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Master's Degree Thesis

Distance Aware Cluster Based Hierarchical Routing Protocols for Energy Efficiency in Wireless Sensor Networks

Graduate School of Chosun University

Department of Information and Communication Engineering

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무선센서네트워크에서 에너지 효율성을 위한 거리 인지
클러스터기반의 하이라키컬 라우팅 프로토콜

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Acronyms

WSN: Wireless sensor networks

CH: Cluster head

SCH: Super cluster head

BS: Base station

MTE: Minimum transmission energy

LEACH: Low energy adaptive clustering hierarchy

LEACH-C: LEACH-centralized

PEGASIS: Power efficient gathering in sensor information system

CCS: Concentric clustering scheme

DDAR: Dynamic clustering and distance aware routing

TSC: Track-sector clustering

MEMS: Micro-electro-mechanical systems

QoS: Quality of service

CSMA: Carrier sense multiple access

MAC: Medium access control

TDMA: Time division multiple access

요약

무선센서네트워크에서 에너지 효율성을 위한 거리 인지 클러스터기반의 하이라키컬 라우팅 프로토콜

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무선 센서 네트워크(WSN)은 에너지나 대역폭, 그리고 연산기능과 같은 자원에 제약을 갇는다. 또한 노드들은 접근하기 어려운 지형에 설치된다. 그 결과, 설치되기 전에 위에 언급된 제약사항이 고려되어야 한다. 언급된 제약 조건등 중에, 에너지는 WSN 응용프로그램과 프로토콜 설계에서 가장 중요하고 가장 많이 제기되는 제약 조건들 중 하나이다. 라우팅 프로토콜의 다양한 클래스들이 WSN 에서 더욱 큰 에너지 절약을 위해 제시되어 지고 있다. 라우팅 프로토콜에 기반을 둔 계층적 클러스트링은 다른 flat counterparts 와 비교했을 시, 더 큰 에너지 절약을 위한 프로토콜 계층 중의 하나이다.

이 논문에서, 나는 무선센서 네트워크 환경에서의 , 다이나믹 클러스트링과 거리 인식 라우팅 프로토콜(DDAR), 그리고 에너지 효율적인 라우팅을 위한 트랙 섹터 클러스트링(TSC), 위 두가지 새로운 라우팅 프로토콜을 제안합니다 제안된 프로토콜은 더 먼 전송거리, 여분의 데이터 전송 그리고 클러스트 헤드(CH)노드들을 모드는 데이터 메시지 때문에 더 큰 에너지를 WSN 에서 소모하는 환경에서 공헌을 할 것입니다. 그 결과로, 나는 non-CH nodes 와 CH

nodes 들간, 그리고 CH nodes 과 base station (BS)간의 전송거리를 최소화 하는 식의 방법으로 프로토콜을 설계 하였습니다.

제안된 DDAR 에서 CH 들로서 잔여 에너지를 갖는 노드들이 네트워크에서 평균에너지를 가지고 있는 노드들 보다 커야 하고, BS 로 부터의 거리또한 평균 거리를 같는 노드들 보다 길어야 합니다. 또한, BS 로부터 가까운 거리에 있거나 더큰 에네지를 갖는 노드는 비교적 짧은 전송 거리 이상으로 전송되는 슈퍼 CH(SCH)로서 선택이 됩니다. 나는 많은 수들의 CH 들이 고정적이지 않기 때문에, CH 선택을 위한 동적 방법을 적용하였다. 그러나 네트워크에서 갈아 있는 노드의 개수에 따라 다소 변경이 되어 진다.

유사하게, 제시된 TSC 에서, 나는 네트워크를 동심 원형 트랙과 삼각 섹터로 나누었다. 트랙과 섹터의 교차점이 네트워크에서 클러스트 번호를 만들어 낸다. 각각의 클러스터에서, 나는 모든 non-CH 노드들로부터의 데이터를 수집하기 위한 책임을 갖는 CH 노드를 선택하였고, 단일 데이터 메시지로 양식화하기 위해 모아진 데이터를 융합 시키고, 융합 데이터를 압축하는 작업을 수행한다. 트랙과 섹터의 분할로 최소화된 여분의 데이터 전송과, head 노드들과 BS 간의 최단거리 제공으로 에너지 소비를 줄이는데 도움을 준다.

제안된 프로토콜은 low energy adaptive clustering hierarchy (LEACH), LEACH-centralized (LEACH-C), power efficient gathering in sensor information system (PEGASIS) 에서의 그리고 concentric clustering scheme (CCS). 같은 라우팅 프로토콜 기반의 종래의 클러스터와 비교 했을 때 더 큰 에너지를 보존한다.

ABSTRACT

Distance Aware Cluster Based Hierarchical Routing Protocols for Energy Efficiency in Wireless Sensor Networks

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Wireless sensor network (WSN) is constrained with resources such as energy, bandwidth, and computational capabilities. Also, the nodes are deployed in an unattainable terrain. Therefore, the constraints mentioned above have to be considered before deployment. Among the stated constraints, energy is one of the most important and discussed constraints in the WSN application and protocol designs. Various classes of routing protocols have been proposed in order to achieve greater energy conservation in WSN. Hierarchical clustering based routing protocol is one of the classes of protocols which achieve greater energy conservation as compared to flat counterparts.

In this thesis, two new routing protocols are proposed, dynamic clustering and distance aware routing (DDAR) protocol for WSNs (DDAR) and track-sector clustering for energy efficient routing in WSNs (TSC).

The proposed protocols exploit the facts that a greater energy is consumed in WSN because of greater transmission distance, redundant data transmission, and larger data message gathering at the cluster head (CH) nodes. Therefore, the protocols are designed in such a way that the transmission distances between non-CH nodes and CH nodes and between CH nodes and the base station (BS) are minimized.

In proposed DDAR, the nodes as CHs whose residual energies are greater than the average energy of the nodes in the network, and whose distances from the BS are greater than the average distance of the nodes from the BS. Also, a node which is at near distance from the BS and having greater energy is selected a super CH (SCH) node such that the data are transmitted relatively over a shorter transmission distance. Dynamic method for CH selection is applied, so that the number of CHs is not fixed, but rather changes according to the number of alive nodes in the network.

Similarly, in the proposed TSC, the network is divided into concentric circular tracks and triangular sectors. The intersection of tracks and sectors forms a number of clusters in the network. In each cluster, a CH node is selected, which is responsible for gathering the data from all the non-CH nodes, fuse the gathered data to form a single data message, and perform compression operation on the fused data. This division of tracks and sectors helps to reduce the energy consumption by minimizing redundant data transmission and providing shortest distance between head nodes and the BS.

The proposed protocols conserve greater energy as compared to the conventional cluster based routing protocols such as low energy adaptive clustering hierarchy (LEACH), LEACH- centralized (LEACH-C), power efficient gathering in sensor information system (PEGASIS), and concentric clustering scheme (CCS).

I. Introduction

WSN has wide range of applications like environment monitoring, health care, battle field surveillance, and habitat monitoring. The sensor nodes are constrained with resources such as battery power, memory, bandwidth, and computational capabilities. Energy conservation is one of the most discussed issues in WSN application and protocol development [1-9].

Routing protocols highly affect the performance of WSN. Therefore, the routing protocols should be developed effectively for balancing the energy load and prolonging the network lifetime. Many routing protocols have been proposed in the past to achieve the energy efficiency in WSN.

Routing protocols can be broadly classified into several classes on the basis of network structure and protocol operation [8]. On the basis of network structure, routing protocols in WSN have been divided into flat, hierarchical, and location-based routings [8]. Specifically, hierarchical routing protocols in WSN have significant energy conservation [12]. In hierarchical routing protocols, clusters are created and a head node (In this work, the term head node is used to denote the CH node in LEACH and LEACH-C and leader node in PEGASIS) is assigned to each cluster. These head nodes have responsibilities of collecting and aggregating the data from their respective clusters and transmitting the aggregated data to the BS. The aggregation of data at head nodes greatly reduces the energy consumption in the network by minimizing the total data messages to be transmitted to the BS. Also, the head nodes act as local sinks for the data, so that the data are transmitted relatively over a short distance.

Popular routing protocols based on clustering schemes, such as low energy adaptive clustering hierarchy (LEACH), energy LEACH, multi-hop LEACH,

LEACH-centralized (LEACH-C), power efficient gathering in sensor information system (PEGASIS), and concentric clustering scheme (CCS) proposed in [1-5] are effective in conserving energy. However, these conventional routing protocols have many energy consumption loopholes due to redundant data transmission and unequal depletion of energy in head nodes.

In this thesis work, two protocols have been proposed for energy efficient routing in WSN: dynamic clustering and distance aware routing protocol for wireless sensor networks (DDAR) and track sector clustering for energy efficient routing protocols (TSC) scheme, to globally remove the redundant data transmission and distribute the energy depletion in the network uniformly by minimizing the distance between the head nodes and the BS [10][11]. Also, the proposed DDAR and TSC contribute to the conservation of energy by reducing the number of data messages aggregation at the head node.

II. Background concepts on wireless sensor networks

Before going through the details of the proposed protocols, some of the fundamental concepts of WSN like definition of WSN, sensor nodes, routing, and challenges in WSN routing are presented in this chapter.

A. Wireless sensor networks

A WSN consists of spatially distributed autonomous sensors to cooperatively monitor physical or environmental conditions such as temperature, pressure, vibration, humidity, motion or pollutants. The sensed data are sent via radio transmitter either directly or through a data concentration center to base station (BS)[20].

