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Wireless Sensor Network over High Altitude Platform

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Abstract

One of Machine Type Communication (MTC) applications is Wireless Sensor Network (WSN). WSN is an intelligent network application system to collect, integrate, and transmit data autonomously. Sensor nodes in WSN, communicate over short distance via a wireless medium and collaborate to accomplish a common task, such as enviroment monitoring, military surveillance and industrial process control. The constraining aspect of WSN usage is the limited power of each sensor node, so energy efficiency becomes an important issue in WSN. Routing is a function in WSN, which consumes a substantial amount of energy. One of the routing protocols that can increase the energy efficiency of WSN is Low Energy Adaptive Clustering Hierarchy (LEACH). In this paper, High Altitude Platform (HAP) is used to replace Base Station (BS) as sink node in WSN. HAP is designed at altitudes of 17, 20 and 22 km. Then WSN over HAP using the LEACH routing protocol evaluated its performance. Performance indicators that we evaluated are engergy consumption, number of dead nodes and total average packets which is sent to HAP. From a series of simulations conducted, the results obtained that the higher the laying of HAP, then the coverage area will be greater. So that the energy consumption will be smaller, the number of dead node less and the avarage of total packet delivered to the HAP will be greater.

Keywords: WSN, HAP, LEACH, energy consumption

1. Introduction

Wireless Sensor Network (WSN) is one of Machine Type Communication (MTC) application for monitoring and sensing. WSN is an intelligent network application system to collect, integrate, and transmit data autonomously [1]. The sensor node collects the needed data from an observation region. Then the data are processed in a processing unit and subsequently forwarded over a wireless channel to a base station (BS), where they can be accessed by a user [2].

The constraining aspect of WSN usage is the limited power of each sensor node, so energy efficiency becomes an important issue in WSN. Routing is a function in WSN, which consumes a substantial amount of energy. Without specific routing protocols, even with low energy consumption, the lifetime and WSN connectivity will be degraded. One of the routing protocols that can increase the energy efficiency of WSN is Low Energy Adaptive Clustering Hierarchy (LEACH).

High Altitude Platforms (HAPs) are airships or planes operating in statosphere at 17 – 22 km altitude. These platforms have the ability to deliver information quickly and are able to serve a number of users using less communications infrastructure than required by terrestrial transmission system [3]. HAPs system has many advantages, such as ease of implementation and configuration, low operating cost, low delay propagation, high elevation angle, wide coverage, has the ability to broadcast as well as broadband capabilities and the ability to move in emergency situation [4].

In this paper, a Base Station (BS) will be replaced with HAP. So, the data collected by the sensor nodes is forwarded over wireless channel to HAP using LEACH routing protocol.

2. Research Method

In WSN over HAP, HAP is used to replace the BS as sink node. HAP is designed at an altitude of 17, 20 and 22 km. The coverage diameter can be obtained by using equation (1) [5].

$$d = 2R \left(cos^{-1} \left(\frac{R}{R+h} \cos(\alpha) \right) - \alpha \right)$$

(1)

Where h is altitude platform in km, R is radius of the earth in km, α is elevation angle in degree. In the design, it is assumed that elevation angle and radius of the earth are 0° and 6384 km. Therefore, the diameter of the coverage area of HAP is 1000 km for an altitude. In the design of WSN, HAP is used to replace Base Station.

WSN over HAP is implemented using clustered topology. In clustered topology, the sensor nodes inside the HAP cell are organized into a cluster, and each cluster has a cluster head (CH). Sensor nodes in each cluster sends data to CH respectively. CH will collect the data and send it to the HAP. Clustering is one form of hierarchical routing that can help power saving sensor nodes and thus can extend the lifetime of the network.

For this topologies, Low Energy Clustering Hierarchy (LEACH) routing protocol is used. LEACH is an adaptive clustering protocol that uses rotation randomization method to balance energy load for each sensor in the network [6]. LEACH algorithm is divided into two phases [7]:

2.1. Set Up Phase

In the setup phase, the process of determining the cluster head (CH) and cluster formation, or often called clustering algorithm, is carried out. In this phase, LEACH selects several sensor nodes to act as a CH. Once the CH is formed, the CH node must broadcast an advertisement (ADV) Multiple Access/Collision Avoidance (CSMA/CA). This message contains the ID Node and Header. When the non-CH nodes receive the ADV message, they will send a joint request (JOIN-REQ) message that contains ID Node and ID Header to the CH node that they choose based on the strongest received signal to join and form a cluster [6]. When the CH nodes receive a JOIN-REQ message, they will make a TDMA schedule for each member of their cluster.

