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Minimising Energy Consumption in Wireless Sensor Network by Enhancement of LEACH Protocol

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Abstract

Wireless sensor network (WSN) is smart technology that consists of complex components, in which low battery life and energy consumption have become serious issues. Currently, the application of WSN keeps increasing, while the problem of energy consumptions also increases. Several studies have been conducted to overcome such issues, but still the issue remain challenging. To offer possible solutions, there is a need to introduce new technique that regulates the problems. This paper proposed possible schemes for enhancing energy saving in WSN by improving the algorithm "*Low Energy Adaptive Clustering Hierarchy*" (LEACH) Protocol. The research also analyses how to minimise energy dissipation and power required in WSN taking into consideration the total power, transmission frequency, transmission distance and transmission time between the sensors in a network. It also presents energy manipulations that help in solving the mentioned issues in various application of WSN.

Keywords*: Energy saving; Power dissipation; Wireless Sensor Networks; Low energy adaptive, Cluster Head, Node.*

1. Introduction

Wireless Sensor Networks (WSNs) are modern technology for data communication through wireless networks. WSNs consume more power and dissipate substantial amounts of energy in order to perform in-networks, detection and monitoring operations at various levels of applications. Energy consumption and power dissipation in WSNs have become serious challenges to the performance of their operations. In WSNs, the energy required to provide smart monitoring, detection and in-network activities remains a problems particularly for indoor operations, in which the data-centric temperature increases that eventually leads to more energy requirement [4].WSNs are smart system of communication that promises various applications at different deployment levels. They have unlimited resources ready to provide an exchange of data from deployment area to the base station. Some of the applications of WSN include: wildlife monitoring, pollution detection, marine applications, security applications, military, application, wildfire detection, medical sensing, marine, industrial detection system, hazard monitoring, alarm detection and the like [16][10]. However, in every algorithm or protocol of WSN, energy consumption has become necessary irrespective of the type of application or the nature of deployment. Considering the types of applications, thorough research will be conducted aimed at minimising the rate energy consumption in WSNs. Fig.1 illustrates the architecture of WSN.

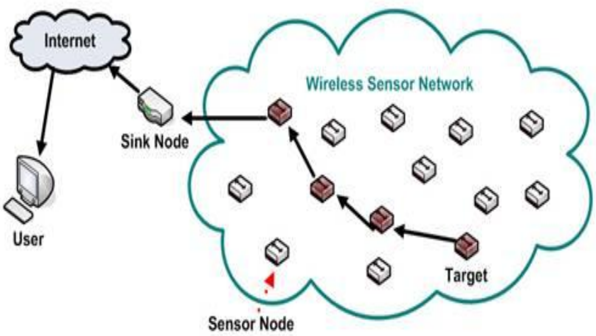

Fig. 1 Architecture of WSN [14]

Several techniques and procedures have been proposed aimed at reducing energy consumption and improving a lifetime of WSNs, but due to their dimensions and complexity, the requirement of energy is high and this leads to the network failure. To provide better solutions to the problems, in-depth research will be conducted aimed at minimising energy consumption in WSNs by enhancing the Low Energy Adaptive Clustering Hierarchy (LEACH)-protocol.

LEACH protocol improves a network's lifetime, the energy efficiency and reduces the energy consumption in the ecosystem of WSNs. It also improves the reliability and the robustness of the entire network [7][9][19]. According to [1][5][15][17], LEACH is a cluster-based protocol and it is self-organising system, in which the network is divided into a *set-up phase* and *a steady- state phase*. In the set-up phase, a cluster formation or clustering of the sensor nodes is established, where a number of nodes form a group headed by a cluster-head (CH) called a *cluster*. However, during the steady-state, communication and exchanges of information between the members of the clusters and from the CH and the base station (BS) is established [18].

This paper comprises the following sections: Section **2** review of the related works, Section **3** presents the employed research methods , Section **4** analyse the proposed improvement to LEACH-protocol, Section **5** discusses the proposed schemes and recommendation for further studies and this is followed by conclusion and future work in Section **6.**

2. Related Works

Several studies have been proposed aiming at improving energy efficiency, minimising energy consumption and power utilisation in WSN by enhancing the algorithm "Low Energy Adaptive Clustering Hierarchy" (LEACH) Protocol.