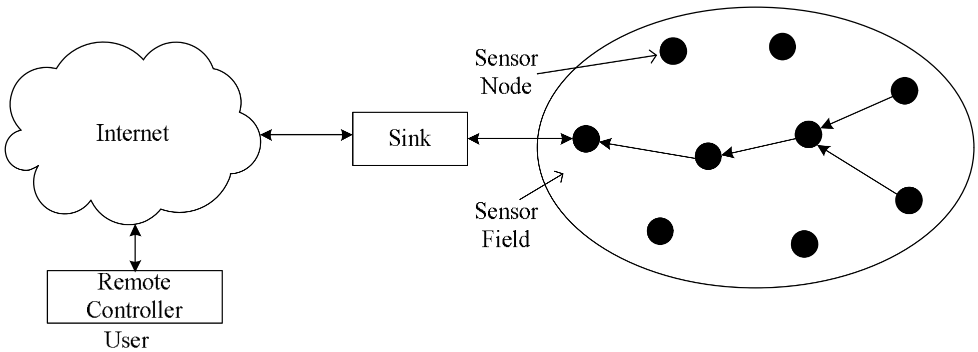

Figure 2.1 Sensor network architecture

Because of the technological advances in micro-electro-mechanical systems (MEMS) and low power and highly integrated digital electronics, the size of the sensor has decreased and has made it possible to deploy a large number of disposable unattainable sensors. Such sensor nodes might be dropped in the deployment area by using airplanes or helicopters. An effective and natural method of achieving the effective networks of such sensors is the networks consisting of wireless links connected together in an ad-hoc fashion [14][16][17]. Networking the wireless nodes in ad-hoc manner has advantages in many military and civil applications like battle field surveillance, disaster management, and wildlife preservation where human approach might be practically difficult or impossible. The basic architecture of the sensor network is shown in Figure 2.1.

B. Sensor node

Sensor nodes can be considered to be the basic unit of WSN. A typical sensor node consists of sensing unit, processing unit, transmission unit (transceiver), mobilizer, position finding system, and power unit.

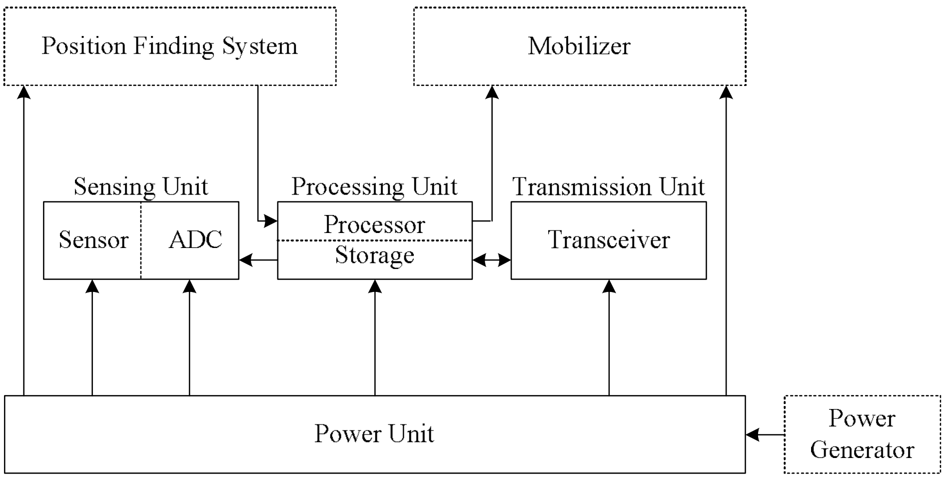

Figure 2.2 A typical sensor node

Sensing unit is responsible for sensing the environment to find the value of the attribute. The processing unit processes the sensed value for transmitting to the BS. Transmission unit is responsible for transmitting the processed data to the external BS by using its radio or antenna. Similarly, mobilizer is responsible for the node mobility. Position finding system finds the position of the sensor node by using position finding devices like GPS. And power unit is responsible for supplying the energy to the node [8]. The architecture of a typical sensor node is shown in Figure 2.2.

C. Routing

Routing is the process of selecting paths in a network along which data or network traffic is sent [5][8]. Routing has significant importance in WSN because of the inherent characteristics that distinguish these networks from the other wireless networks such as mobile ad hoc networks or cellular networks [8][12][13]. First, it is practically impossible to build a global addressing scheme because of large number of sensor nodes in the network. This limits the use of traditional IP-based addressing in WSN. Second, in contrast to the traditional communication networks, application of WSNs requires the flow of data from the multiple sources to a single sink or BS. Third, sensor nodes are constrained in terms of energy, computational capabilities, memory, and bandwidth. A careful resource management is therefore necessary. Fourth, nodes in the sensor networks are generally stationary after deployment, in contrast to the mobile nodes in the mobile ad-hoc networks. Therefore, traditional routing protocols used in mobile ad-hoc networks cannot be adopted in WSN. Fifth, sensor networks are application-specific. Therefore, the routing protocols designed for one application might not be effective for another application. Sixth, position awareness is important in case of WSN.

Finally, data redundancy is prevalent in WSN. Such redundancies have to be exploited by routing protocols for improving the performance of the routing [8].

Many algorithms and protocols have been proposed in the past to address the needs and overcome the deficiencies in WSN. The protocols can be fairly divided into flat, hierarchical, or location based according to the network structure. On the basis of protocol operation, these protocols can be furthermore classified into multi-path based, query-based, negotiation-based, quality of service (QoS) based, and coherent-based ones [8][13]. The classification of WSN routing protocols is shown in Figure 2.3.

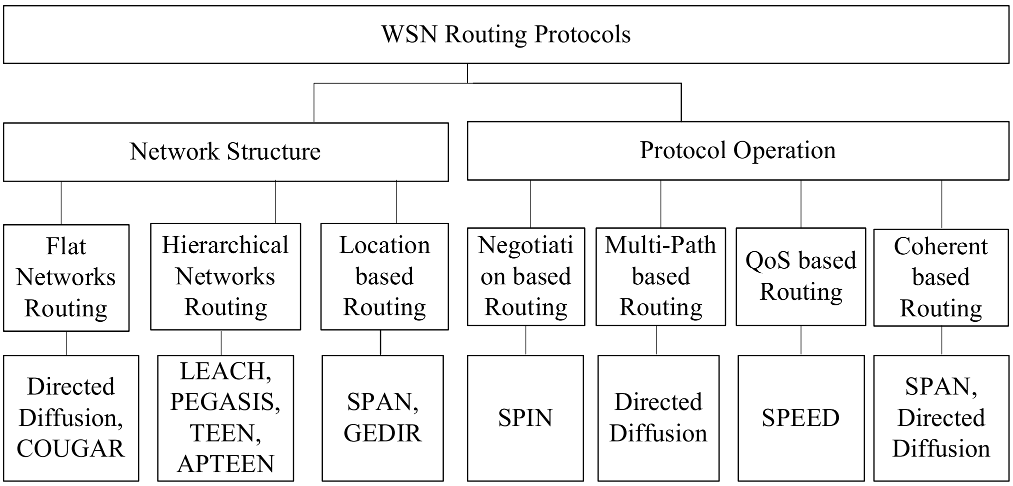

Figure 2.3 Classification of WSN routing protocols

D. Challenges in WSN routing

Although WSN finds its application in many areas, the inherent properties and constraints still prevail in WSN applications. Because of these constraints, WSN applications might have to compromise certain factors like delay, energy, and QoS to maximize the usability and efficiency of their particular application. Some of the routing issues and challenges are discussed below:

1. Node deployment

This refers to the topology of the network. The nodes deployment might either be deterministic or self-organizing. In deterministic methods, the nodes are manually placed and data are routed through pre-determined routing paths [14]. However, in self-organizing systems, the nodes are distributed randomly and thus they create the network in an ad-hoc fashion [14]. In this type of systems, the positions of the BS and CHs become crucial.

2. Network dynamics

Nodes in the WSN are generally stationary. But sometimes, the sink might be mobile or sometimes the sensed event can be mobile. For example, in target tracking applications, the sensed event, i.e., the target is mobile, whereas in fire detection system, the fire is static. Monitoring static and dynamic events requires separate methods of routing [14].

3. Scalability

Once deployed, the nodes in WSN cannot be generally replaced. Some nodes in the network might drain out their battery power soon. On the other hand, some new nodes might join the network. WSN routing protocol should be scalable enough to accommodate such changes. In case of node death, it should be able to reconstruct a new routing path to avoid the holes in the network and in case of addition of new nodes; it should include new nodes in its routing path [14].

4. Energy consumption

Energy consumption is one of the most discussed issues in WSN applications and protocols design. The transmission power of a wireless radio is directly proportional to the square of the distance between the transmitter and receiver or even of higher order in the presence of obstacles [10]. Therefore, multi-hop routing obtains greater energy conservation as compared to the direct transmission. WSN routing should be able to address this energy issue carefully.

5. Transmission media

WSN uses wireless media for communication and data transmission. The wireless media is prone to errors and attacks. WSN Routing should address the data accuracy and data safety needs without losing its energy conservation property.

6. Data aggregation

Data aggregation refers to the combination of data from different sources by using suppression (eliminating duplicates), min, max, and average [15]. In some cases data fusion might be deployed through signal processing techniques to reduce the data size and produce more accurate signal. Data aggregation can have an influential effect in energy conservation [14].

7. Quality of service

Though feebly present, QoS is an issue which can't be overlooked in case of time critical applications, where timely delivery of data is more important [14]. Also, in some multimedia applications, QoS might be an important issue. However, there should be trade-offs between energy conservation and QoS, as more energy will have to be spent to achieve the desired level of QoS.