The nodes that act as a CH will expend more energy than non-CH nodes [6, 8-10]. This is because the CH nodes receive data from all other nodes in the cluster, compress the data, and send the data to the Base Station located farther than the distance between one non-CH node to another [6]. Therefore, in order to keep the energy consumed by each node equitable, each node that acts as a CH will be substituted by other non-CH node at the next round (r+1). Every node has a chance to be a CH. Each node number i that contends to be a CH will choose a random number between 0 and 1. If the random number is less than the threshold (P_i) and the number of clusters that have been formed is smaller than the desired number of clusters, then the node number i will be elected as CH. The threshold value can be calculated using (2) [6,9,11].

$$P_i(t) = \begin{cases} \frac{k}{N - [k\, r(\mathrm{mod}(N/k))]} : C_i(t) = 1 \\ \\ 0 \qquad\qquad : C_i(t) = 0 \end{cases}$$

(2)

where k is the number of CH, N is the number of sensor nodes in the network and r is the number of rounds that have been completed. C_i is a function that indicates whether or not the node number i is a CH in the most recent round. If node i is a CH in the most recent round the value of C_i is 0 and C_i is 1 if node i is eligible to become a CH. The threshold value for the node that acts as a CH will be set to 0 in the next round. A node that acts as a CH will be re-elected as a CH after N/k rounds because the energy of every node is expected to be the same after N/k rounds. Equation (2) is used if the existing nodes in the network have the same energy. If the energy of each node is different, then the threshold can be determined using (3) [6,9,11].

$$P_i(t) = \frac{E_i(t)}{E_{total}(t)}\, k$$

(3)

where E_i is the current energy of node i in Joules, E_{total} is the total energy of all nodes in the network in Joules and k is the number of clusters. Thus, the nodes that have more energy will be chosen as a CH more often.

2.2. Steady State Phase

In the steady state phase, the CH nodes receive all data from each member of the cluster, compress the data and forward the data to the Base Station (BS). The non-CH nodes will send the data to CH nodes according to a TDMA schedule.

The power used to transmit the message is affected by the distance between the transmitter and receiver. If the distance between the transmitter and receiver is smaller than d_0, a threshold value, the free space propagation model is used in the simulation. Otherwise, if the distance between transmitter and receiver is greater than the crossover distance, the two-ray ground propagation model is used in the simulation. A threshold value can be calculated using (4) [12].

$$d_0 = \frac{4\,\pi\,h_R h_r \sqrt{E}}{\gamma} \tag{4}$$

where h_R and h_R are the height of the receiver and transmitter antenna in meters, γ is the wavelength in meters and E is the energy consumed during transmission. Power used to transmit information/message can be calculated using (5) [6, 12].

$$E_{Tx}(l, d) = \begin{cases} l\,.\,E_{elec} + l\,.\,\varepsilon_{fs}\,.\,d^2, & d < d_0 \\ l\,.\,E_{elec} + l\,.\,\varepsilon_{amp}\,.\,d^4, & d \gg d_0 \end{cases} \tag{5}$$

where E_{Tx} (l,d) is the energy consumed while sending l bit data by sensor nodes from d distance, d is the data transmission in meters, l is the length of data packege sent, E_{elec} is energy consumed by radiating circuit when processing 1 bit data in J/bit, ε_{fs} is energy consumed by transmit power amplifier when sending 1 bit data to unit area in free space channel model in J/bit/m^2, ε_{amp} is energy consumed by transmit power amplifier when sending 1 bit data to unit area in multipath fading channel model in J/bit/m^4. Put $d0$ into the equation (5), so threshold value will be [12]:

$$d_0 = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{amp}}} \tag{6}$$

The simulation is performed using MATLAB R2016b. The number of CH is varied, that is 1,2,3,4 and 5. For the simulation, 100 nodes are positioned randomly in the network. The purpose of this simulation is to see the effect of HAP altitude on HAP-based WSN performance using LEACH routing protocol. Performance indicators that we evaluated are energy consumption, number of dead nodes and the average total packets sent to the sink node. The energy consumption observed in this simulation is the total energy used by each node in the network to send and receive data. The simulation parameters are shown in Table 1.