2.1 LEACH Protocol

Low Energy Adaptive Clustering Hierarchy (LEACH) protocol is cluster-base hierarchical protocols that provide high energy efficiency and low power dissipation in application of WSNs. It constitutes two operating states include: *set-up* and *steady-state phases* [13,12]. In LEACH every node in a cluster is privileged to be the head of the cluster by selecting a number randomly between 0 and 1, and if found that the selected number is less than the value of the threshold *T(n)* as expressed in research by Ma and Yu[11,8]: where ***P*** is the percentage of the nodes that preferred to be cluster-heads, **r** is the current round of cluster**,** and **G** is the nodes to waiting to be CHs**.**

[9] Described that Low Energy Adaptive Clustering Hierarchy (LEACH) is TDMA-based or cluster-based MAC protocol that improve low power consumption by segregating the sensor nodes into cluster, so that each node is controlled by a particular cluster that selected as cluster-head. The cluster-head is liable to set a time division for communication between the members of the cluster. In LEACH, there is no direct communication between the nodes and the sink, in its place the cluster-head is responsible for communicating the collected data to the sink. In this protocol, power consumption is regulated since nodes are operating based on time division.

In addition, [8] described that LEACH protocol has some limitation due to increase in overheads generated by dynamic clustering of the nodes, where an increase in overhead may result to low power storage or high energy consumption by the nodes. Thus, LEACH operates on two different phases that include *set-up* phase and *steady-state* phase, in which *set-up phase* compromises the forming of clusters and nomination of the cluster-heads, while in the *steady-state* phase, transmission of data between the nodes and the cluster-head is established.

However, a LEACH protocol introduces spatial clustering of sensor nodes for WSN and performs data aggregation using cluster-head. It improves balancing of power consumption of the nodes and the cluster-head. The protocol increases the mobility tolerance of the network protocol, where time is segregated into constant interval with equal dimension known as *topology update*. Thus, each sensor node becomes cluster-head at the beginning of time interval [13]. **Fig**.**2.** Scenario of Cluster formation in LEACH Protocol.

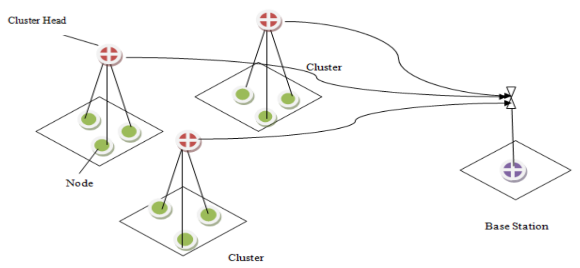

Fig. 2 Cluster formation of nodes in LEACH

2.2 Cell-LEACH

[20] Proposed an algorithm *called* Cell-LEACH aiming at improving network lifetime, minimising energy consumption during the steady-state phase of LEACH protocol. They proposed that each and every CH of the network comprises of seven subgroups of nodes called *Cell*, where in every cell, a Cell-head chosen to heading the cell. In this algorithm, Cell-head is responsible for aggregating information from the members of cell and communicates to the cluster-head (CH) and therefore the CH forwards the data to the base station (BS) for computation.

The researchers described that the algorithm prolongs network lifetime, reduces energy dissipation during the set-up phase, when sensor nodes are at *rest* during the data transmission from cell-heads to CHs. They further found that the cell-heads are responsible for sending an average energy to the nodes, and comparing this with the residual energy during cell formation. This algorithm is designed in such a way that all nodes are set on *sleep* or *off* from energy requirement except the one that is in-charge of the time slot.

