

Wireless Sensor Network Exploiting High Altitude Platform in 5G Network

Jaringan Sensor Nirkabel Menggunakan High Altitude Platform pada Jaringan 5G

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ABSTRAK

Perkembangan teknologi dan transformasi sosial-ekonomi telah menyebabkan bisnis jaringan seluler 5G mengalami perubahan, sehingga jaringan seluler 5G diharapkan dapat mengirim informasi dengan cepat dan mendukung kasus penggunaan yang banyak bermunculan dari berbagai aplikasi. Salah satu kasus penggunaan pada jaringan 5G adalah massive Machine Type Communication (MTC). Salah satu aplikasi massive MTC adalah jaringan sensor nirkabel (JSN). Tantangan bagi jaringan seluler 5G ini adalah bagaimana memodelkan arsitektur/topologi untuk mendukung JSN dan bagaimana mengatasi masalah efisiensi konsumsi energi di JSN. Untuk menjawab tantangan ini, maka diterapkan sistem HAP yang terintegrasi JSN dan menggunakan protokol routing Low Energy Adaptive Clustering Hierarchy. Sistem HAP dirancang untuk digunakan di ketinggian 20 km dengan topologi tanpa dan dengan clustering, menggunakan 1.000 node sensor. Sistem ini telah disimulasikan dengan menggunakan MATLAB. Simulasi dilakukan untuk melihat konsumsi energi, jumlah node yang mati dan rata-rata total paket yang dikirim ke HAP untuk topologi tanpa dan dengan clustering. Dari serangkaian simulasi, terlihat bahwa topologi dengan clustering dapat mengurangi konsumsi energi dan jumlah node yang mati, sekaligus meningkatkan total paket yang dikirimkan ke HAP.

ABSTRACT

Technology development and socio-economic transformation have increased the demand for 5G cellular networks. They are expected to send information quickly and support many use cases emerging from a variety of applications. One of the use cases on the 5G network is the massive MTC (Machine Type Communication), wherein wireless sensor network (WSN) is a typical application. Challenges faced by a 5G cellular network are how to model an architecture/topology to support WSN and to solve energy consumption efficiency problem in WSN. So, to overcome these challenges, a HAP system integrated with WSN which uses Low Energy Adaptive Hierarchy routing protocol is implemented. The HAP system is designed to be used at a 20-km altitude, and the topologies used are those with and without clustering. It uses 1,000 sensor nodes and Low Energy Adaptive Clustering Hierarchy protocol. This system was simulated using MATLAB. Simulations were performed to analyze the energy consumption, the number of dead nodes, and the average total packets which were sent to HAP for non-clustered topology and clustered topology. Simulation results showed that the clustered topology could reduce energy consumption and the number of dead nodes while increasing the total packet sent to HAP.

1. Introduction

Development of technology and socio-economic transformation have changed the business of 5G cellular network. This fact is marked by the change of customers, technologies, and operators. 5G mobile network is expected to send information quickly and deliver one-touch connectivity (Hattachi and Erfanian, 2015).

5G will support use cases that are emerging with various applications and performance attributes, such as video applications that are sensitive to delay, high-speed internet entertainment application in vehicles, best-effort applications, and applications that are reliable. These use cases will be delivered through a variety of devices, such as Smartphones and Machine Type Communication (MTC) (Hattachi and Erfanian, 2015).

One of use cases on a 5G network is massive internet of things, which includes massive MTC with low cost/long distance/low power and broadband MTC. One case of MTC is wireless sensor networks (WSN). In the WSN, device sensors will be deployed in urban, suburban, and rural areas for metering (e.g., gas, energy, and water), city or building lights management, environment monitoring (e.g., pollution, temperature, humidity, and noise) and vehicle traffic control. To support massive MTC, the 5G network must meet several requirements, such as high data rate, high quality of experience for users, low end-to-end latency, and energy consumption is lower than the previous generation (Ekram and Monowar, 2015). With their requirement in sub-millisecond latency, and considering the bandwidth limitations in the traditional wireless spectrum, the cellular wireless network is expected to shift 5G network topology from base station-centric to a device-centric network (Boccardi et al., 2014) and (Agiwal et al., 2016).

