other processes including the calculation on the sensor node. Therefore, we propose solutions ATTS-DF *(Adaptive Target Tracking Solution for multi-sensor Data Fusion in wireless sensor networks)* which save energy by optimizing energy of sensor nodes to track and measure the target and to send the results to the CH for data fusion (in CH). The paper includes 3 main parts: Analysis of the strategic monitoring target of sensor nodes by radio waves; proposed solution of ATTS-DF; analysis of efficiency and simulation evaluation of the proposed solution using NS-2 network simulator.

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II. Strategy of tracking target

A. Spatial classification

1) Target tracking methods

a) Complementary type

This tracking type in *Figure 1a*, the sensor nodes are not directly depended on each other. Each sensor node monitors different parts of target, measured results may be different but all measure events of the target. Thus, the measured value of the sensor nodes can be complemented to each other. Inputs to data fusion from the sensor nodes can be better [6].

b) Competitive type

In the *Figure 1b*, each sensor node independently measures all properties of the entire target. Fusion data from multiple measurement results of sensor nodes on the same set of attributes of the target, the measurement results can be different depending on the time sensitivity of the sensor nodes to the target at the same measuring time or at different measuring time. In this tracking type,the CH can tolerate better because CH can compare measured results of sensor nodes in the data fusion process [6].

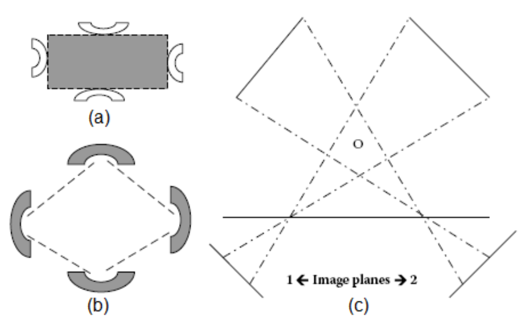

Figure 1. Models tracking [6].

c) Cooperative type

This type of tracking is shown in *Figure 1c*. Two sensor nodes measures by image of the target. A sensor node cannot measure all the target, CH uses additional measurement results (the intersection) of another sensor nodes [6].

2) Benefits and challenges

Sensor 1 can receive the signals where sensor 2 is not "seen". Sensor 1 provides additional information other than the information attributes are preconfigured in sensor 2. This enhances the ability to receive more information for sensor 2 as shown in *Figure 1c*. Using multiple sensor nodes will increase the dimension of space measurement, for example optical sensor, ultrasonic sensors will reduce noise data received, increasing the reliability of data and improving spatial resolution measurement data to create better resources data when data fusion at CH node.

However, a sensor signal reception can only receive signal in one certain range which it can observe (local characteristic). The sensor node which is far from target will consume a lot of energy to "hear" and may have received incorrect information due to the noise on the transmission line. The uncertainty of the obtained data depends on event source (the object to obtain information). If the noise is too big, the data obtained is only noise signals and has no value (no knowledge).

B. Classification based on time

1) Methods

Sensor nodes operate with 802.15.4 standard protocol, transmitting data to the destination node in each round and frames with the type of access CDMA *(Code Division Multiple Access)* and TDMA *(Time Division Multiple Access)*. Each sensor in the cluster nodes only transmits data in the time slot respectively defined by CH. Sensor nodes measures the target on the "wake - sleep" pattern, which means the sensor node can measure the target when it is at “wake” mode (active) and it does not measure when sensor node is in “sleep” mode, even if the target is changing which is required measurement. For that reason, measurement adaptive solution is proposed, sensor nodes "persistently" track the target and measure if the target change exceeds a threshold previously known δ. For example, temperature sensor node of electronic devices automatically turns off when the temperature is change X^0C where $|X| \leq \delta$, sensor nodes will measure and send this data to the control electronic device.

2) Benefits and challenge

Absolute advantage of this measurement method is adequacy measurement data because the sensor nodes are always in an alert state and send the data regularly to the destination even when measured data is exactly the same previously measured data. Using multiple sensor nodes will ensure the continuous availability, improve the ability to detect events when tracking overlooked.

Because the sensor node must need finite time to start perform some basic operations and send data to destination, thus it limits the frequency of measurements. Therefore, target tracking method is only appropriate when the target has a low frequency of change.

C. Energy consumption of the sensor node

According to the statistics [2], the energy consumed by transceiver radio signals is many times greater than the energy consumes to process other tasks of sensor node, including the calculation on the sensor node. The *figure 2* is the chart of energy consumption when the sensor node is operating.