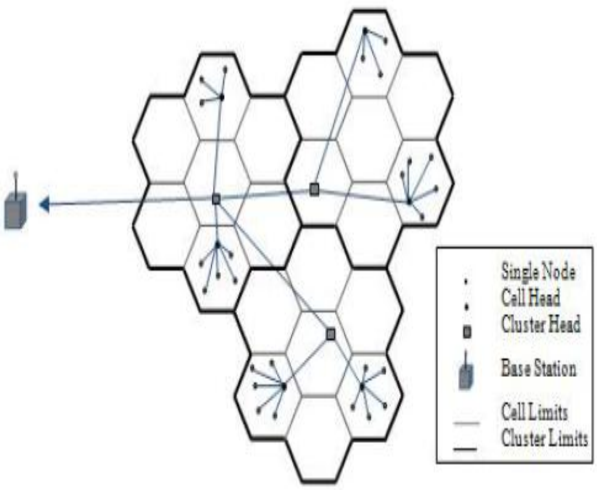

Fig.3 Structure of proposed Cell-LEACH [20]

2.3 LEACH-TLCH

[6] Proposed an improved algorithm based on LEACH referred to as two LEACH-TLCH or two levels cluster-head. The algorithm is proposed to improve the reliability of sensor nodes and reduces the rate of energy dissipation during the steady-state phase of the protocol in the ecosystem of the WSNs. In LEACH-TLCH, the original LEACH has been modified by introducing an additional CH *called* secondary-CH, where the secondary-CH is responsible for collecting information gathered by the spatially distributed nodes and disseminating to the main CH. LEACH-TLCH has provided good procedures for minimising energy consumption during the steady-state, because insertion of secondary-CH leads to decrease in distance between the CH and the BS. **Fig. 4** Proposed LEACH-TLCH.

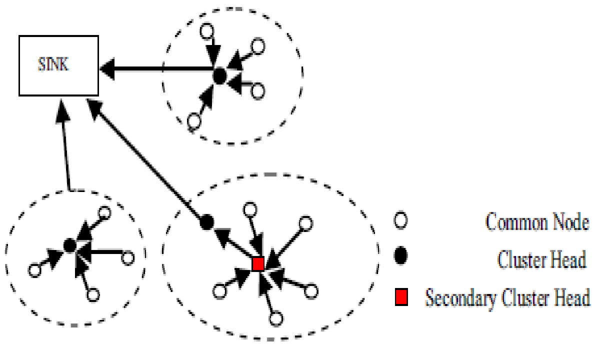

Fig.4 Structure of proposed LEACH-TLCH [6]

2.4 K-LEACH

[2] Proposed a modified LEACH-based protocol *called* K-medoids or K-LEACH. It aiming at improving network lifetime and provides energy balance within the network using Euclidian distance. In K-LEACH, a uniform clustering is established instead of random clustering as in non-improved version of LEACH. The algorithm shows that in first round of clustering, a node with higher residual energy is selected to be a CH, whereas for other round onwards a method of Euclidian distance is employed for CH selection, meaning a node that is next to CH is chosen as to be the CH.

2.5. Energy Improvement in LEACH Protocol

LEACH is a self-organised protocol and uses a round as entity that consists of a *set-up phase*, and a *steady-state phase*. During the *set-up phase*, clustering is established and a cluster of nodes is formed. In every round a node is elected as cluster-head (CH) after a number is randomly chosen between 0 *and* 1, a number is less than the threshold value T (*n*) is formed. Thus, the CH is now head of the cluster that consist of a number of nodes. The election procedure is expressed by the formula, T (*n*) given in research by [8]: ***P*** is the percentage of the nodes that desired to be cluster-heads, ***r*** is the current round of cluster**,** and ***G*** is the nodes to waiting to be CHs**.**

$$T(n) = \begin{cases} \dfrac{P}{1 - P \times [r \bmod (1/P)]}, & n \in G \\ 0, & \text{otherwise} \end{cases}$$

The primary objective is how to minimise energy consumption and improve network lifecycle during those phases, when more energy is exhausted. An increase in energy consumption can result in decrease in network lifetime, and a decrease in network lifecycle might lead to failure of the entire system. LEACH proposed a number of improved algorithms to overcome such challenges.