5G mobile technology works with a large number of users as well as a wide range variety of devices and services. Some of the challenges in 5G mobile technology are how to model an architecture/topology for massive communication to support WSN and to solve high energy consumption problem in WSN. To overcome these challenges, a HAP system integrated with MTC is used. In this case, HAP is integrated with WSN, where sensor nodes in WSN are grouped in clusters using Low Energy Adaptive Clustering Hierarchy (LEACH) routing protocol. The HAP-WSN system was subsequently simulated using MATLAB to analyze the energy consumption, the number of dead nodes, and the average number of total packages sent to HAP for two different topologies: non-clustered topology and clustered topology. In this paper, the author only evaluates the system performance based on the number of clusters in WSN.

2. Literature review

2.1. 5G Cellular Network Architecture

The latency requirement in sub-millisecond order, and the fact that bandwidth limitation exists in the traditional wireless spectrum, have triggered the 5G cellular wireless network to shift its topology, from Base Station (BS)-centric to a device-centric network (Boccardi et al., 2014) and (Agiwal et al., 2016), as illustrated in Figure 1.

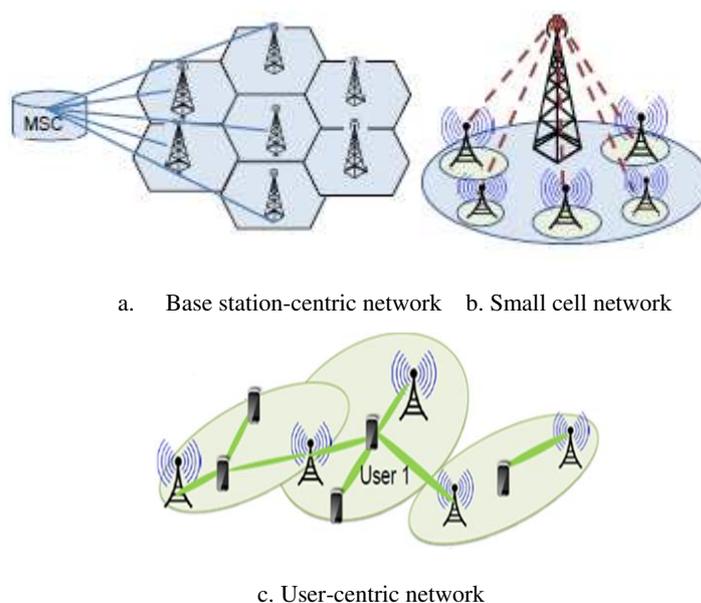


Figure 1. The shift from BS-centric to user-centric architecture (Agiwal et al, 2016).

Figure 1 describes the gradual movement from BS centric to device-centric network. The increased demand of wireless industry is motivated by the progress of implementation of smaller cells. Currently, researchers focus on how to design a network using user-centric architecture network. Users in the network are expected to participate in the storage, forwarding, content delivery, and also in performing computations. Future networks are expected to connect a variety of nodes in different distances.

2.2. Cellular Network Architecture System using High Altitude Platforms

High Altitude Platforms (HAPs) are airships or planes operating at the stratosphere at 17 – 22 km altitude. These platforms have the ability to deliver information quickly and can serve a number of users using fewer communications infrastructures than which are required by terrestrial transmission system (Grace et al., 2002).

HAPs system has many advantages, such as ease of implementation and configuration, low operating cost, low delay propagation, high elevation angle, wide coverage, having the ability to broadcast as well as broadband capabilities and the ability to move in an emergency situation (Karapantazis and Pavlidou, 2005).

Djunik et al. (1997) proposed following HAPs architectures on cellular system:

a. Ring-shaped Cell Clustering

This architecture has a coverage area which consists of a set of concentric rings. It can simplify the design of multibeam steerable antennas and handoff algorithms; since each cell has only one or two neighbours.

b. Cell Scanning

In this architecture, the beam scans each cell at regular or irregular intervals. The traffic intended for a cell should be buffered until the scanning beam visits that cell. Likewise, the data at each user terminal should be buffered until the beam visits the representative cell. More than one beam can be used to perform a scan.

c. Stratospheric radio-relay

This architecture was proposed for maritime communications systems. In this architecture, the HAPs chain can be placed on top of Atlantic ship lanes, offering typical maritime services, such as voice, data, video, paging, and broadcasting.

2.3. Massive Type Communication

Massive-Type Communication (MTC) occurs between machines having the ability to compute without human intervention. The main feature of MTC is its ability to generate the data automatically, and subsequently process, transmit, and exchange information between intelligent machines with minimal human intervention (Zhang et al., 2012).