III. Previous works in WSN routing and motivation

In this chapter, some existing routing protocols for WSN and energy consumption loopholes present in these protocols are discussed. The proposed TSC scheme is largely based upon the protocols discussed in this chapter, and motivated with the problems prevalent in these conventional protocols.

A. LEACH

LEACH is a self organizing clustering protocol that uses randomization to distribute energy load evenly in the network. In LEACH, sensors organize themselves into local clusters. In each cluster, a node is elected as CH node. The CH is not fixed throughout the network lifetime; rather the role of CH is rotated with each round of communication [1]. If the CH was fixed throughout the network lifetime, then the node elected as CH would drain out its energy quickly. The topology of the LEACH protocol is shown in Figure 3.1.

In LEACH, sensors elect themselves as CHs with certain probability. These CH nodes broadcast their status to other sensors in the network. Each node determines its respective cluster by choosing the CH that requires the minimum communication energy. Once, the clusters are created, each CH creates a schedule for the nodes in its cluster. This allows all the nodes to turn off their radio during the other nodes' transmission time. Once the CH receives all the data from the nodes, it then aggregates the data and finally transmits the compressed data to the BS. Since the BS is far away in the scenario and since the CHs have to perform many computations, transmissions from CHs to BS incur high energy. Therefore, to avoid the early death of CH nodes, the role of CH should be changed with each round of communication [1].

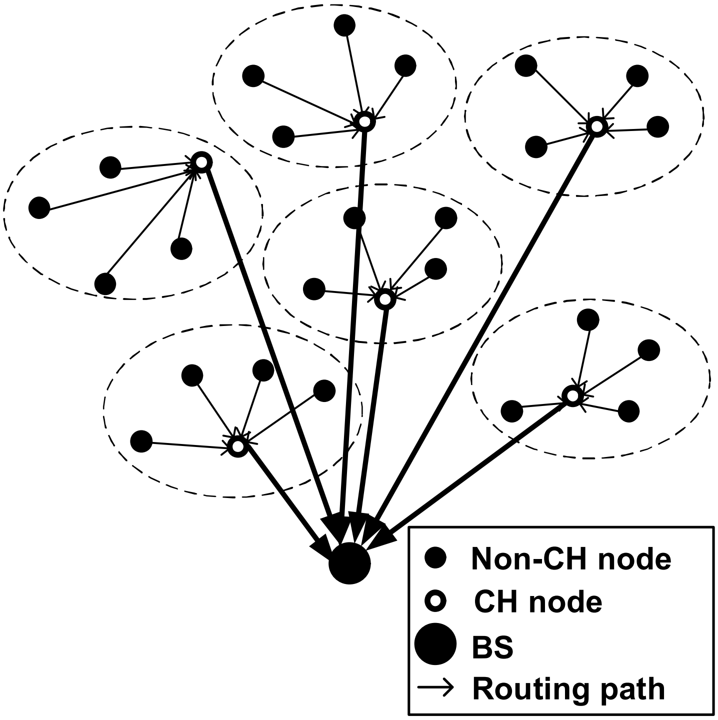

Figure 3.1 Topology of LEACH protocol

LEACH protocol operates in rounds, where each round begins with a setup phase in which the clusters are organized, and steady state phase in which data transmission occurs. The operation of LEACH can be divided into four phases: advertisement phase, cluster-setup phase, schedule creation phase, and data transmission phase.

1. Advertisement phase

When the clusters are being created in the beginning, each node decides whether or not to become a CH for the current round. The decision is made by choosing a random number between 0 and 1. If the number is less than a threshold *T(n)*, the node becomes a CH for the current round. The threshold *T(n)* is calculated as shown in equation 3-1.

$$T(n) = \begin{cases} \dfrac{p}{1 - p \times \left(r \bmod \dfrac{1}{p} \right)} & if \;\; n \in G \\ 0 & Otherwise \end{cases} \tag{3-1}$$

where p is the desired percentage of CHs, r is the current round, and G is the set of nodes that have not been CHs in the last $1/p$ rounds.

Each node that has elected itself a CH for the current round broadcasts an advertisement message to the rest of the nodes. All the other non-CH nodes must keep their receivers on during this phase of set-up to hear the advertisements of all the CH nodes. After this phase is complete, each non-CH node decides the cluster to which it will belong to in this round. The decision is based on the received signal strength of the advertisement. The CH advertisement heard with the largest signal strength is the CH to whom the minimum amount of transmission energy is needed for communication. In case of ties, a random CH is chosen [1].

2. Cluster set-up phase

After each node has decided to which cluster it belongs, it must inform the CH node that it will be a member of the cluster. Each node transmits the information back to the CH again using the CSMA MAC protocol. During this phase, all the CH nodes must keep their receivers "on" [1].

3. Schedule creation

The CH node receives all the messages for nodes that would like to be included in the cluster. Based on the number of nodes in the cluster, the cluster-head node creates a TDMA schedule telling each node when it can transmit. This schedule is broadcast back to the nodes in the cluster [1].

4. Data transmission

Once the clusters are created and TDMA schedule is created, data transmission can begin. Each node transmits the sensed data to its CH node during its TDMA schedule. Other nodes turn off their radios during other nodes' data transmission slot. When all the data has been received in the CH nodes, the CH nodes perform signal processing functions to compress the data into a single signal. This composite signal is sent to the BS. Since the BS is far away from the CHs, this is a high-energy transmission [1].

B. LEACH-C

LEACH protocol offers no guarantee about the placement and/or number of CH nodes. This might result in a poor cluster setup, thus causing the unequal energy load distribution in the network. LEACH-C addresses this deficiency in LEACH by dispersing the CHs throughout the network and producing better clusters [2].

During the setup phase, each node sends information about its current location and energy level to the BS. The BS computes the average node energy, and the nodes which have their energy greater than this average energy can be cluster heads for the current round. With these possible CH nodes, the BS finds clusters using simulated annealing algorithm to solve the NP-hard problem of finding k-optimal clusters [2]. This algorithm attempts to minimize the amount of energy for the non-CH nodes to transmit their data to the CH, by minimizing the total sum of squared distances between all the non-CH nodes and the closest CH node.

Once the CHs and associated clusters are found, the BS broadcasts a message that contains the CH ID for each node. If a node's CH ID matches its own ID, the node is a CH; otherwise, the node determines its TDMA slot for data transmission and goes to sleep until its own transmission time. The steady-state phase of LEACH-C is identical to that of LEACH [2].

C. PEGASIS

In PEGASIS, the nodes are organized to form a chain and a leader node (same as CH node in LEACH) is selected in the chain [4]. This approach helps to distribute the energy load in the network uniformly.

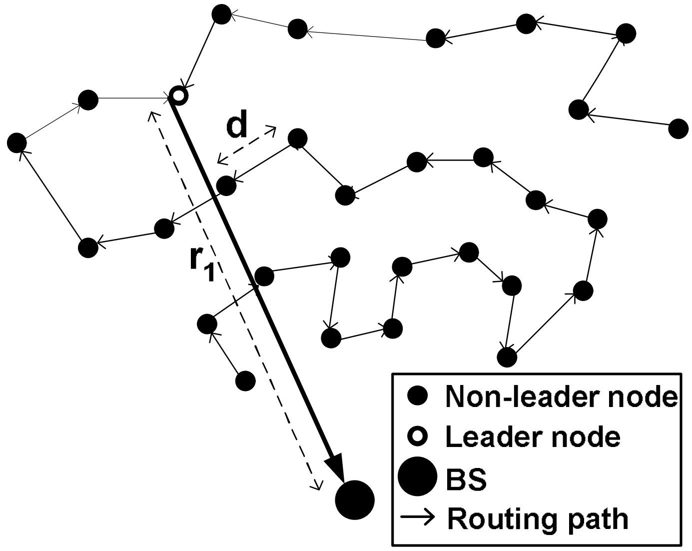

Figure 3.2 Topology of PEGASIS protocol.

In PEGASIS, the nodes organize themselves into a chain. In the chain, a node is selected as the leader node. For the node in some random position *j* on the chain, the node number, *i mod N* is selected as the leader node, where N represents the number of nodes and *i* represents the current round number [4]. Thus, the leader node in current round will be at some random position in the chain. This leader node in the chain is responsible to collect the data from each side of the chain, compresses the collected data, and transmits them to the BS. Each node in the chain transmits the data to one hop neighbor in the chain towards the leader node. The advantage of using the chain for clustering is that each node in the chain receives at most two data messages from two sides of the chain. Therefore, the number of data messages gathering at the leader node is at most two. The topology of PEGASIS protocol is shown in Figure 3.2.

D. CCS

In CCS, the network is partitioned into concentric circles, each circle representing a cluster [5]. In each circle, the nodes are arranged in a chain and a head node (same as CH node in LEACH and leader node in PEGASIS) is selected in each chain as in PEGASIS. The division of network into concentric circles helps to reduce the redundant data transmission present in PEGASIS. The CCS protocol operation can be divided into four rounds: level assignment, chain construction in the level area, head node construction in chain, and data transmission [5]. The topology of the CCS protocol is shown in Figure 3.3.