2.6 Analysis of LEACH-Based Protocol

In this research, various algorithms based on LEACH protocols have been analysed. The research found that the Low-Energy Adaptive Clustering Hierarchy (LEACH) protocol played an important role in reducing the amount of energy wastage in WSNs. LEACH protocol divides the network into two main phases: *a set-up* or cluster formation phase and a *steady-state* or data transmitting phase. In LEACH, apart from the energy consumption during the *set-up* and the *steady-state phase*s, there is also a radio transmitter circuit that consumes more energy in the nodes. Thus, it is required to focus on how to reduce consumption of power in this particular circuit or stage.

WSNs have been promised to provide new technology for information transfer from the distributed sensor nodes to the base station through wireless medium. This in turn extends the expectation of the system in large and continual basis at various levels of applications, where a disseminating of information from the source to end-user is achieved. Therefore, there is a need to find out a possible solution for minimising the amount of energy wastage as the results of these transformations.

In LEACH protocol, most of the algorithms were analysed using *experimental* or *simulations* analysis, and this will not provide actual energy consumption in WSN, because they only provides some assumptions or an expectation result using application software , but with calculation all the necessary analysis will be achieved.

3. Research Method

In this research, in-depth study has been conducted into various algorithms on energy consumptions and power dissipations in WSNs. Low Energy Adaptive Clustering Hierarchical (LEACH)-based protocol was selected as an appropriate protocol for minimising energy consumption in WSNs, since it provides an energy balance between nodes and their cluster-heads during data gathering and transmission. The authors employed two basic techniques for conducting this research: Review and analysis of various resources, protocols and algorithms proposed by prominent authors on energy saving in WSNs, and Circuit analysis and design of sensor's transmitting system. Several algorithms based on LEACH proposed by various authors were evaluated, after some methods for minimising energy consumption and improving network lifetime in WSNs were identified. This methodology covers energy calculations that involve amount of power dissipation, data transmission time, transmission distance and the transmitting frequency of the system. The design involve the analysis of energy consumption, power dissipation and the propose schemes for energy saving and minimising energy consumption in the wireless sensor network. In this study, we propose a system that provide low power utilisation and enhance energy storage despite the nature of the deployment area, in which the energy, power, frequency and time are the basic parameters used in determining that improvement of energy saving in WSNs.

4. Proposed Improvement on LEACH Protocol

In this research, four schemes were proposed for minimising power consumption and energy dissipation in WSNs by improving the LEACH-based protocol. The methods improve energy saving and reduce power wastage in the network. In LEACH protocol, sensor nodes are used to communicate during *set-up phase*, while disseminating the aggregated data to the cluster head (CH) during a *steady-state*. During these phases more energy is dissipated and maximum power is consumed due to the radio circuit of the transmitting system.

To clearly discuss the process for reducing energy consumption in WSN, Fig. 5 shows the proposed improvement to LEACH. Now, let consider the active *Nodes* A and B in the network, where CH is the cluster-head and BS is the base station. Now, to analyse the schemes for minimising or reducing the energy required and power consumption in WSNs, the transmitter of *Node* A and the receiver of *Node* B are selected to analyse the schemes. The transmitter of comprises of a *transmitting electronics* and a *transmitting amplifier*.

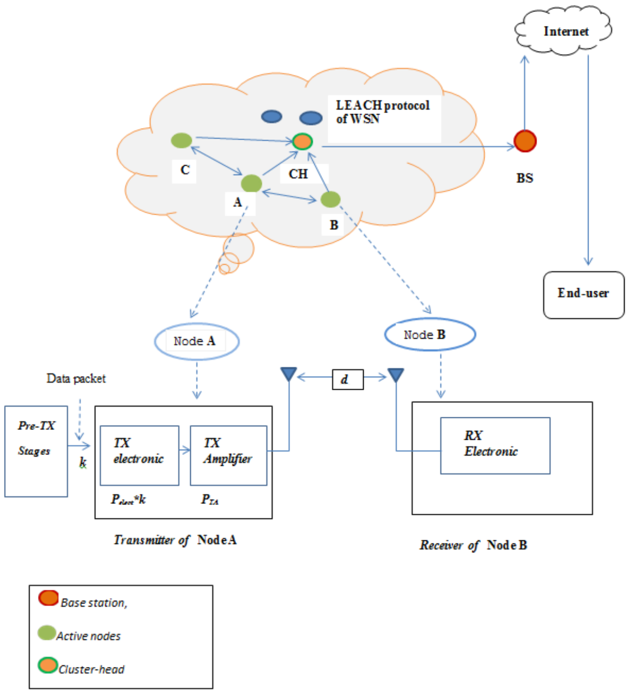

Fig. 5 Proposed improvement to LEACH

In Fig.5, let the power consumption in the transmitting electronics be P_{elect}, the power consumption in the transmitting amplifier to be P_{TA} and the total transmitting power dissipation in the node to be P_{Tx}.