MTC connects a large number of devices, such as smart metering, smart grid sensors, and equipment throughout the area of coverage (Asadi et al., 2014). MTC consists of many devices with small data, sporadic transmission, high reliability, and it operates in a real time.

In 2020, the number of machines that will be integrated into the mobile network is estimated at 50 billion (Morioka, 2016), nearly doubling those existing today. Thus, MTC becomes an important element in the system in the future.

One application of MTC is for monitoring and sensing (Cao et al., 2016). Monitoring and sensing are modeled in Wireless Sensor Network.

2.4. Wireless Sensor Network

Wireless Sensor Network (WSN) is one of MTC's application for monitoring and sensing. WSN is an intelligent network application system to collect, integrate, and transmit data autonomously (Pratap et al., 2012). These sensor nodes communicate over short distance via a wireless medium and collaborate to

accomplish a common task, such as environment monitoring, military surveillance, and industrial process control.

The sensor nodes are usually scattered in a sensor field, as shown in Figure 2 (Akyildis et al., 2002). Each of these scattered sensor nodes has capabilities to collect data and route the data to a sink node. Data are routed to the sink by a multihop infrastructure-less architecture through the sink. The sink may communicate with the task manager node via Internet or satellite. So, the data can be accessed by the users, as shown in Figure 2.

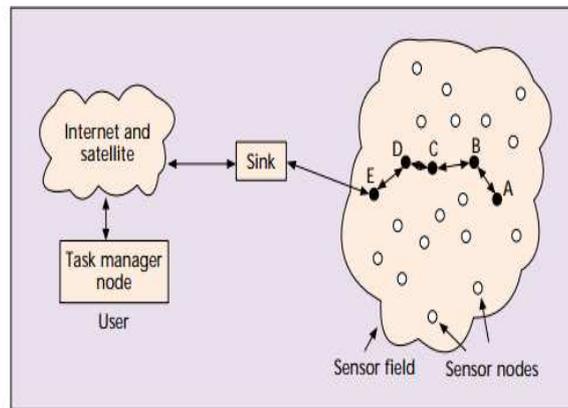


Figure 2. Sensor Nodes are spread in sensor Area (Akyildis et al., 2002)

The constraining aspect of WSN usage is the limited power of each sensor node. Hence, 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).

2.5. High Altitude Platform-Wireless Sensor Network System Configuration

Yang and Mohammed (2008) has researched a HAP system for WSN application in 3G cellular network, where the HAP system was used to replace the sink node. They proposed two HAP-WSN system configurations for different applications, as follows:

- a. Sensor nodes in the HAP cell transmit directly to HAP
- b. Sensor nodes in HAP cells are arranged in a cluster, where one node with a higher level energy compared to other nodes is appointed the cluster head. The sensor nodes acting as cluster members will collect and send information to the cluster head, which will subsequently send all the data to HAP.

Both scenarios were simulated, and their performances were evaluated. The performance indicators evaluated was the ratio of energy bit to noise spectral density ratio (E_b/N_0).

From the simulation result and performance evaluation (Yang and Mohammed, 2008), it appears that E_b/N_0 on HAP-WSN single-cell scenario is larger than the one on HAP-WSN multiple-cells scenario.

According to (Yang and Mohammed, 2008), the implementation of HAP-WSN system to replace the sink nodes in a WSN has the following advantages:

- a. Reduced complexity of multihop transmission and high energy efficiency
- b. Low cost

3. Method

HAP is designed to be used at an altitude of 20 km. The coverage diameter can be obtained by using equation 1) (Iskandar and Shimamoto, 2006), and (Iskandar and Putro, 2008).

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

where h is altitude platform in km, R is the 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. MTC system is modeled for monitoring and sensing applications in the WSN environment. In the design of WSN, HAP is used to replace Base Station. HAP-WSN system is implemented using the following two topologies:

a. Non-clustered Topology

The sensor nodes inside the HAP cells are transmitting information directly to the HAP, as shown in Figure 3.

