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무선 센서 네트워크를 위한 에너지 효율적인 클러스터 기반 라우팅 프로토콜

2018년 12월

Graduate School of Chosun University

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이 논문을 공학석사학위 신청 논문으로 제출함

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ABBREVIATIONS

WSN	Wireless Sensor Network
CM	Cluster Member
CH	Cluster Head
BS	Base Station

ABSTRACT

Energy Efficient Dijkstra-Based Weighted Sum Minimization Routing Protocol for Wireless Sensor Network

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Wireless sensor networks consist of several wireless sensor nodes which have limited transmission power and processing capabilities. Hierarchical cluster-based routing protocols are considered an efficient technique to route data from sensor nodes to base station. This paper proposes a scheme which considers K-means clustering in cluster formation phase and calculates a weight function for the cluster head selection process. Moreover, it considers an optimal fixed packet size with respect to radio parameters and channel conditions of the transceiver. This approach can minimize the energy consumption of individual nodes and increase the network lifetime as a whole. Moreover, different power levels are considered for data transmission from cluster head to cluster member and base station. In data transmission phase, it implements a multiobjective weight function as a link cost using traditional Dijkstra algorithm. This technique results in balanced and efficient energy consumption of nodes within the network. Simulation results show that proposed scheme outperforms the existing routing protocols (such as CERP and TEEN) in terms of energy conservation of nodes in the network and increases the throughput of the overall system.

한글요약

무선 센서 네트워크를 위한 에너지 효율적인 클러스터 기반 라우팅 프로토콜

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무선 센서 네트워크는 전송 파워와 처리 능력이 제한된 여러 무선 센서 노드로 구성된다. 계층적 클러스터 기반 라우팅 프로토콜은 센서 노드에서 기지국으로 데이터를 라우팅하는 효율적인 기술로 간주된다. 본 논문은 클러스터 형성 단계에서 K-평균 군집을 고려하고 클러스터 헤드 선택 프로세스에 대한 가중 기능을 계산하는 계획을 제안한다. 더욱이, 송수신기의 무선 파라미터 및 채널 조건에 관하여 최적의 고정 패킷 크기를 고려한다. 이 접근방식은 개별 노드의 에너지 소비를 최소화하고 네트워크 수명을 전체적으로 증가시킬 수 있다. 또한 클러스터 헤드에서 클러스터 멤버 및 기지국으로의 데이터 전송 시 서로 다른 전력 수준이 고려된다. 데이터 전송 단계에서는 기존의 Dijkstra 알고리즘을 사용해 링크 비용으로서 다중객체 중량 함수를 구현한다. 이 기법은 네트워크 내 노드의 에너지 소비 균형과 효율성을 초래한다. 시뮬레이션 결과는 제안된 계획이 네트워크 내 노드의 에너지 절약 측면에서 기존 라우팅 프로토콜보다 뛰어나고 전체 시스템의 처리량을 증가시킨다는 것을 보여준다.

I. INTRODUCTION

1.1. Research Context

The advancement in the micro electromechanical system (MEMS) and modern wireless technology has led to the development of sensor nodes which are low powered, low memory, small size yet smart devices[1]. In general, an extremely large amount of these sensor devices are mounted to form wireless network of nodes and measure the environment in terms of physical values. This network setup refers to as wireless sensor networks (WSNs).

Wireless sensor network have recently increased its applicability due to their cost effective, flexible and adaptable features. WSNs are a unique category of ad hoc networks in which the devices are wirelessly interconnected sensor nodes with reduced or no mobility, whereas ad hoc networks are defined as infrastructure-less self-configuring networks consisting of mobile sensor nodes[3]. WSNs are data centric, i. e. unlike traditional ad hoc networks which require data query from specific network nodes, these networks collect data according to specific network attributes, for instance, which area has temperature over 35ºC or 95ºF. Sensor nodes forms the basis of wireless sensor network (WSN) and performs functions such as information sensing, data relaying and data exchanging within a geographical area known as network field. A traditional WSN consists of thousands of these sensor nodes which are resource constrained in nature. Initially, the concept of WSNs was motivated by military applications (e. g. security and tactical surveillance, chemical and biological attack detection), however, later it expanded to a wide range of civil applications such as commercial applications (e. g. vehicles tracking and smart home systems) and environmental applications (e. g. weather monitoring, fault detection, diagnosis in industrial processes, and animals tracking).