The relationship between energy consumption E_{TX} when sending *k bit* with distance *d* and E_{RX} when receiving *k bits* have been explained by [1]: $E_{TX} = E_{elec}*k+E_{amp}*d^2$ *and* $E_{RX}=E_{elec}*k$, where E_{elec} is energy consumption of sensor node to send or receiving *1 bit*, E_{amp} is energy consumption of sensor node to sending *1 bit/m²* by radio signals.

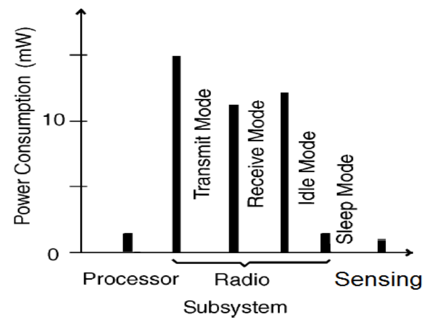

Figure 2. Energy consumption when the sensor node is operating [2]

Thus, the energy of the electromagnetic waves transmitted from the sensor node data will decrease exponentially with the distance between sender node and receiver node. To ensure the packet to its destination, the sensor node must manually adjust (amplifier) power of transmitter with the square of the distance [1]. For this reason, research groups focus to reduce the amount of data sent from sensor node.

III. ATTS-DF Solution

In the *Figure 2*, if classifying the processing based on the time that sensor starts measuring (sensing), the operation of sensor node has following steps:

- Sensing: is the time sensor node is active to track the target by the sensor node and quantity changes in the target with measured value and results.
- Transmit: Sensor nodes receive signals from CH to implement the protocol connecting before sensor nodes send to CH measurement results by radio signals
- Idle and sleep is the time period sensor node in idle state and can sleep depend on solution setting.

Solution ATTS-DF has two key ideas: *First*, the proposed measure is based on the change of target without depending on cycles time measured. That means the sensor nodes measures just when the target changes over threshold required to measure. *Second*, control sensor node to transition from standby state (idle or sleep) to measure in the steady state just in time the change of target to overcome threshold must to measure.

A. Concepts

1) Change measurement point

We propose *3* time points T_{before}, T_{point} , $T_{measure}$, where T_{before} is time point of the sensor nodes begin to turn on idle (or sleep), T_{point} is the time point to consider state transition of sensor node from idle (or sleep) to steady measurement state and called change measurement point, $T_{measure}$ is the time of deciding measurement. Time points and work status of sensor node are shown in *Figure.3*.

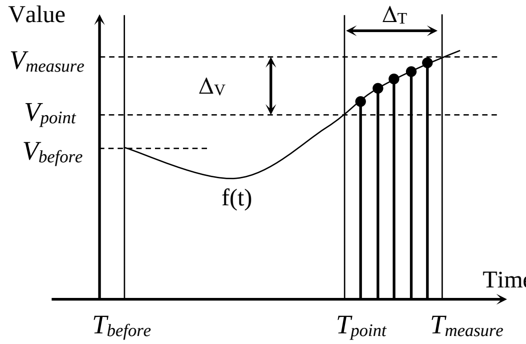

Figure 3. Time points and work status

We use T_{point} as the time to apply ATTS-DF solution. After this time point, the monitoring process of target is used to control and decide the change state of sensor node.

2) Measurement adaptive time

Assuming measurement value about target of sensor nodes can be represented by *f(t)* function of time. At the time point T_{point} , $f(T_{point}) = V_{point}$ tends to change the value to $f(T_{measure}) = V_{measure}$ at time point $T_{measure}$, difference value $\Delta_V = |V_{measure} - V_{point}| \geq 0$. Set Δ_T is measurement adaptive time. In Δ_T , *f(t)* decreases if $V_{measure} < V_{point}$ and *f(t)* increases if $V_{measure} > V_{point}$. Without loss of generality in this paper, we assume *f(t)* increases as *Figure 3*, then $f(t) \in [V_{measure}, V_{point}]$, $\forall t \in [T_{measure}, T_{point}]$.

3) Threshold measurement

We evaluated two subjects of measured threshold that are measurement target and measurement equipment i.e sensor nodes. A target can have multiple properties measurement (eg humidity, temperature, light, etc.), sensor nodes also must be able to measure those attributes if required. When target changes, if measured value of an attribute of the target deviation exceeds threshold value (set before) then sensor node will measure as explained in *Figure 4*. Normally, the change represented by the target and the sensor nodes can shape similarly but not entirely the same explained by the fact that electronics equipment is difficult to represent all change of the target. We set threshold measurement of sensor node is δ and assume δ is known. The valuation of δ quite interesting, we will study in another study.