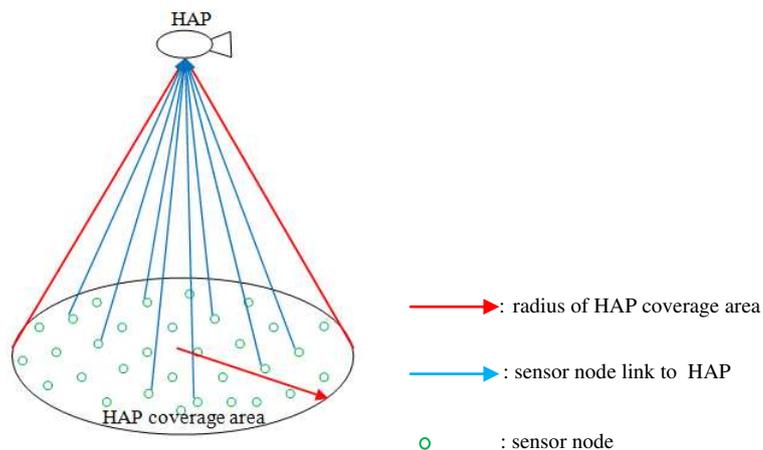


Figure 3. Non-clustered Topology

b. Clustered Topology

The sensor nodes inside the HAP cell are organized into clusters, and each cluster has a cluster head (CH). Sensor nodes in each cluster send data to CH respectively. CH will collect the data and send it to the HAP, as shown in Figure 4. Clustering is one form of hierarchical routing that can help power saving sensor nodes and thus can extend the lifetime of the network.

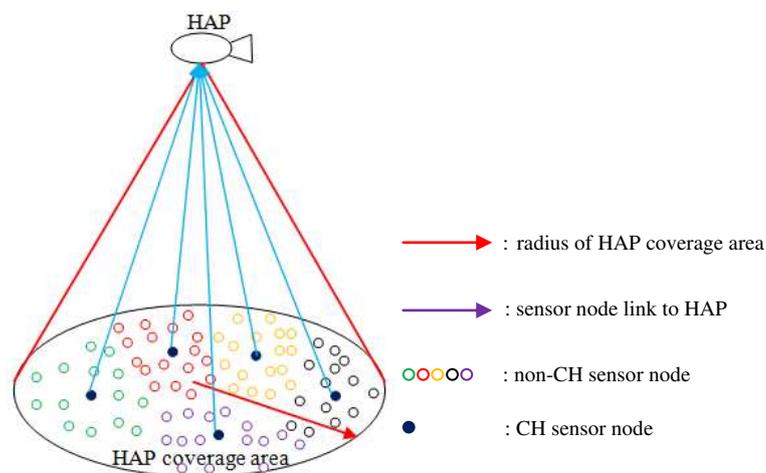


Figure 4. Clustered Topology

For both topologies, a routing protocol known as *Low Energy Adaptive Clustering Hierarchy* (LEACH) is used. LEACH is a routing protocol that forms clusters of several sensor nodes. LEACH is an adaptive clustering protocol that uses rotation randomization method to balance energy load for each sensor

in the network (Heinzelman et al., 2002). In LEACH, nodes are organized in several clusters, with one node performing as a cluster-head (CH). LEACH algorithm is divided into two phases (Manikandan and Purusothaman, 2010):

a. 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 (Heinzelman et al, 2002). 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. It 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 (Heinzelman et al., 2002). Therefore, to keep the energy consumed by each node equitable, each node that acts as a CH will be substituted by another 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) (Heinzelman et al., 2002) and (Mahyastuty and Pramudita, 2013, 2014).

$$P_i(t) = \begin{cases} \frac{k}{N - [k r (\text{mod}(N/k))]} : C_i(t) = 1 \\ 0 : C_i(t) = 0 \end{cases} \dots\dots\dots 2)$$

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 will be 0, where C_i will be 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) (Heinzelman et al., 2002), (Mahyastuty and Pramudita, 2013, 2014).

$$P_i(t) = \frac{E_i(t)}{E_{total}(t)} k \dots\dots\dots 3)$$

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.

b. 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 will be used in the simulation. Otherwise, if the distance between transmitter and receiver is greater than the crossover distance, the two-ray ground propagation model will be used in the simulation. A threshold value can be calculated using 4) (XingGuo et al., 2016).

$$d_0 = \frac{4 \pi h_R h_T \sqrt{E}}{\gamma} \dots\dots\dots 4)$$

where h_R and h_T are the height of the receiver and transmitter antenna, consecutively, 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) (Heinzelman et al., 2002) (XingGuo et al., 2016).