WSN plays a significant role in monitoring and analyzing remote and hostile environments. WSNs application domain can be assumed like a traditional wired or wireless network. However, the reality is completely opposite due to the availability of unlimited resources such as battery power, fixed network topology, computational capability and communication range. Whereas, WSNs suffer due to the limited resources available in each node. Moreover, random distribution of sensor nodes caused by easy deployment techniques for instance spreading sensors by helicopters over forests and deserts, or by ships over lakes and seas, makes the battery recharge or exchange an impossible fact. Dense deployment and small size of the sensor nodes also creates some serious energy consumption considerations. In general, it is an immense necessity to develop a scalable and energy-efficient WSN which will be of great significance.

In order to address such challenges in WSN, network topology control is one of the efficient approaches. Generally, network topology control is defined as the techniques used to enhance the system performance or reducing route cost of the underlying network. Although a lot of techniques have been presented in literature for topology control but the most popular and widely used network topology schemes are cluster-based. Furthermore, cluster-based routing protocols conserves more energy as compared to traditional methods and therefore results in increased network lifetime. Several cluster-based routing mechanisms have been proposed primarily differing in terms of routing objectives and techniques. In addition to this, the general purpose of WSN deployment is to transmit the useful information from source to destination and finally to the end user. This is completed by either a single-hop (direct transmission from one node to another) or multi-hop (one or more relay nodes are involved) transmission which involves transmission of data packet from one sensing node to another sensing node til it reaches the final point. Therefore the routing process to determine the best optimal path between nodes is a significant issue in WSN.

1.2. Research Motivation

In ubiquitous computing environments, WSNs have been broadly studied due to its widespread utilization. The application area of WSNs includes environmental management, health-care services, and military monitoring. Wireless sensor networks involve the deployment of several sensor nodes which are equipped small batteries, memory and processors for information processing. Moreover, the sensor nodes are distributed in the network area to sense information from its surrounding. This sensed data is then forwarded by each node to base station (BS), usually referred as sink node. For this purpose a routing scheme is needed to find a route between original source node and the final sink node. Routing protocols highly impact the efficiency of wireless sensor networks, which eventually effects the lifetime of the network. The challenging issue for designing a routing algorithm is to maximize network energy efficiency along throughput of the underlying network. Therefore, a routing protocol should be designed such that it reduces the energy consumption of the individual nodes for data transmission by determining nodes with enough energy. In addition, a path which offers efficient energy consumption needs to be selected to improve network lifetime and throughput.

1.3. Research Contribution

The main research contribution of this thesis involves a cluster-based routing protocol which increases the network lifetime and throughput of the WSN. The proposed routing scheme operates in four phases: First phase is the network deployment phase which includes the exchange of node's information such as residual energy and current location of the node with neighbouring nodes and BS. The second phase consists of cluster formation phase which uses K-means clustering algorithm to organize the nodes in form of clusters. This technique is used to organize the nodes in an efficient manner and reduce energy dissipation of the nodes. Once nodes are grouped in the form of clusters, the third phase starts which is cluster head (CH) selection phase. In this phase, the cluster head node is selected with the help of two weight functions. The calculated weight function results in the selection of the node with maximum energy and minimum distance to the initial cluster center. Since the residual energy and location of the node is considered when selecting CHs, this approach can efficiently utilize high-energy nodes in the network. Finally, the data transmission phase is executed on the occurrence of an event. It calculates a multiobjective weight function to be used as a link cost between data transferring nodes. The cost function is then fed into the dijkstra algorithm to calculate a path with minimum weight(cost) to the BS. As a result, the network efficiency is enhanced and it also avoids node isolation problem occurring in some parts of the network.