Therefore:

$$P_{Tx} = P_{elec} + P_{TA} \;\ldots\ldots\ldots\ldots\ldots\; (1) \text{ in (watts)},$$

Thus, both the transmitting electronics and the transmitting amplifier consume more power and dissipate energy due to time delay as the result of filtering, oscillating and amplifying the *data packet* transmitted to CH or to *Node* B. Therefore, this *time* multiply the *power* consumed and yield to energy dissipation as in equation (2).

$$E_{Tx} = E_{elect} + E_{TA} \text{ ………………. (2) in (joules)}$$

Hence, the transmitting energy is increased by multiplying a *data packet* ***k*** into equation (2) and yield, the total energy consumed is given in equation (3).

$$E_{Tx}(k, d) = k{*}E_{elec} + \varepsilon_{amp}{*}k{*}d^2 \text{…… (3) in (joule/bit)}$$

Where, E_{Tx} is the total transmitting energy of *Node* A, $k{*}E_{elect}$ is the energy dissipated in the transmitting electronics. But, in any *RF* amplifier, amplification factor ε_{amp} is key factor to determine the efficiency of the amplifier after a data or signal is being amplified, it then moves to the antenna for transmission. However, transmission distance is also leads to energy wastage in the network. Now, let us consider ***d,*** which is the transmission distance from transmitter of *Node* A to receiver of *Node* B or CH as in Fig.

Considering the given parameters, we proposed a new improvement to LEACH that minimises the rate of power consumption and energy dissipation in WSN by designing the sensor system base on following schemes.

- Minimising the amount of power dissipation in transmitting *electronics* of the sensor, denoted by $E_{elect}{*}k$.
- Reducing the amount of power dissipation in *transmitting amplifier* of system, E_{TA}.
- Improving the power output ***Po*** of the *transmitting amplifier*.
- Minimising the total time, *T* that transmit a data ***k*** from the transmitter of Node A to the receiver of *Node* B as in Fig.**5**

4.1 Reduction of energy dissipation, $E_{elect}{*}k$ of the system

Power consumption in the transmitting electronics can be minimising by creating a two stages of power based on two *time frames*. The power stages are: *active power* and the *sleep power* with the time frames: time taken when power is *active* and time taken when the power is at *sleep* mode.

From equation (1), P_{elect}, is the power consumption in the transmitting electronics. Now let the power consumption when the P_{elec} is active to be P_{ap}, the power consumption when the P_{elect} is at sleep to be P_{sp}, the transient power due to discharge capacitor or inductance components to be P_{tr}, the time taken to dissipate an active power to be T_a, the time taken to dissipate the sleep power to be T_s and the transient time due the capacitance or inductance components to be T_{tr}. Fig. **6** Energy stored and power dissipated in the sensor's transmitter during *active* and a *sleep* time.