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

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 package 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/m², 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/m⁴. Put d_0 into the equation 5), so threshold value will be (XingGuo et al., 2016):

$$d_0 = \sqrt{\frac{\epsilon_{fs}}{\epsilon_{amp}}} \dots\dots\dots 6)$$

The simulation was performed using MATLAB R2016b. For nonclustered topology, it was assumed that the number of CH = 0. And for clustered topology, the number of CH varied, including 2, 5, 11, 13, 16, and 17. Based on the number of CH, the optimum number of clusters can be determined. For the simulation, 1,000 nodes were positioned randomly in the network. The energy consumption observed in this simulation was the total energy used by each node in the network to send and receive data. The simulation parameters are shown in Table 1.

Table 1. Simulation Parameters

Parameter	Value
Simulation Area	1000 km x 1000 km
Simulation duration	2,000 iteration
HAP position	(500,500,20)
Number of nodes	1,000
Initial Energy of each node	0.5 Joule
ϵ_{fs}	1.10^{-11} Joule
ϵ_{amp}	13.10^{-15} Joule

4. Results and Discussion

The parameters given in Section 3 were used to simulate the LEACH routing protocol in Wireless Sensor Network by using MATLAB. In the simulation, the number of nodes was 1,000 nodes, and the

number of clusters used were 0, 2, 5, 11, 13, 16, and 17. Figure 5 shows nodes and HAP position in simulation area, while Figure 6 shows the energy consumption for the first and second scenario.