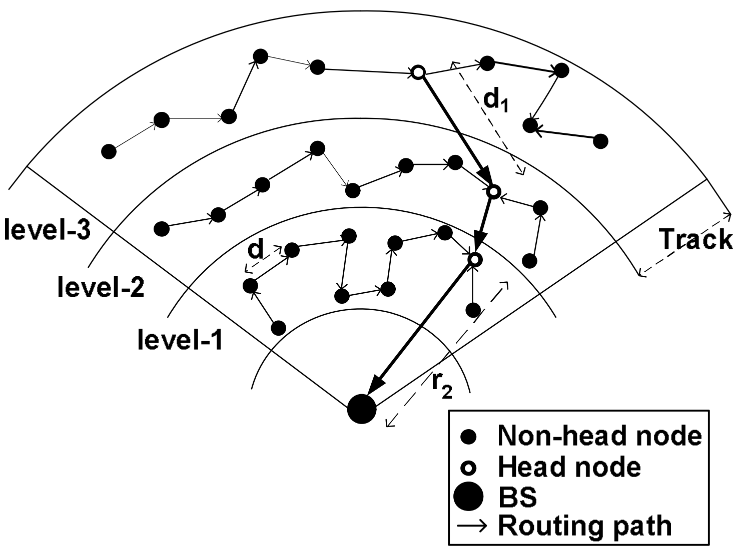

Figure 3.3 Topology of CCS protocol.

1. Level assignment

Each node in the network is assigned its own level from the BS, starting from the lowest level near to the BS to the highest level furthest from the BS. The level is assigned to the nodes using the signal strength. The number of levels or concentric circle depends upon the factors such as number of nodes and density of nodes in the network [5].

2. Chain construction in the level area

In each level area, the chain construction is started at the farthest node from the BS [5]. The process of chain construction is similar to the chain construction in PEGSIS protocol.

3. Head node construction in the chain

In each of the chains, one of the nodes is selected as a head node. A head node in *L level* is selected node number, $i \bmod M_L$, where M_L represents the number of nodes which have the same level in *i* round. After being selected as head node, each head node sends its location information to the head nodes in the upper level head node and lower level head node [5].

4. Data transmission

The data transmission in CCS is same as that in PEGASIS protocol. In each concentric circle, each node in the chain receives from a one-hop neighbor in the chain and fuses the received data with its own data and transmits the data to one hop neighbor in the chain towards the head node. The head node in each circle fuses the received data and transmits to the head node in the lower level chain. Finally, the head node nearest to the BS transmits all the received data to the BS [5].

E. Motivation

The conventional routing protocols focus mainly on cluster formation so as to obtain uniform consumption of energy in the clusters. However, these protocols do not consider the transmission distances between the head nodes and the BS, position of the BS, and the possible redundant data transmissions due to reverse flow of data from BS. CCS proposes to form clusters in concentric circles in order to remove the redundant data transmission seen in PEGASIS protocol and to minimize the number of data messages gathering at the head node as seen in LEACH. However, the chains formed in the clusters are long over the concentric circles. Therefore, the redundancy still remains, as data have to flow around the BS over a long circular chain before reaching to the BS. Also, the distance between the head nodes and the distance between the head node in lowest level track and the BS could still be larger in the case of large and non-uniform network. This could consume more energy in the network.

The proposed protocols in this thesis work get the motivation from the shortcomings present in the conventional routing protocols, such as large number of data messages gathering at head nodes, large distance of head nodes from the BS, reverse flow of data from the BS, and formation of bottleneck at the head nodes. Thus, in this work two new routing protocols called DDAR and TSC scheme for energy efficient routing in WSN are proposed. The proposed schemes reduce the energy consumption caused by large distance between head node and the BS, in the case of uniform as well as non-uniform network.

IV. Effect of distance on energy consumption

A. Mathematical analysis

For a first order radio model, the total energy for a transmitter to send a *k-bit* message over a distance d is given by

$$E_{Total}(k,d) = E_{elec}k + \varepsilon_{amp}kd^2, \qquad 4\text{-}1$$

where ε_{amp} is the energy constant for the radio transmission and E_{elec} is the energy per bit [4].

The first term $E_{elec}k$ in equation 4-1 is the energy used to run the circuitry to handle k-bit message. The second term $\varepsilon_{amp}kd^2$ is the energy for transmitter to send k-bits over distance d. This second term is the reason for variable energy consumption in a network, as d is variable. Therefore, as the distance d and the number of bit k increase, the energy spent for the transmission of message increases. The sensor nodes adjust the transmission power according to the transmission distance d. Hence, energy can be conserved by minimizing the transmission distance. Also, by compressing the data before transmission, we can conserve considerable amount of energy.

B. Simulation analysis

To study the effect of transmission distance on energy consumption, I simulated LEACH protocol with BS located at various positions. In a square area of $100m$ x $100m$, a total of 100 sensor nodes were deployed starting from the origin (0, 0) and BS located at positions (50, 50), (50, 175), (200, 200), and (250, 250). As shown in Figure 4.1, the energy spent was the least when the BS was located at the position (50, 50), slightly higher at the positions (50, 175) and (200, 200), and highest at (250, 250). Therefore, equation 4-1 and simulation result in Figure 4.1 validate the argument that the energy consumption increases as the transmission distance between CH node and BS increases.

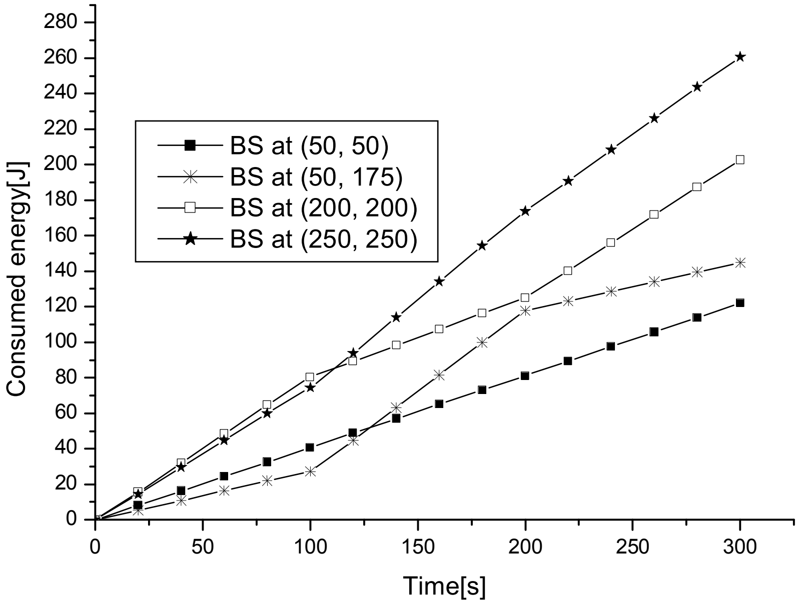

Figure 4.1 Energy consumption for various locations of BS.

V. Proposed DDAR protocol

Clustering in WSN has an advantage in that it distributes energy consumption in the nodes uniformly. The proposed DDAR protocol is also based on clustering scheme in WSN. In DDAR protocol, distance of nodes from the BS is taken into account to select CHs and dynamically set the number of CHs.

Also, two-level clusters are created with the introduction of SCH node. Similarly, residual energy of the node is considered for selecting CHs [10].

The proposed DDAR protocol operation is divided into rounds as in LEACH and LEACH-C protocol [1][2][10]. Each round has both setup and steady state phases. The setup phase consists of network setup, routing path construction, and schedule creation phases. Data transmission occurs in the steady state phase. The proposed DDAR protocol setup and operation is explained in the subsections below:

A. Network setup phase

In the beginning, during the setup phase, each node sends its current location and residual energy information to the BS. The BS selects appropriate number of CHs in the network on the basis of number of alive nodes. The optimal number of CH is 5% of the total alive nodes in the network [2][10]. The BS computes both the average node energy (E_{avg}) and the average node distance (D_{avg-BS}). E_{avg} is calculated by summing up the residual energies of all the nodes in the network and dividing the total amount by the number of nodes. Similarly, D_{avg-BS} is calculated by summing up all the distance of nodes from the BS and dividing the total amount by the total number of nodes. If the node energy (E_{node}) is greater than or equal to E_{avg} and if the distance of the node from the BS ($D_{node-BS}$) is less than or equal to D_{avg-BS}, then the nodes are eligible to become CH for this round. Therefore, the nodes are selected as CHs only when the following two conditions are satisfied.

$$E_{node} \geq E_{avg}, \tag{5-1}$$

$$D_{node-BS} \leq D_{avg-BS} \tag{5-2}$$

The conditions set in equations 5-1 and 5-2 allow only those nodes to be selected as CHs which have adequate energy and which are at nominal distances from the BS. Therefore, the nodes with low energy and larger distances from BS prolong their lifetime by performing the tasks that require less energy [10].

After the CHs are chosen, the BS selects a node as SCH node if it satisfies the following two conditions:

$$E_{SCH} \geq E_{avg}, \tag{5-3}$$

$$D_{SCH-BS} < D_{CH-BS}, \tag{5-4}$$

where E_{SCH} is the energy of the candidate SCH. Similarly, D_{SCH-BS} and D_{CH-BS} are the distance of candidate SCH from the BS and distance of each CH from the BS respectively.

Since, a huge amount of energy is spent in data transmission from the CH nodes to the BS over a large transmission distance; the introduction of SCH node near to the BS in the proposed DDAR protocol reduces the energy consumption in the CH nodes due to data transmission over a large distance. The selection of SCH node by using the conditions in equations 5-3 and 5-4 distributes the energy load in the network by allowing only the node with greater energy and smaller distance to be selected as SCH.

Once the CHs and SCH are selected, the BS forms the first-level cluster, which is termed as child cluster, using simulated annealing algorithm proposed in [8] to solve the NP-hard problem of finding the k-optimal clusters. In this work, simulated annealing algorithm as implemented in LEACH-C is used [2][15]. This algorithm attempts to minimize the amount of energy for the non-CH nodes in transmitting their data to the CH, by minimizing the total sum of squared distances between all the non-CH nodes and the closest CH [2]. After constructing the child cluster, the BS constructs the second-level cluster which is termed as parent cluster. The parent cluster is constructed as minimum spanning tree (MST) with SCH node as root and CH nodes as leaves [2].