The performance evaluation of the proposed scheme is done with some of the existing routing protocols using MATLAB as a simulation platform. The simulation results indicate that the proposed technique performed better as compared to other routing schemes in terms of energy efficiency of individual nodes, network lifetime and increased throughput of the overall system. Furthermore, the advantages and disadvantages of compared routing schemes are discussed and illustrated based on the simulation results. The following are the published papers which contribute to the work reported in this thesis:

- Routing protocol for WSN using K-means clustering and optimal packet size.
- Dijkstra based weighted sum minimization routing protocol for WSN.

1.4. Thesis Structure

The remainder of the thesis is organized as follows. Chapter II gives the introduction of Wireless Sensor Network (WSN) and literature review of existing clustered based routing protocols. Chapter III describes the proposed scheme in detail and Chapter IV provides details of simulation parameters and results to support the energy efficiency of the proposed idea. Finally, Chapter V concludes the thesis with some suggestions for the future work.

II. BACKGROUND

2.1. Introduction to Wireless Sensor Network

Wireless sensor network is a network of spatially distributed autonomous and self organized nodes called sensor nodes[1]. These nodes are equipped with the capabilities such as sensing, processing and data communication among each other wirelessly over a radio frequency channel. However, these sensor nodes have a small footprint, low power and several resource constraints limiting their performance. A typical sensor node consists of four main functional units such as embedded processor, memory, transducer, transceiver and power source as illustrated in the Fig. 1. Power unit consists of a battery which supplies energy to other functional units to accomplish their tasks.

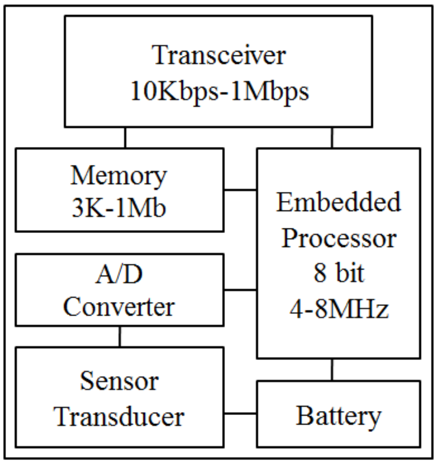

Figure 1. A typical sensor node structure

The sensing unit measures physical environmental conditions like temperature, pressure and humidity, the processing unit is responsible for processing the data (sensed information) while the communication unit helps in transmitting data from a source node to sink node. Sensor nodes work in collaboration to perform the sensing and communication tasks which is the foundation for the Internet of things (IoT)[2]. Additionally, these sensor nodes are randomly deployed in a network area to monitor the environment and send the data to BS or sink node to reach the end user as shown in Fig. 2.

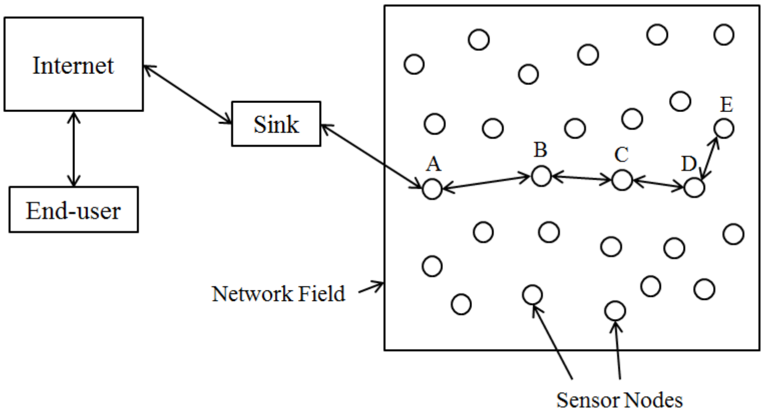

Figure 2. System structure of wireless sensor network

2.2. Energy Efficiency in Wireless Sensor Network

Wireless sensor network being unique in its characteristics form an important part of various industrial, commercial and environmental applications. These applications require a sizeable number of sensor node deployment in an outlying area, and the replacement of these devices is quite difficult in many scenarios. Sensor nodes have limited battery power which needs appropriate utilization to maximize the lifetime and functionality of a network. Therefore, senor nodes in WSN should be equipped with energy efficient algorithms and techniques to prolong its functionality for a reasonable duration.