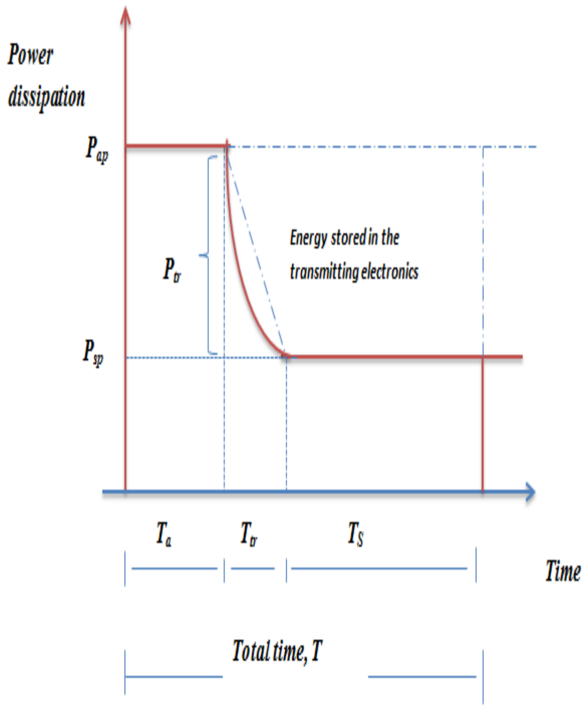

Fig. 6 Energy saved and power dissipated in the sensor's transmitter.

Consider the plot in Fig. 6 the total area under the curve is given by active power P_{ap} on vertical axis and the total time ***T*** at horizontal axis which is equal to the ***total energy consumed*** when the P_{elect} is at active mode.

In this stage energy consumption is higher due to the magnitude of the power and time, where $P_{elect} = P_{ap}$, and the energy dissipation in the transmitting electronics is given by**:**

$$E_{elect(active)} = P_{ap}{*}T{*}k$$

However, power consumption in the electronics is low if the stage is set at sleep mode, because the area under the curve is reduced and is given by:

$$E_{elect(sleep)} = k(P_{ap} * T_a) + (P_{sp} * T_s) + (P_{tr} * T_{tr}),$$

Where $P_{tr} = P_{ap} - Ptr$

$$= k(P_{ap} * T_a) + \left(\frac{Ptr * Ttr}{2}\right) + (P_{sp} * T_s)$$

Therefore, the energy stored in the transmitting electronic is given by

$E_{stored} = E_{elect(active)} - E_{elect(sleep)}$, and is equal to the area under the dotted lines.

4.2 Reducing the Energy Dissipation, E_{TA} of the Sensor

Equally, the energy dissipation, E_{TA} can be minimised by reducing the power consumption of the transmitting amplifier or the, P_{TA} at time, T as in **Fig. 7**

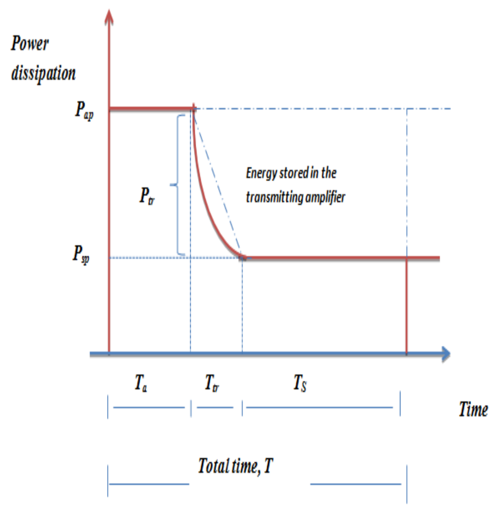

Fig. 7 Show the energy stored and power dissipated in the transmitting amplifier of a sensor node.

Thus, the energy dissipation in the transmitting amplifier at *active power* is given by*:*

$$E_{TA(active)} = P_{ap} * T * k,$$

Where the energy dissipation during *sleep* power will be:

$$E_{TA(sleep)} = k(P_{ap} * T_a) + \left(\frac{Ptr * Ttr}{2}\right) * + P_{sp} * T_s)$$

Therefore, the total energy stored in the transmitting amplifier electronics will be,

$E_{stored} = E_{TA(active)} - E_{TA(sleep)}$, which is equal to the area under the dotted lines.

It is now clear that the power consumption and the energy dissipation in the transmitter can be minimised by introducing a time *slots* or *frames* that automatically switch "*off*" or set to "*sleep*" the transmitting electronics when is not operating and switch "*on*" or set to "*active*" when is operating, and equally for the transmitting amplifier. **Fig**. **8** shows the total power dissipated and energy stored in the transmitter of a sensor system during the *active* and the *sleep* operation time.