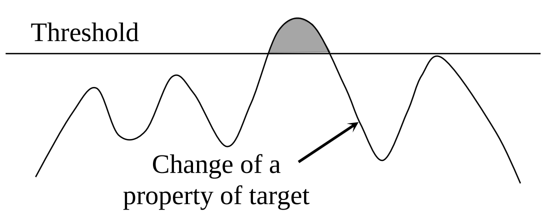

Figure 4. change of a property over the threshold

4) Steady state

Measurement of the target of sensor nodes bases on quantities electronically without the electrical properties of the target to become the quantities can be measured and processed by electronic signals. The stimulation of the target will affect the electronic components of sensor nodes which has delay response time Δ_{start} to operate in steady state as *Figure 5*. For the sensor, based on the physical properties of materials, components and production of sensor, Δ_{start} known and defined by hardware designers.

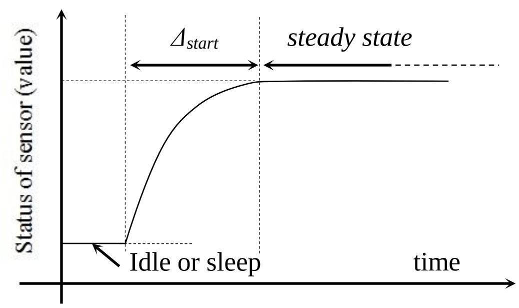

Figure 5. State switch model of sensor

5) Data prediction

Assume that Δ_{start} is delay response time, the ATTS-DF solution focuses on the relationship between Δ_{start} and Δ_T , where Δ_T as in *Figure 3* and is called adaptive measurement time, adaptive is ideal when $\Delta_T = \Delta_{start}$. In other cases, set $\Delta_{Adap} = |\Delta_T - \Delta_{start}|$, *then* $f(T_{measure}) = V_{measure} = \delta$. The problem to be solved is to predict the $f(T_{measure})$ value such that during Δ_T then *f(t)* increases with assumptions, $f(T_{measure}) \geq \delta$ and $\Delta_T = \Delta_{start}$. Means the sensor node start up to steady state timely target change to Threshold measurement shown in *Figure 6*.

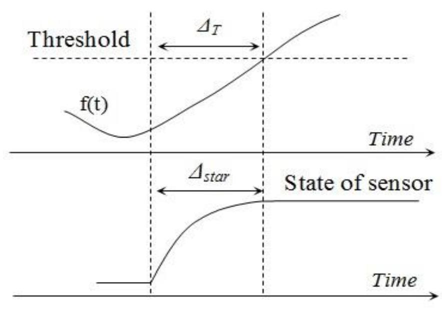

Figure 6. Adaptive of the ATTS-DF

Set Smo_{value} is smooth measurement of sensor nodes, $Smo_{value} = l$ means the sensor node can measure with *l* level $(V_1, V_2, \ldots V_l)$ *where* $V_1 < V_2 < \ldots < V_l$, smooth measurement will increase if *l* greater. Set Smo_{freq} is sensitivity or frequency measurement per 1 second (s) of sensor nodes in measurements steady state, set $Smo_{freq} = k$. Set *m* is the number of measurement about target of sensor node during Δ_T *(unit is second)*, $m = k * \Delta_T$, means the period Δ_T , *f(t)* can receive *m* in *l* value $(m \leq l)$ can be measured by the sensor node. Set $f(t)_{mi}$ is *f(t)* value at i^{th} measurement in period Δ_T . For example as shown in Figure3, $m = 7$, because *f(t)* increase in Δ_T , so $f(T_{point}) = f(t)_{m1} < f(t)_{m2} < f(t)_{m3} < \ldots < f(t)_{m7} = f(T_{measure})$.