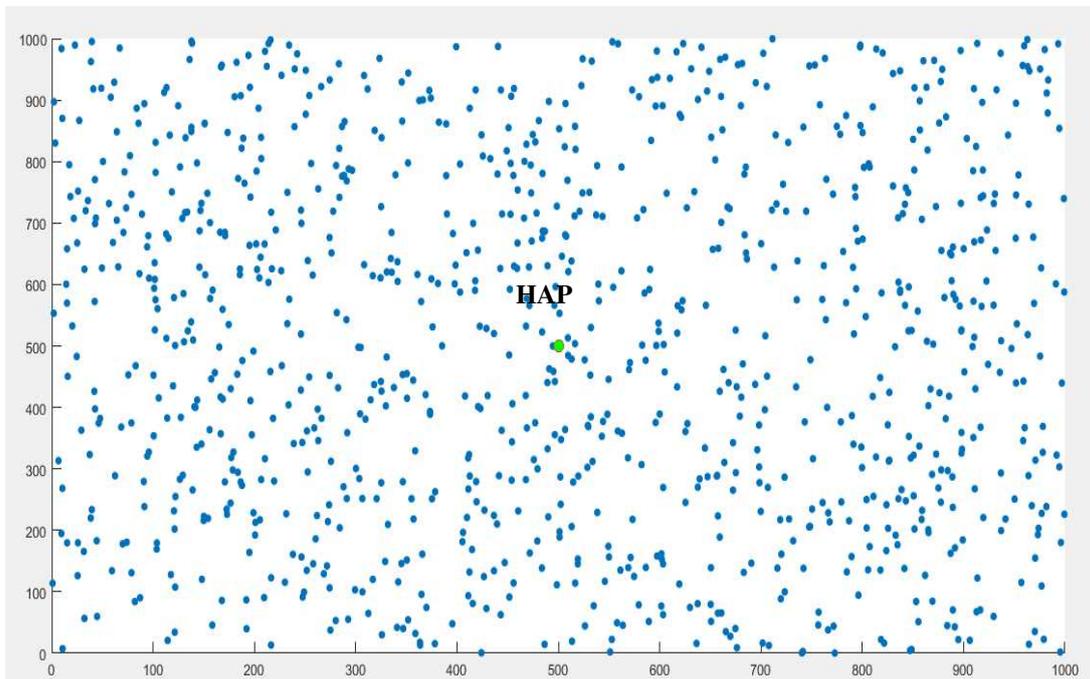


Figure 5. Nodes and HAP position in simulation area

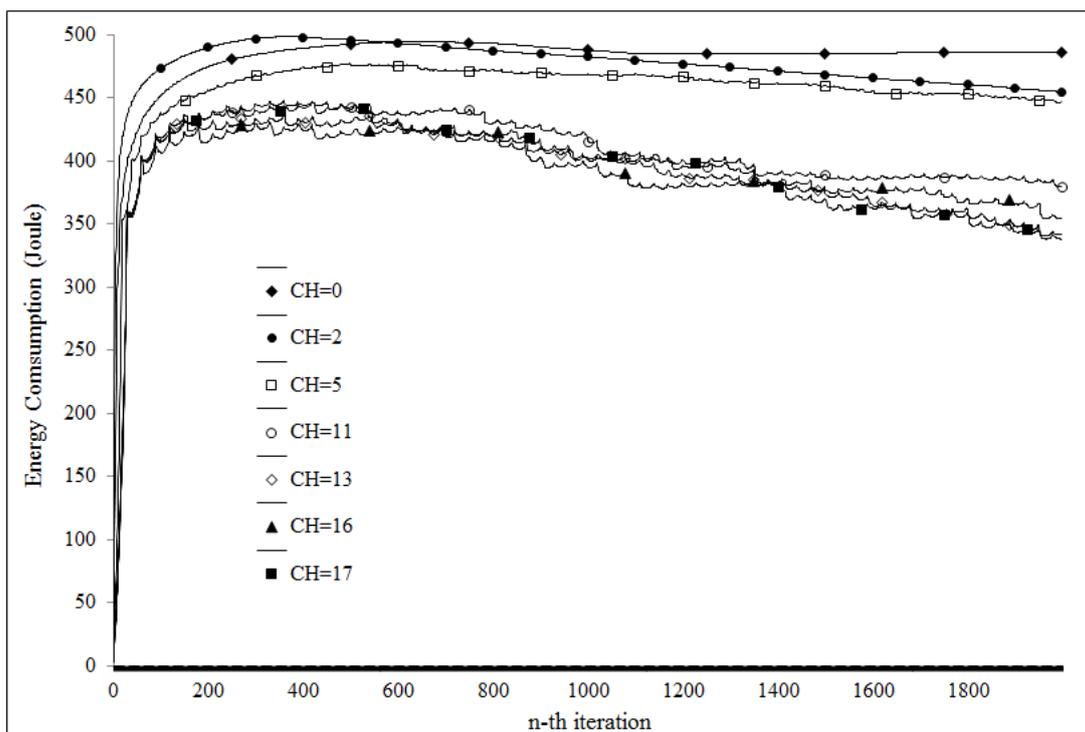


Figure 6. The Effect of the cluster number to the energy consumption

Figure 6 shows that the energy consumption for nonclustered topology is greater than the energy consumption for clustered topology. This is because each sensor node within the coverage area of HAP directly transmits data that belongs to HAP. For clustered topology, the simulation result shows that the

optimal cluster number is 16. It is because the energy consumption for the number of clusters equals to 16 is smaller than the energy consumption for other numbers of clusters.

Table 2. Number of clusters vs. number of dead nodes

Number of clusters	Number of dead nodes
0	962
2	979
5	897
11	837
13	837
16	828
17	832

Table 2 shows the number of dead nodes in the nonclustered topology is greater than the number of dead nodes in the clustered topology. It is because each node in the nonclustered network should send the data to the HAP directly. And from Table 2, it can be seen that for the clustered topology, the least number of dead nodes can be achieved when the number of clusters equals to 16.

Table 3. Number of clusters vs. average total packets

Number of clusters	Average total packets [bytes]
0	18.705
2	15.993
5	21.671
11	23.739
13	23.501
16	24.872
17	24.072

Table 3 shows that the average total packet sent to HAP for nonclustered topology is smaller than that for the clustered topology. It is because, in non-clustered topology, the number of dead nodes is higher than the one in clustered topology. This table also shows that when the number of clusters is equal to 16, 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 16, the number of dead nodes is smaller than that of other clusters. From Table 3, we can also see that when the number of clusters is equal to 2, the average total packet sent to the HAP is smaller than that of other clusters. It is because the location of CH is far away from the sensor node. Thus, the data from node sensor can not reach the CH.

Figure 6, Table 2, and Table 3 show that the optimal number of clusters is 16. It allows the network to have a fewer number of dead nodes with low energy consumption, which means energy-efficient. The average of the total packet sent to HAP is also greater compared to that of other simulated clusters.

5. Conclusion

Simulation results show that HAP-WSN system clustered topology can minimize the energy consumption, the number of dead nodes, and can increase the average total packets sent to HAP. To achieve the minimum energy consumption levels, it is necessary to determine the optimum number of clusters. It can also be seen that the optimum number of clusters is 16. For further research, communications from HAP to users needs to be considered. The influence of HAP coverage area should also be taken into consideration to see its effect on energy consumption.

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