After the decision of CHs, SCH, and their associated nodes, the BS broadcasts a message containing both the CH ID for each node and SCH ID for each CH. If the node's CH ID matches with its own ID, then the node is a CH. Otherwise it is just a member of that cluster. Similarly, if the node's SCH ID matches with its own ID, then the node is a SCH. Otherwise it is just a member of one of the child clusters. With the CH ID, the nodes associate themselves with their respective CHs and form the child cluster [10].

B. Routing path construction phase

Once the CHs, SCH, and the associated nodes are determined, the BS calculates the distance of the CHs from the BS (D_{CH-BS}), distance of chosen SCH node from the BS (D_{SCH-BS}), and the distance between the CHs and SCH (D_{CH-SCH}). The BS then constructs the routing path by connecting the CHs in child clusters with the SCH node, if the condition stated in equation 5-5 is satisfied. Otherwise, the CH is connected directly to the BS.

$$D^2{}_{CH-SCH} + D^2{}_{SCH-BS} < D^2{}_{CH-BS} \qquad \text{5-5}$$

The condition in equation 5-5 selects the minimum distance for transmission of data from the CH to the BS via SCH node.

C. Schedule creation phase

The nodes in each child cluster determine their TDMA slot for data transmission and go to sleep until they get their data transmission time. The use of TDMA schedule for data transmission minimizes the collision and thus contributes to the energy conservation goal of the DDAR protocol.

D. Data transmission phase

Data transmission occurs in the steady-state phase of protocol operation. The steady-state phase of the proposed DDAR protocol is identical to that of LEACH and LEACH-C protocol. The major activities in this phase are: data sensing and gathering, data fusion and compression, and data routing which are explained in subsections below:

1. Data sensing and gathering

The proposed DDAR protocol is a proactive routing protocol, i.e., the sensor nodes sense the environment continuously and transmit the sensed data to their respective CHs or BS. Therefore, in the beginning of the data transmission phase the data have to be gathered at the CHs where they go through some operations before being transmitted to the BS. To do so, sensor nodes transmit the sensed data to the CH nodes where they are buffered as in LEACH and other clustering protocols [1][2][10].

2. Data fusion and compression

From equation 4-1, it can be concluded that the size of data also affects the energy consumption in the node. The data gathered in the CH nodes are huge in number as well as in size. Therefore, these data need to be compressed into a single data message before transmitting to the BS to conserve the energy in the network. The CHs fuse the data gathered from the sensor nodes into a single data message and compress the fused data so that relatively smaller sized data messages are transmitted to the BS.

3. Data routing

The compressed data is transmitted to the SCH node or BS along the path determined in routing path construction phase. The SCH node collects the data from CH nodes and transmits the aggregated data to the BS.

The proposed DDAR protocol operates in rounds similar to the LEACH and LEACH-C protocol [10]. After each round of communication, the phases explained above are repeated.

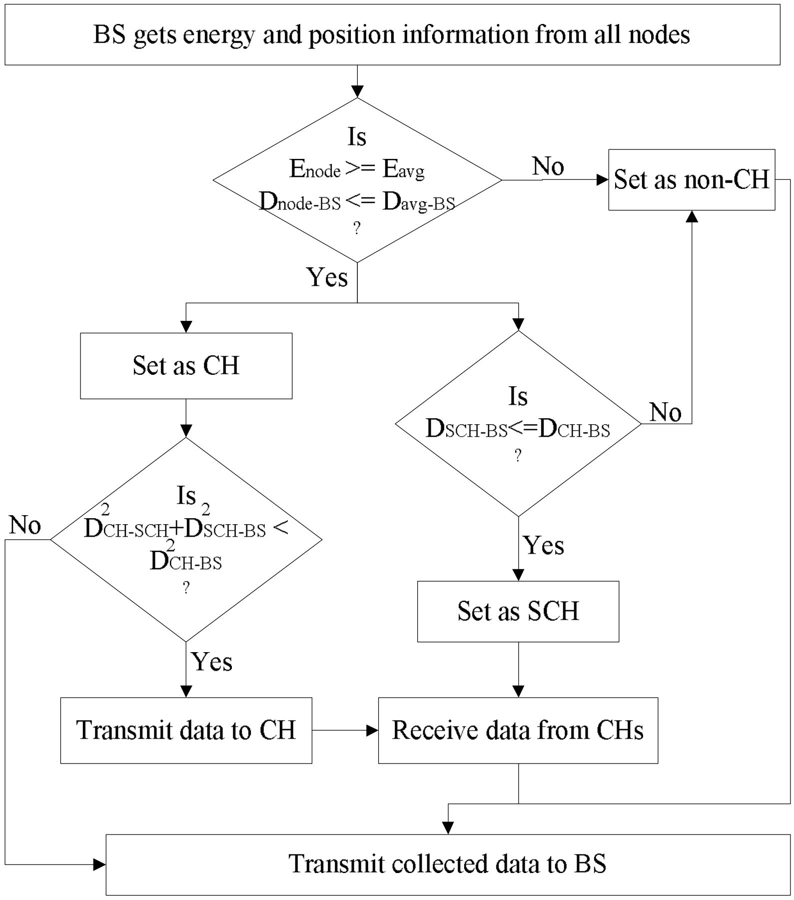

Figure 5.1 Flowchart for cluster formation in DDAR protocol

In the proposed DDAR protocol, a SCH node is selected at a distance near to the BS so that the data is transmitted from the CH nodes over small distance. Thus, a considerable amount of energy is conserved in each round of communication. Also, the number of CHs is not fixed and changes dynamically during the protocol operation phases. This dynamic setting of the number of CHs has a contribution in saving energy by minimizing unnecessary selection of a large number of CHs even when the number of alive nodes is low. The most significant reason for the energy conservation is the selections of CH nodes based on the higher residual energy and lower distance of the node from the BS, because of which low energy nodes or distant nodes do not die out early [10].

The flowchart for the cluster formation in the proposed DDAR protocol is shown in Figure 5.1. The basic topology of the proposed DDAR protocol is shown in Figure 5.2.

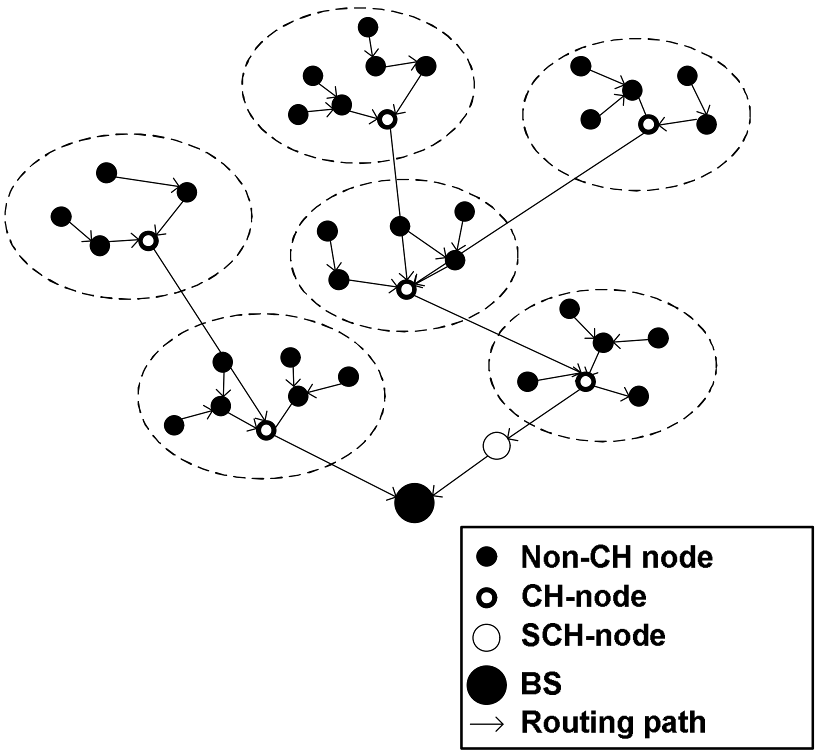

Figure 5.2 Topology of DDAR protocol.

VI. Experimental results and analysis for proposed DDAR protocol

A. Simulation environment

Ns-2.27 was used for performance evaluation of the proposed DDAR protocol [18][19]. At this simulation environment, a network of 100 nodes was deployed in an area of $100m \times 100m$ with BS at (50, 50). The initial energy of each node was set to $10J$. The number of CHs was set to 5% of total alive nodes in the network [1]. The channel bandwidth was set to 1 Mbps. The packet header size was set to 25 bytes and size of each data was set to 500 bytes. The simulation time was set to 3600 seconds. However, 600 seconds of simulation time is taken for the analysis, because for MTE, the simulation terminated after 600 seconds as the number of nodes was below 5. The simulation parameters are summarized in the Table 6.1.

Table 6.1: Simulation parameters for DDAR protocol.

Type	Value
Transmitter amplifier	10^{-12}J
Data Bit	2000 bps
Number of nodes	100
Number of clusters	5% of total alive
Initial Energy of node	10 J
Position of BS	(50,50)

B. Simulation results

The proposed DDAR protocol is compared with conventional routing protocols such as MTE, LEACH, and LEACH-C. Two performance metrics are used for comparison: energy consumption over simulation time and number of nodes alive over simulation time. The first performance metric, energy consumption over simulation time, gives an idea of the rate of consumption of energy in the network. Similarly, the second metric, number of nodes alive over simulation time, gives an idea of the time and rate at which the nodes in the network die.