In general, we apply probability theory to calculate the probability of the case $f(T_{measure}) \geq \delta$. Set $Pr_m(V_{tt})$ is probability of occurring measured values is V_{tt} of m^{th} measurement, where V_{tt} in $\{V_1,V_2...V_{l-1},V_l\}$, then $f(t) = V_{tt}$ and $Pr_m(V_{tt})$

$$\text{where} \sum_{t=1}^{l} \Pr_m\left(V_{tt}\right)=1$$

At m^{th} with time point $T_{measure}$, set $MaxPr_m(V_{tt})$ is the maximum probability of $Pr_m(V_{tt})$ to appear V_{tt} at time pointe $T_{measure}$ and set $f(T_{measure}) = V_{tt}$ used to control sensor node to steady state. That is, each measure gets only 1 in *l* value of sensor node measure level, the probability of getting results of *m* times measurements in Table 1.

TABLE 1. PROBABILITY OF MEASUREMENT

times measure in Δ_T	**smooth measurement of sensor**				$\sum_{t=1}^{l} \Pr_m(V_{tt})$
	V_1	V_2	….	V_l	
1	$Pr_1(V_1)$	$Pr_1(V_2)$	….	$Pr_1(V_l)$	1
2	$Pr_2(V_1)$	$Pr_2(V_2)$	….	$Pr_2(V_l)$	1
….	….	….	….	….	…..
m	$Pr_m(V_1)$	$Pr_m(V_2)$	….	$Pr_m(V_l)$	1

B. ATTS-DF Algorithm

1. *Input* $\delta, \Delta_{start}, l, k, f(t)$
2. *Specify* $m = k * \Delta_{start}$
3. *If* $f(T_{point})$ *increase (or decrease) then*
4. *For {set i 1} {$i <= $m } {incr i}*
5. *For {set tt 1} {$tt <= $l } {incr tt}*
6. *Specify* $Pr_i(V_{tt})$, *Select* $MaxPr_i(V_{tt}) = V_{tt}$
7. $f(t_i) = V_{tt}$

   # the case f(t) increase
8. *If* $(f(t_1) < f(t_2) < ... < f(t_m))$ *and* $f(t_m) \geq \delta$ *then*
9. *Turn on sensor status = steady state*
10. *If* $f(T_{point}) = f(t_1)) < f(t_{1+i})$ *and* $f(t_{1+i}) \geq \delta$ *then*
11. *Turn on sensor wait* $= (T_{point} + \Delta_{start} - t_{1+i})$
12. *Turn on sensor status = steady state*
13. *Return sensor status*
14. *End.*

Line 1, enter input value is the threshold *(δ)*, sensor response time Δ_{start} , smooth measurement of sensor nodes *(l)*, frequency measurement per *1s* of sensor nodes is *k*. Line 2, specify number of measurement about target of sensor node during Δ_T . Line 3, if at time point T_{point} , $f(t)$ increases *(or* decreases*)* then starts computing systems. Line 4, repeat scan to specify m values $f(t)$: $f(t_1), f(t_2)... f(t_m)$. Line 5, 6, 7, repeat scan to specify values $f(t_i)$, where $f(t_i)$ in $\{V_1,V_2...V_{l-1},V_l\}$, select the values $f(t_i)$ if it is the maximum probability.

This algorithm, we applied to *f(t)* increase. In the case of *f(t)* decrease, algorithms is similar. Line 8, 9 if *m* values of *f(t)* increase and at time point t_m, $f(t_m) \geq \delta$ just in time sensor node turn on steady state, it mean $\Delta_T = \Delta_{start}$. Line 10, if the period of time points T_{point} and t_m, *f(t)* increases, $\Delta_T < \Delta_{start}$ and at time point t_i where $i = 2..m$, $f(t_i)$ exceeds threshold while sensor nodes is not yet ready to steady state, then line 11, sensor node must be in waiting time $(t_i ... t_m]$ until the end of start-up time Δ_{start}. In this period, the sensor node will not measure data. This is an interesting problem, we will study in future articles. Line 12 to 14, switch status of sensor and return algorithm result.

IV. SIMULATION

A. Scenario for simulation

WSNs is established with *100* sensor nodes and one target. WSNs is divided into clusters, each cluster must have a CH node to receive data from all nodes in the cluster. After each cycle *T*, WSNs to divide into new clusters, each cluster votes a new CH to continue operate.

During operation, sensor node tracks the target and sends data to CH. The target randomly changes that also change the data the sensor sends to CH. ATTS-DF algorithm is applied when the data exceeds threshold. ATTS-DF with LEACH is evaluated in reducing packet and energy savings of sensor nodes.