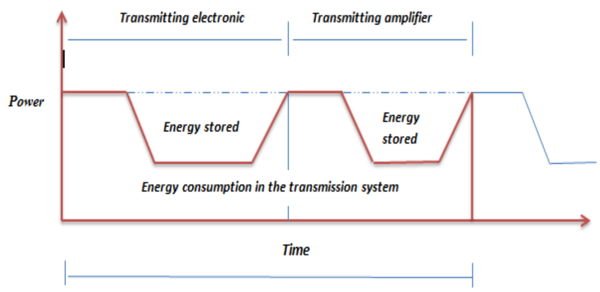

Fig. 8 Total energy consumed and energy stored in the transmitter of a sensor system.

4.3. Improving the Output Power P_o of the Transmitting Amplifier

Another scheme for minimising energy consumption in WSNs is to improve the power output ***Po*** of the transmitting amplifier of a sensor node and this can be achieved by reducing the wavelength **λ** and the impedance mismatches parameter between the antenna and the amplifier **η**.

Now**,** consider the **Fig. 9** that shows the transmitting system of a sensor node, which consists of a tune circuit and an amplifier. The aim is to improve the P_o of the amplifier so that the energy dissipation will be reduced.

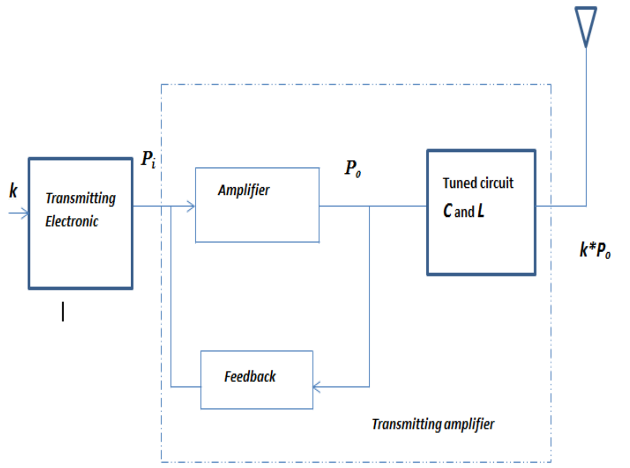

Fig. 9 Shows a block diagram of a transmitting system of a sensor node

To achieve this, the equation (4) is the power output P_o of the transmitting given in research of Goldsmiths (2005): d is the transmission distance, n is the path loss, G_T and G_R are the transmitting and the receiving antenna gains, λ is the RF signal wavelength and Prx is the receiver sensitivity.

$$P_o = (4\pi/\lambda)^2 * (d^n/\eta G_T G_R) P_{rx} \;\ldots\ldots\ldots\ldots\; (4)$$

But, WSNs uses an Omni-directional or isotropic antenna, where $G_R * G_T = 1$ and for wireless medium or free space, n = 2 and by substituting these values equation (4) is yield to (5).

$$P_o = \left(\frac{4\pi}{\lambda}\right)^2 * (d^2/(\eta)) P_{rx} \;\ldots\ldots\ldots\ldots\; (5)$$

In equation (5) the power output Po can be improve by increasing the value of the parameters λ , η and the distance d , but assume the distance d between the sensor nodes are static and η is constant. Therefore the adjustable parameter is λ.

But, WSNs are on UHF Band: with frequency ranges 300-3000MHz, a wavelength λ is between 1m – 100mmn and the Radio frequency (RF) signal is given by:

$$f = \frac{\lambda}{v} = \frac{1}{T} \text{(Herz)} \ldots\ldots\ldots\ldots (6)$$

v is the velocity of the transmission radio signal and is roughly $3x10^8$m/s, λ is the distance travelled by radio wave in meters (Louis, 2008, p.13).

Therefore: $\lambda = f * v$ (meter)

In addition, the transmitting frequency is automatically selected within the given range of 0.3 – 3GHz for WSNs.