The simulation results are shown in Figures 6.1 and 6.2. Figure 6.1 shows that the proposed DDAR protocol consumes about 74.6% less energy than MTE protocol. Similarly, the proposed DDAR protocol consumes about 52.5% and about 39.25% less energy than LEACH and LEACH-C respectively. The number of alive nodes for proposed DDAR protocol is 80 after 600 seconds of simulation time, whereas for MTE, LEACH and LEACH-C, the number of nodes alive after 600 seconds of simulation time are 4, 59, and 67 respectively. Figure 6.2 shows the number of nodes alive over simulation time.

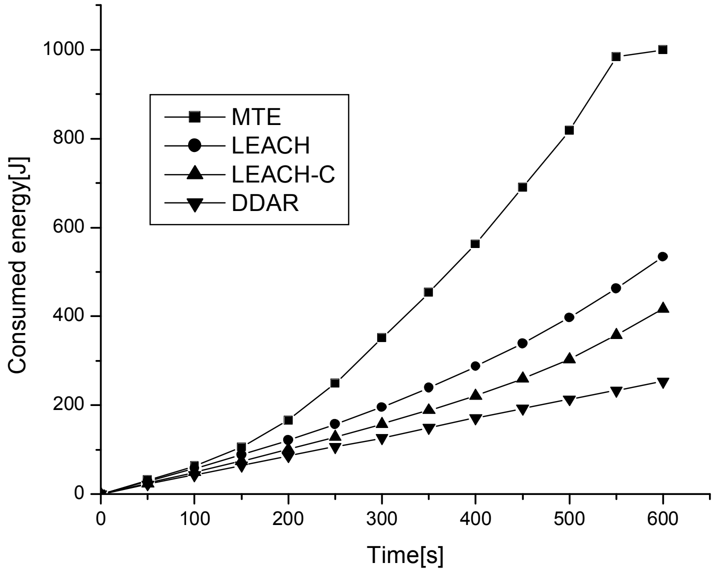

Figure 6.1 Energy consumption over simulation time.

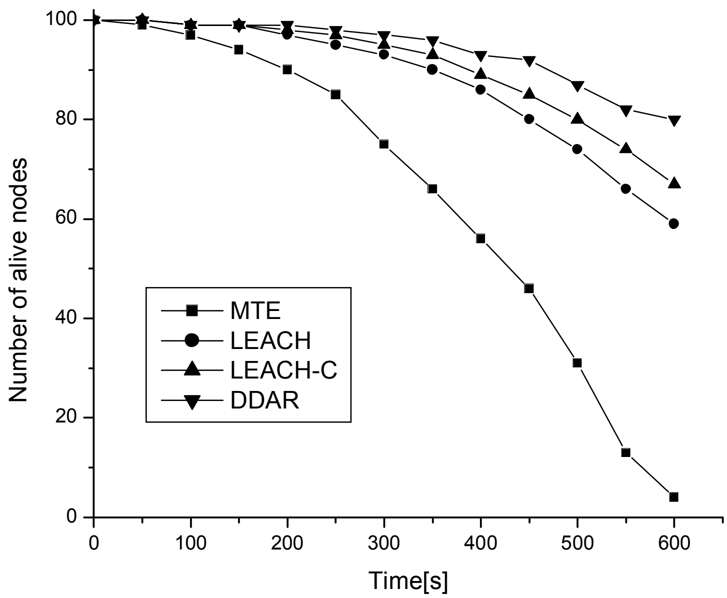

Figure 6.2 Number of nodes alive over simulation time

VII. Proposed TSC scheme

The proposed TSC scheme is basically a hierarchical clustering scheme with one head node selected in each cluster. As shown in Figure 8.1, the proposed TSC scheme uses tracks and sectors to form clusters. Therefore, a cluster is an area under curved strip formed by the intersection of a circular track and a triangular sector. The formation of clusters using tracks and sectors reduces redundant data transmission in the network by breaking the long chain in the track into smaller chains. Also, it reduces the total distance for transmission of data from the nodes to their respective head nodes and then finally to the BS. In addition, the number of data messages gathered in the head node in TSC is still not greater than the number of data messages that are gathered in CCS [11].

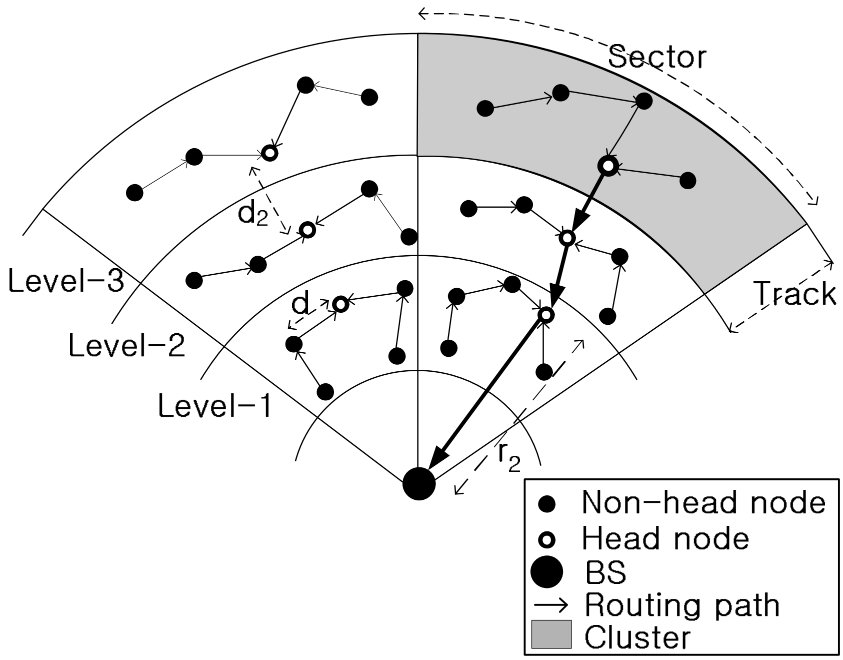

Figure 8.1 Topology of proposed TSC scheme.

The proposed TSC protocol operation can be divided in four phases: track setup, sector setup and head node selection, chain construction, and data transmission [11].

A. Phase I: track setup

The BS sets the concentric circular tracks with itself as geometric center of the concentric circular tracks. The nodes are assigned their respective tracks by using the signal strength and the position information of each node. The track nearest to the BS is leveled as level-1 and the level goes on increasing for the tracks far from the BS, i.e., the tracks with higher level are further away from the BS. The number of tracks to be formed is determined initially as in CCS [5]. The number of tracks depends upon parameters such as distribution density of the network, the number of sensor nodes, and the location of the BS. The track setup remains unchanged throughout the network lifetime [11]. The basic topology of TSC is depicted in Figure 8.1.

B. Phase II: sector setup and head node selection

In this phase, sectors are constructed over the network. The BS selects *Ns* number of head nodes, which is equal to the number of sectors, in each track. At first, a head node is selected at random in level-1 track. Then, with the position information of the selected head node, the BS calculates the slope of the selected head node with respect to the BS. It is assumed that the location information is determined by using GPS devices attached to the nodes as in LEACH-C [2]. The slope is calculated using the coordinate geometry as $slope = \dfrac{y_{node} - y_{bs}}{x_{node} - x_{bs}}$, where ($x_{node}$, y_{node}) and (x_{bs}, y_{bs}) are the coordinates of the node and the BS respectively. Then the slopes of each of the nodes in other higher level tracks are calculated. Finally, a node that has slope similar to the slope of the head node at level-1 track is selected in each of the higher level tracks. This selection of head nodes with similar values of slopes ensures that all the first head nodes in different tracks lie in the same sector. Finally, other head nodes in each track are selected at a distance given by

$$d_h = 2r\sin(k\theta)\begin{cases} \theta = 360^\circ/(2\times Ns) \\ k = 1,2,3,\ldots Ns/2, \end{cases} \qquad \text{7-1}$$

where N_s is the number of sectors and r is the distance of first head node from the BS.

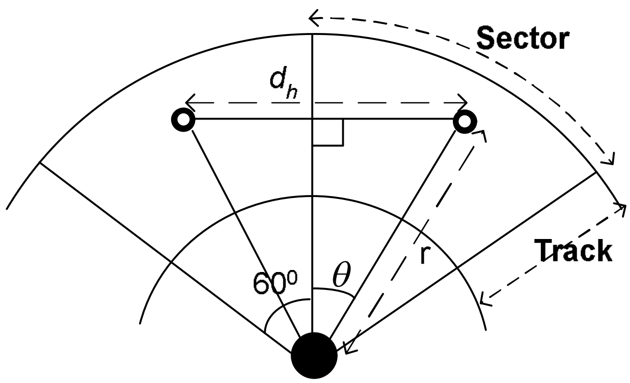

Figure 8.2 Calculation of distance between head nodes in the track.

Equation 7-1 can be explained with Figure 8.2. If trigonometric method is applied to calculate the side of triangle in Figure 8.2, half of the distance between the two head nodes is given by $r\sin(k\theta)$. Therefore, the distance d_h is given by $2r\sin(k\theta)$, where $k = 1$ for the nodes in adjacent sectors. Therefore, equation 7-1 ensures the selection of head nodes in different sectors of the same track.

The number of sectors is also determined initially in BS. The number of sectors depends upon various factors such as distribution density of the network, number of nodes, distance among the nodes, and the transmission delay. However, the number of sectors is selected in such a way that the angle projected at the BS by each sector is 60°, as shown in Figure 8.2. The selection of a sector with projection angle of 60° constructs sector in an equilateral triangle. Thus, the distance between any two nodes in the sector is limited within the length equal to the radius of the highest level track. The sector setup remains unchanged throughout the network lifetime [11].