B. Configure simulation

We use NS2 simulation software, version 2.34 installed on Ubuntu 12.04 operating system and source code from MIT *(Massachusetts Institute of Technology)*. The parameters of ATTS-DF simulation are in Table 2:

TABLE 2. THE MAIN PARAMETERS

Parameter	***Value***
Number of sensor nodes	*100*
Coordinates node in the (100mx100m)	*Random*
Number of BS, BS coordinates	*1, option*
Initial stored energy of sensor nodes	*2 J*
Energy to receive 1 bit	*5 nJ*
Energy consumption to send 1 bit	*50 nJ*
Amplification factor radio transmissions	$10pJ/bit/m^2$
Capacity of node while Idle or Sleep	*0 W*
stored energy of BS	*No limit*
Speed of radio transmissions	*1 Mbps*
Header size (hdr_size)	*25 Byte*
Sensing data size (sig_size)	*500 Byte*
Time per round (T)	*10 s (option)*
Number of sensor nodes in cluster (n)	*Random*
Number of measurement level (l)	*100*
Threshold (δ)	*26 (option)*
Frequency measurement per 1s (k)	*6 (option)*
Time of steady state (Δ_{start})	*2s*

C. Analysis and evaluate efficient

We use tracking model is competitive and target oriented method for tracking due to the known number of target and the result is measured per cycle *T* (in this article is *10s*). This study only refers to input data for data fusion at CH node.

We analyze *100* sensor nodes during the simulation time of *420* seconds, sensor nodes transmit data to CH with *T = 10s*. In each cycle, each node belongs to a cluster, 2 sensor nodes of a cluster in a particular cycle cannot be together in another cluster in a different cycle. However, we can calculate the total data *(sig_size)* which sensor nodes send and receive in each cycle and in all whole simulation. Data transmission of *100* sensor nodes during *420s* as shown in *Figure 7*.

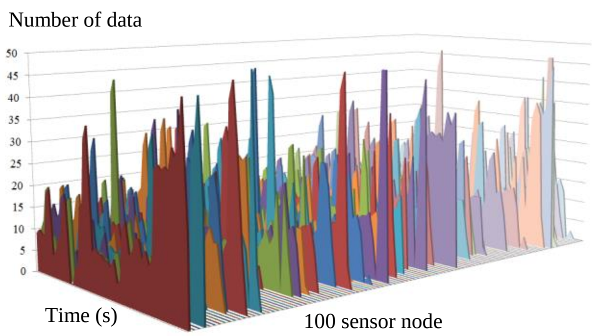

Figure 7. Data transmission of 100 sensor nodes

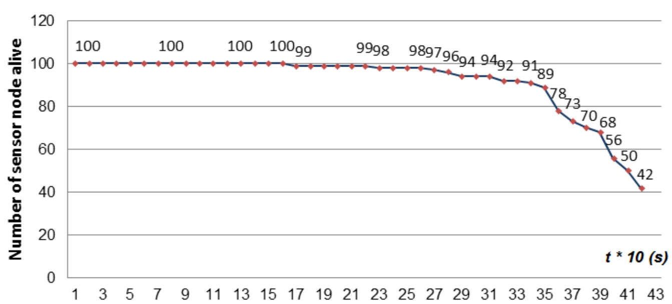

Figure 8. Number of sensor node alive in 420 s

Figure 8 shows the total number of sensor nodes alive in the survey during each round *T = 10s* during *420s*. During the survey, some sensor nodes will run out of energy and not participate in this sensor network. According to the simulation, from the *180th* second, some sensor start to die. number of sensor nodes dies increasing when time using sensor nodes stretching.

The amount of data assuming equal if they have the same information, the increase means that packets is increasing urgency to measure. For example, *Figure 9* is a graph data transmission of sensor node *16th* in *420s*, $\delta = 26$ *data*.