4.4. Minimising the Transmission Time, *T*

The total time taking to convey a packet data from the transmitter of a *Node* **A** to the receiver of *Node* **B** might lead to more energy dissipation in the transmitter and the transmission distance d, because energy depend on power consumption and time. The next step is to minimise the time taken T to transmit the k bits across the transmission channel, where T is inversely proportional to the transmitting frequency **f** of the RF signal as in equation (7)

A time, T can be reduced by increasing the value of the signal frequency f_s, as in equation (8). Therefore, f_s can be adjusted by altering the value of L or *C*, where **L** and **C** are the inductance and the capacitance of the tuned circuit as Fig. 10.

$$T = \frac{1}{fs} \;\ldots\ldots\ldots\ldots\; (7)$$

$$f_s = \frac{1}{2\pi\sqrt{LC}} \;\ldots\ldots\ldots\ldots (8)$$

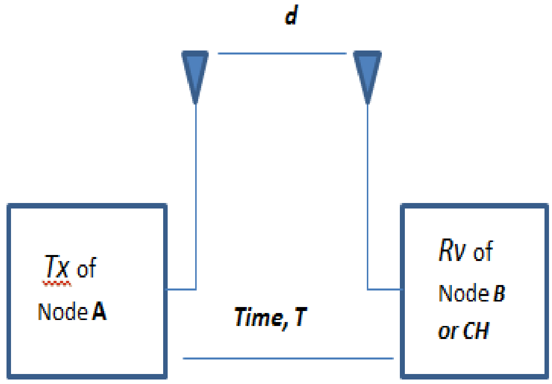

Fig.10 Transmission system from Node A to *Node* B

5. Analysis of Improved LEACH Protocol

In LEACH-based protocols, sensor hops are inserted between the CHs and the BS to minimise power consumption and energy dissipation *across the transmission channel.* The point here is that multiple of *hops* reduce distance ***d*** from one sensor to another, but this lead to transmission delay. This delay lead to increases in *transmission time,* while increased in transmission time ultimately lead to high energy consumption despite the fact that energy is a function of (*power, time*). If the value of ***T*** is reduced, the amount of energy consumption and power wastage will be minimum in the system. In addition, it is also important that frequency generator should be introduced to the system that will automatically switch to the desired transmitting frequency between 0.3 – 3GHz based on distance ***d*** and wavelength λ of the *RF* signal.

The proposed schemes are based on energy and power manipulation despite the fact that they offer clear expression and approximates values of power dissipation, data transmission time, transmission frequency and energy consumption in the network, unlike an *experiment* or a *simulation,* where the software and application errors usually the problem. This research provides low error results compare to *simulation* or an *experiment* that are probably subjected to inaccuracy and variations of results. This technique is simple to manipulate and easy to determining an error since the input and output of each stage of the sensor can determined measure with high accuracy.

5.1 Future Work

For further research, its recommended that, the researchers should put more emphasis on how to design and implement a *time frame* or *time slots* using digital electronics or software switching system that provides two switching operation: *active* and *sleep* mode as discuss under the analysis. So that during data computations, the transmitting electronics is at "*active*" while the transmitting amplifier is at *"sleep"* mode and vice versa. It also important to investigate further research on how to design a software program or digital circuit that determine the operating frequency of the RF signal by specifying or adjusting the transmitting distance between the transmitting and the receiving nodes. Most importantly, it is suggested that other researchers should try to improve the power amplifier of a sensor node by designing a low-power inductive or capacitive chip and avoid high resistance or impedance chip, despite the fact that high resistance power amplifier consume more power.

Meanwhile, software expert or programmers should design an automatic switching program that set the transmitting electronics into *sleep* mode when other stages such as filters, oscillator, or controllers are *active* and set such stages to *sleep* mode when transmitting amplifier is *active*. Thus, if this achieve, energy consumption and power dissipation will be less and in turn energy efficiency will be improved.

6. Conclusion and Future Work

In this research, four possible methods for improving low energy consumption and power saving in wireless sensor network (WSN) have been proposed. The authors analysed the process, procedures and manipulations for regulating the substantial amount of energy and power utilisation in WSN. The research offered an improvement to Low Energy Adaptive Clustering Hierarchy (LEACH) Protocol using a radio model of sensor's transmitter. It also studies the parameters that offer possible solutions that improve energy saving in WSNs. Finally, this paper has not provided a complete analysis of the findings due to scope, material limitation and the constraint of the methodology employed. For future research

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