C. Phase III: chain construction

In this phase, chains are constructed within each cluster area formed by the intersection of tracks and sectors. For the construction of the chain, greedy algorithm is employed as in PEGASIS [4][11]. In the first round, the head nodes are selected as described in sector setup and head node selection phase. In the following rounds, the head nodes in the chain are selected with the node number obtained by calculating $i \bmod M_L$, where M_L represents the number of nodes that have the same level in i round. In case, if any node in the chain dies, the chain is reconstructed to bypass the dead node.

D. Phase IV: data transmission

In this phase, all the non-head nodes receive from and transmit to a one-hop neighbor in their respective clusters. The head node in each cluster aggregates the data and transmits to the head node of another cluster in lower level track. Thus, the data are gathered in multi-hop fashion and finally transmitted to the BS. For example, as shown in Figure 8.1, the head nodes in level-3 transmit the data to the head nodes near to them in level-2 and then to level-1 and finally to the BS.

VIII. Mathematical analysis of energy consumption

A. Energy relations for PEGASIS, CCS, and proposed TSC scheme

For developing the energy relations for PEGASIS, CCS, and the proposed TSC scheme we use equation 4-1 in chapter IV. The first term $E_{elec}k$ in 4-1 is the total energy used to run the circuitry to handle k-bit message. Therefore, the value of first term remains constant for a network. The second term $\varepsilon_{amp}kd^2$ is the energy for transmitter to send k-bits over distance d. This second term is the reason for variable energy consumption in a network setup, as d is variable. This second term is denoted by the expression $E_{Tx}(k, d)$.

For PEGASIS, let the distance between the head node and the BS is r_1, as shown in the Figure 3.2. Therefore, for a network with n nodes, the radio transmission energy consumed to transmit from both ends to the head node over distance d and then to the BS over distance r_1 is calculated by changing the second term in equation 4-1 as in 8-1.

$$E_{Tx}\left(k,d\right) \; = \varepsilon_{\mathrm{amp}} k\left[(n-1)d_2 + r_1^{\;2}\right] \qquad \text{8-1}$$

For CCS, let the number of concentric circles or tracks be N_T as shown in Figure 3.3. Then the radio transmission energy consumed to transmit *k-bit* message over distance d_1, from head node to the head node in lower level track and finally to the BS over distance r_2 is calculated as

$$E_{Tx}(k,d) = \varepsilon_{amp} k\left[N_T(n'-1)d^2 + \sum_{i=1}^{N_T-1} d_1^{\;2} + r_2^{\;2} \right], \qquad \text{8-2}$$

where n' is the average number of nodes in the track and d_l is the distance between the head nodes in two neighboring tracks.

For proposed TSC scheme, let the distance between the head node and the BS is r_2 as shown in the Figure 8.1. Therefore, the radio transmission energy consumed to transmit the k-bit data from the source node to the BS is given by

$$E_{Tx}(k,d) = \varepsilon_{amp} k \left[N_S(n''-1)d^2 + \sum_{i=1}^{N_S-1} d_2{}^2 + r_2{}^2 \right], \qquad \text{8-3}$$

where N_s is the number of sectors, n'' is the average number of nodes in a sector, and d_2 is the distance between head nodes in two neighboring clusters of the same sector.

For the mathematical analysis, it is assumed for simplicity that the network is uniform.

B. Mathematical analysis of energy relations for PEGASIS, CCS, and proposed TSC Scheme

In the case of PEGASIS, the value of r_1 ranges from the distance of node nearest from BS to the distance of the node furthest from the BS. But in CCS and proposed TSC scheme, the distance r_2 is always near to the BS and it never exceeds the radius of the lowest level track, as shown in Figures 3.2 and 8.1. That is, it is certain that $r_1 >> r_2$. Therefore, it can be concluded that less energy is consumed in CCS and proposed TSC scheme as compared to PEGASIS.

Now, CCS is compared with the proposed TSC scheme. It can be concluded that $d_1 >> d_2$, as shown in Figures 3.3 and 8.1. This is because the distance between head nodes might not be uniform in long chains in the neighboring tracks in the case of CCS. Therefore, proposed TSC scheme consumes less energy than the CCS.

Also, there is redundant data transmission in case of PEGASIS, as the nodes near to the BS might have to transmit the data to the head node, which might be far away from BS. This is known as reverse flow of data from BS [5]. Similarly, redundancy is not removed completely in CCS, because the data might have to travel from the end of the chain through a large distance around the BS in circle, before reaching to the head node of the chain. The redundancy of such type could be removed if the data could travel through a short chain before reaching the head node. In the proposed TSC scheme, all the nodes including the head node within a cluster are more or less at equal distance from the BS. Therefore, the redundant data transmission caused by reverse flow of data from BS is reduced, and energy is much saved. Similarly, the long chain seen in CCS is divided into small chains by the use of sectors. This division of long chain into smaller chains reduces the redundancy problem that can be seen in CCS. Therefore, the proposed TSC scheme is more energy efficient as compared to PEGASIS and CCS.

C. Numerical analysis of energy relations for PEGASIS, CCS, and proposed TSC scheme

Formal radio model is used as in [1][9] to compare the performance of the proposed TSC protocol with PEGASIS and CCS protocols. The variables used for numerical analysis are summarized in the Table 10.1. For the calculation, it is assumed that the area of network is 100m × 100m and the BS is located at center (50, 50). With the values in Table 10.1 and equation 8-2, the energy consumed for data transmission in CCS is then given by

$$E_{TX}(k,d) = 2\times 10^{-7} \times \left(d_1^{\,2} + r_2^{\,2}\right) + 7.6\times 10^{-5}. \qquad 8\text{-}4$$

The value of d_1 in equation 8-4 ranges from 0 to 90m. Similarly, the value of r_2 ranges from 0 to 20m.

Similarly, by using values in Table 10.1 and equation 8-3, the energy consumed for data transmission in proposed TSC is given by

$$E_{TX}(k,d) = 2\times 10^{-7} \times \left(d_2^{\,2} + r_2^{\,2}\right) + 7.6\times 10^{-5}. \qquad 8\text{-}5$$

The value of r_2 in equation 8-5 ranges from 0 to 20 m. The range of values for r_2 is same for equations 8-4 and 8-5. Therefore, the energy consumption depends solely upon the values of d_1 and d_2.

But, we know that $d_1 >> d_2$. Therefore, the energy consumption for CCS is greater than the energy consumption for the proposed TSC scheme.

IX. Experimental results and analysis for proposed TSC scheme

A. Simulation environment

For the performance evaluation of the proposed TSC scheme NS-2.27 was used [18][19]. The simulation environment was same as that of the DDAR protocol in chapter VI. The number of tracks was set to 5. Because the BS was located in the center, the number of sectors was set to 6, so that each sector projected an angle of 60° at the BS. Each sector had variable number of nodes. The other parameters for the simulation such as transmitter amplifier and data bit are expressed in Table 10.1.

Table 10.1 Variables for numerical analysis and simulation in TSC.

Type	Parameter	Value
Transmitter amplifier	ε_{amp}	10^{-12}J
Data bit	k	2000
Distance between nodes	d	2m
Number of nodes	n	100
Number of tracks	N_T	5
Number of sectors	N_S	6
Avg. no. of nodes in a track	n'	20
Avg. no. of nodes in a sector	n"	100/6

B. Simulation results

Two performance metrics are used for the performance evaluation of the proposed TSC scheme: energy consumption over simulation time and number of nodes alive over simulation time. The first performance metrics, energy consumption over simulation time, gives an idea of the rate of consumption of energy in the network and the second metrics, number of nodes alive over simulation time gives an idea of the time over which the network can send the data before all the nodes in the network die. The proposed TSC scheme is compared with popular routing protocols such as LEACH, PEGASIS, and CCS. These above mentioned protocols are chosen for our analysis because the proposed TSC scheme is also a hierarchical clustering scheme as these protocols.

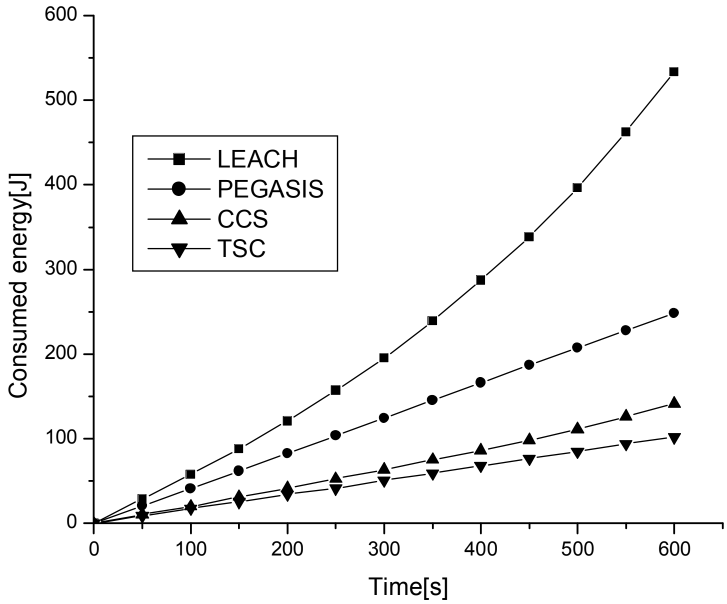

Figure 10.1 Energy consumption over simulation time.