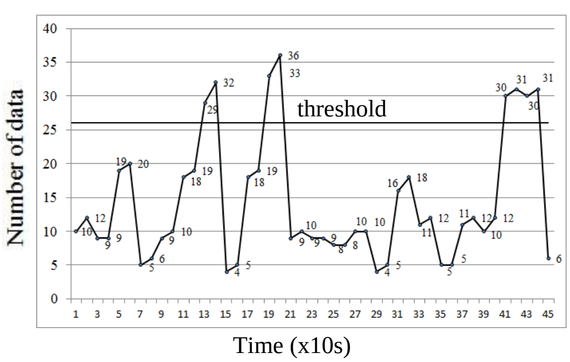

Figure 9. Data transmission of sensor node *16th*

At second *120th to 130th*, the period has exceeded measure δ and second *120th* data tends to increase. With *k=6* (mean is *6 times* per second), in the range increases of data from *19* data to $\delta = 26$ data at second *127th*, the number of times sensor node can be measured is *7s*6=42* times and *m=2*k=12* times. We calculated the case $\Delta T = \Delta_{start} = 2s$ and case $\Delta start > \Delta T = 1s$ means to wait for the transition sensor status is *1s*. Similarly for *180s to 190s* and *400s to 410s*. Sensor effective for sensor *16th* in the *02* cases that the sensor will not waste energy to transmit radio signals during Δ_{start} *(Figure 10a)* or Δ_{start}–ΔT *(Figure 10b)* compared to transmit continuous of LEACH in *420s*.

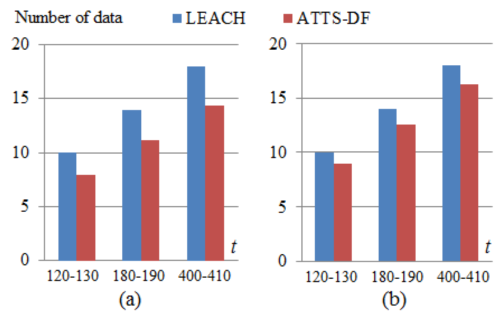

Figure 10. Effectively reducing the number of data of the sensor 16

Similar to consider energy efficiency of *100* sensor nodes during the *480s* with *48* rounds. In each round *T = 10s*, the algorithm will setup the clusters, each cluster selected *1* sensor node as cluster head node. We consider efficiency energy of each node during *480s*, of course *100* sensor nodes are not alive and active in this time. We apply ATTS-DF algorithm for each node per round *T = 10s*.

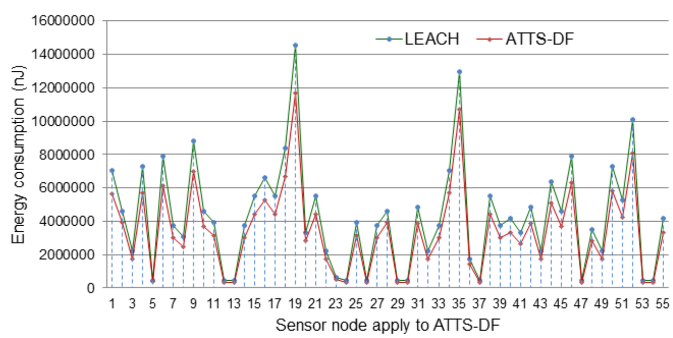

Figure 11. Energy consumption of ATTS-DF vs LEACH

The simulation results that, ATTS-DF can be applied to some of sensor node in some round. If the δ is reduce will increases the number of sensor nodes apply ATTS-DF algorithm. For example, with $\delta = 26$, there are *55* sensor nodes apply algorithm with the first time, *14* sensor nodes two times and *3* sensor nodes three times.

Evaluate the effectiveness of energy saving when applied ATTS-DF for sensor node and compared with the energy consumption of the respective sensor node when to applying LEACH. Results showed that, ATTS-DF save from *13.3%*

to *20%* of the energy of the corresponding sensor node. Graph of the energy consumption of the ATTS-DF algorithm and LEACH of sensor nodes as *Figure 11*.

CONCLUSION AND FUTURE RESEACH

ATTS-DF solution proposed a method base on measure of the changer of target, proposed switch status from idle (or sleep) to active/steady state just in time data exceeded threshold; proposed concept: change measurement point, measurement adaptive time, threshold measurement, steady state, data adaptive prediction method base on probabilistic theory.

The effectiveness of ATTS-DF versus LEACH [1] include: *first*, ATTS-DF is not measure target with fixed cycle that adjusted for measurement of target threshold have limited data capacity the same information data and energy saving because sensor node is not send this data to CH; *second*, the proposed measure the state switch of sensor node from idle (or sleep) mode to active mode just in time the sensor nodes can be measured in the normal state. This has limited the maximum time sensor node is enabled in active status but it have not yet reached the best state (steady state), this the cause to energy loss.

In fact, ATTS-DF algorithm is installed on the sensor to control operation of the sensor. ATTS-DF algorithm will promote the efficiency when the sensor network to measuring target with less volatility, less mutation

Future research: Define the relationship between energy of the sensor node, measurement and threshold value of δ. Also when the target sudden change measurement results exceeded sensor nodes before reaching a steady state measurement of a problem is interesting, we will study in the future.

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