Tabel 1. Simulation Parameter

Parameter	Value
Simulation Area	1000 km x 1000 km
Simulation duration	1000 iteration
HAP position	(500,500,20)
Number of nodes	100
Initial Energy of each node	0.5 Joule
ε_{fs}	1.10^{-11} Joule
ε_{amp}	13.10^{-15} Joule

3. Results and Analysis

The parameters given in Section 2 are used to simulate the WSN over HAP using LEACH routing protocol. In this simulation, the number of nodes were 1000 nodes, and the number of clusters used are 1, 2, 3, 4 and 5. Figure 1 shows nodes and HAP position in simulation area.
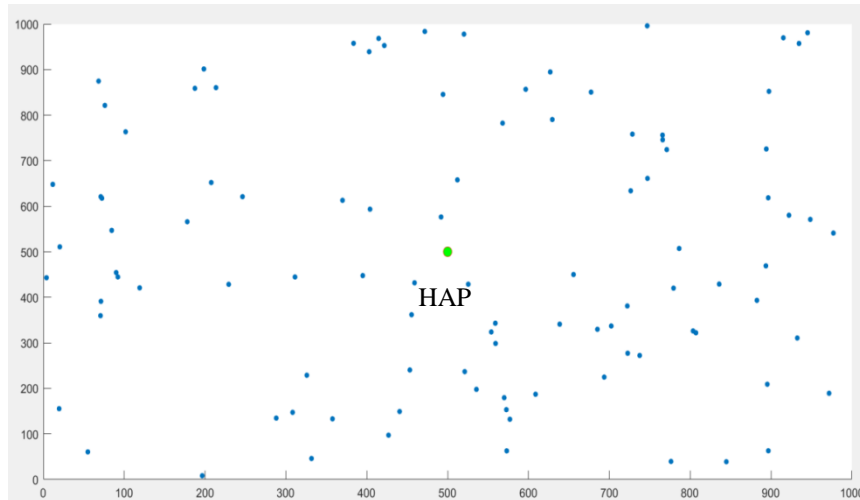

Figure 1. Nodes and HAP position in simulation area

The result of energy consumption for WSN over HAP for altitude of HAP are 17 km, 20 km and 22 km in Table 2.

Tabel 2. Energy Consumption for WSN Over HAP

Number of Clusters	Energy Consumption [Joule]		
	17 km	20 km	22 km
1	48,8932	47,2982	47,1847
2	45,7700	45,2782	40,3985
3	47,0786	40,4505	37,7874
4	47,1841	47,7674	38,5067
5	47,6137	46,8150	43,8322

Tabel 2 shows that optimal cluster number is 3. It is because the energy consumption for the number of clusters equals to 3 is smaller than the energy consumption for other numbers of clusters. And also from Table 2, it can be seen that, the higher the HAP, the less energy consumption. Because, on a network with a 17 km HAP altitude, there is a sensor node that is outside the HAP range, so the sensor node tries to continue sending to CH, CH to HAP, because it is out of range, the data can not reach the HAP and energy is exhausted for the communication.

Table 3 shows that the least number of dead nodes can be achieved when the number of clusters equals to 3.

Tabel 3. Number of Dead Nodes

Number of Clusters	Number of Dead Nodes		
	17 km	20 km	22 km
1	95,8450	92,8370	91,6690
2	92,7350	92,1040	92,7840
3	91,2040	89,5680	88,6980
4	92,5890	92,1440	91,3360
5	92,9140	92,0260	91,7290

Table 4 shows that when the number of clusters is equal to 3, the average total packets sent to HAP is greater compared to that of other simulated clusters. It is because, when the number of clusters is equal to 3, the number of dead nodes is smaller than that of other clusters.

Tabel 4. Total Average Packet

Number of Clusters	Total Avarage Packet [Bytes]		
	17 km	20 km	22 km
1	1898,8	2701,4	2979,1
2	2306,6	2506,5	2660,9
3	3082,2	3106,7	3374,3
4	2775,7	2830,7	2906,6
5	2680,2	2834,9	2939,7

4. Conclusion

A set of simulation showed, it appears that the high of HAP will affect the performance of WSN. The higher the HAP layout, the greater the coverage area. So the energy consumption will be smaller, the number of dead node less and the total package delivered to the HAP is high. And from the simulation, that the number of optimum cluster when the number of clusters is equal to 3. Because, when the number of cluster is equal to 3, the energy consumption is low, the number of dead nodes less and the total average packet sent to HAP is the highest.

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