Figure 10.1 shows the simulation results for energy consumption over simulation time. The simulation results showed that the proposed TSC scheme is about 5.5 times, 2.5 times, and 1.4 times efficient in conserving the energy as compared to LEACH, PEGASIS, and CCS respectively. As seen in Figure 10.1, in the beginning, the energy consumption in the proposed TSC scheme is more or less similar to the energy consumption in LEACH, PEGASIS, and CCS. However, as the simulation time increases, TSC performs better in terms of energy conservation as compared to the conventional routing protocols. Similarly, Figure 10.2 shows that the proposed TSC scheme performs well in terms of number of nodes alive over simulation time. The proposed TSC scheme had 93 alive nodes, whereas LEACH, PEGASIS, and CCS have 59, 83, and 89 alive nodes, respectively, at the simulation time of 600 seconds. The number of alive nodes after the completion of simulation determines the life of the network. More the number of alive nodes after simulation time, longer will be the life of the network. Also, Figure 10.2 shows that the time for the death of the first node is more in case of TSC than the time for the death of the first node in LEACH, PEGASIS, and CCS. Therefore, from the simulation results shown in Figure 10.2, it can be concluded that the network lifetime for proposed TSC scheme is also greater as compared to the network lifetime of LEACH, PEGASIS, and CCS.

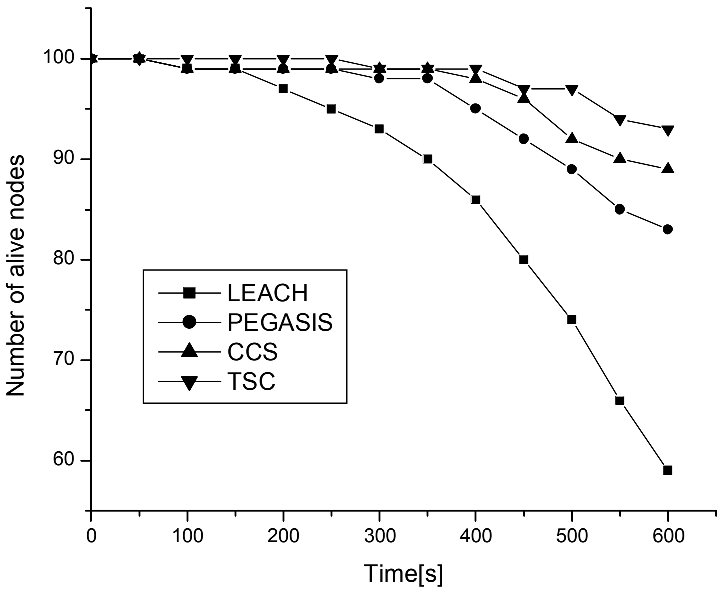

Figure 10.2 Number of nodes alive over simulation time.

C. Comparison of simulation results between DDAR and TSC

In this sub section, the two proposed protocols DDAR and TSC are compared. Two performance metrics energy consumption over simulation time and number of nodes alive over simulation time are used for comparing the performance of DDAR and TSC. Simulation results showed that the TSC scheme has 59.76% energy efficiency as compared to DDAR. Similarly, the number of alive nodes for DDAR was found to be 80 after 600 seconds of simulation time. Whereas, the number of alive nodes in TSC was found to be 93 after the simulation time of 600 seconds. Therefore, it can be concluded that TSC achieves greater energy conservation as compared to DDAR. The simulation results are shown in Figures 10.3 and 10.4.

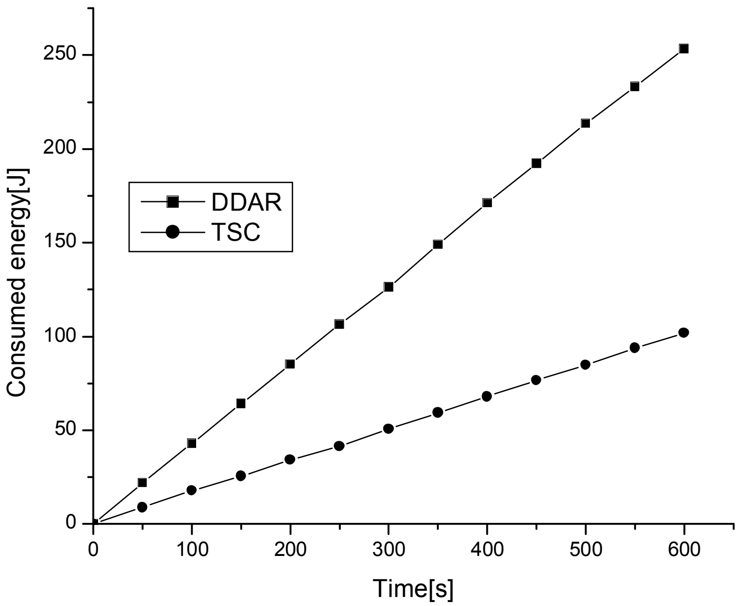

Figure 10.3 Energy consumption in DDAR and TSC.

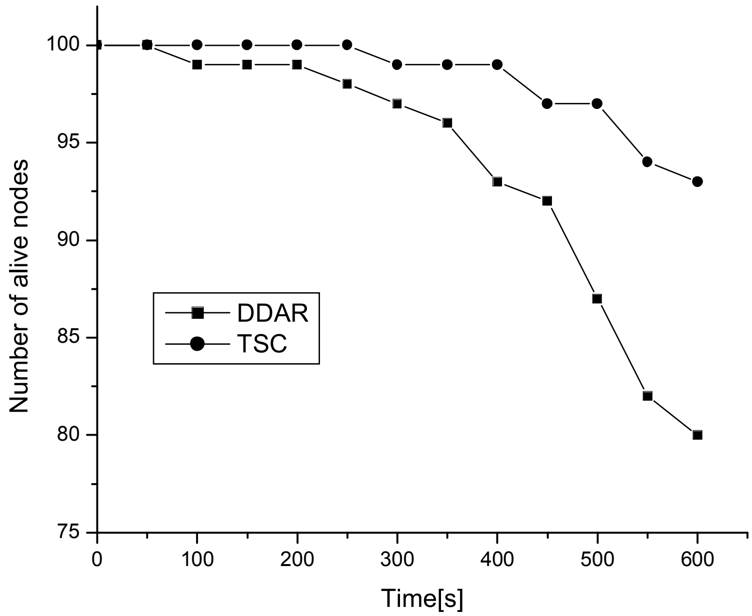

Figure 10.4 Number of alive nodes in DDAR and TSC.

X. Conclusion and future works

In this thesis work, two protocols DDAR and TSC schemes are proposed for energy efficient routing in WSN. The simulation results showed that the proposed DDAR protocol consumes about 75% less energy as compared to MTE, about 56% less energy as compared to LEACH, and about 40% less energy as compared to LEACH-C protocol at 600 seconds of simulation time. Similarly, the mathematical analysis and simulation results showed that the proposed TSC scheme is at least more than 1.4 times and at most more than 5.5 times efficient in conserving energy as compared to the conventional routing protocols. This considerable amount of energy conservation is obtained at the cost of increasing computational complexities only at the beginning of network setup. Because, almost all the computations are done in the BS, the additional computations at the beginning of the network setup do not increase the energy consumption in the network. Therefore, the proposed DDAR and TSC schemes for WSN routing can be adapted in the applications where energy conservation is of prime importance. Unlike in PEGASIS and CCS, there is no or very less redundant data transmission caused by reverse flow of data from the BS in the proposed TSC scheme. Therefore, the proposed TSC scheme may also be adapted in applications, where redundant data transmission has to be minimized and where end-to-end delay is also a major factor.

As the future work, dynamically determining the number of CHs and selecting high energy nodes as CHs in DDAR will be adopted to the TSC protocol to select the head nodes in the clusters for more uniform depletion of energy in the network. Also, the TSC scheme can be used for time critical applications with some modifications in the sector formation process. In future, the two protocols will be combined and extended for energy efficiency in time critical applications.

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저작물 이용 허락서

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논문 제목	한글: 무선센서네트워크에서 에너지 효율성을 위한 거리 인지 클러스터기반의 하이라키컬 라우팅 프로토콜				
	영문: Distance Aware Cluster Based Hierarchical Routing Protocols for Energy Efficiency in Wireless Sensor Networks				

본인이 저작한 위의 저작물에 대하여 다음과 같은 조건 아래 -조선대학교가 저작물을 이용할 수 있도록 허락하고 동의합니다.

- 다 음 -

1. 저작물의 DB 구축 및 인터넷을 포함한 정보통신망에의 공개를 위한 저작물의 복제, 기억장치에의 저장, 전송 등을 허락함.
2. 위의 목적을 위하여 필요한 범위 내에서의 편집과 형식상의 변경을 허락함. 다만, 저작물의 내용변경은 금지함.
3. 배포・전송된 저작물의 영리적 목적을 위한 복제, 저장, 전송 등은 금지함.
4. 저작물에 대한 이용기간은 5년으로 하고, 기간종료 3개월 이내에 별도의 의사 표시가 없을 경우에는 저작물의 이용기간을 계속 연장함.
5. 해당 저작물의 저작권을 타인에게 양도하거나 출판을 허락을 하였을 경우에는 1 개월 이내에 대학에 이를 통보함.
6. 조선대학교는 저작물 이용의 허락 이후 해당 저작물로 인하여 발생하는 타인에 의한 권리 침해에 대하여 일체의 법적 책임을 지지 않음.
7. 소속 대학의 협정기관에 저작물의 제공 및 인터넷 등 정보통신망을 이용한 저작물의 전송・출력을 허락함.

동의여부 : 동의(○) 반대( )

2010년 2월 25일

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조선대학교 총장 귀하