Energy consumption in a node can be categorized into three components such as; sensing energy, processing energy and communication energy. Most of the sensor’s energy is consumed during the data communication phase as compared to the data sensing or data processing phase[3]. Studies illustrate that the main sources of energy loss in WSN are idle listening, control message overhead, collision, retransmission, over emitting and over-hearing [4] as illustrated in Fig. 3. Idle listening refers to the energy loss when the sensor is being active but not sensing or communicating. In WSNs, sensors have to receive data from its corresponding nodes and transfer to other nodes immediately, which requires sensor to be active in idle state. Control packet overhead is the amount of energy required by the sensing nodes to send, receive and transmit control packets among the network [6]. Collision occurs generally when two or more nodes try to transmit data at the same instance of time, thus inhibiting delay in the network efficiency. This leads to retransmission of data which results in unnecessary energy consumption of node. Over emitting takes place when sending node transmits a packet to the receiver but the receiver is not ready to accept it while over hearing happens when node receives an irrelevant data from its neighboring nodes [4].

Numerous routing algorithms have been proposed to increase the efficiency of WSN and ensure maximum network lifetime [8], [10]. Routing strategies such as clustering based routing algorithms have been proposed to increase the energy efficiency of WSN and ensure maximum network lifetime [11], [3]. Additionally,

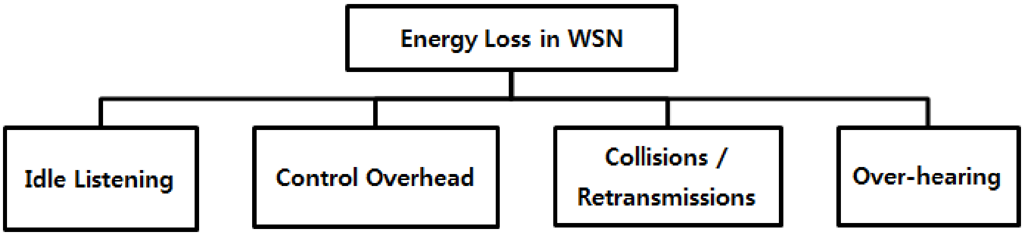

Figure 3. Sources of energy loss in WSN

efficient data aggregation techniques and optimal design of routing protocols can ensure the existence of an energy efficient network. These techniques are necessary for maximizing battery lifetime of sensing nodes in network and at the same time minimizing power consumption [7]. Data aggregation techniques can be utilized to compress the data being sensed, computed and transmitted. In this way amount of data which needs to be transmitted can be reduced and more energy consumption can be avoided [7].Other techniques such as MAC layer protocols can be used to increase energy efficiency of a network by reducing collision probabilities with the increase in network size and topology [9].

2.3. Challenges of Routing Protocols in Wireless Sensor Network

According to ISO communication model, routing protocol is a network layer protocol. A communication protocol is a set of standard rules which describes how to transmit data across a network. Similarly, a routing protocol specifies how network routers communicate with each other and disseminate the related information which helps them to identify multi-hop paths between the nodes in the network[13].

In WSN, the sensor nodes are deployed randomly in a network region. These sensing nodes are equipped with mechanisms which enable them to communicate even when an established network infrastructure is not available. Moreover, the due to the node failure and poor channel conditions the network topology is continuously changing, despite the fact that nodes in WSN is immobile. Furthermore, the size of the network should not effect the performance of the wireless sensor network. That means the performance of the network should not be affected with the increase in number of nodes. As the sensor nodes are deployed in remote territory, the power supply of a node cannot be replaced. Therefore, the efficient management of network topology, node energy and scalability are some of the design challenges of routing protocol in WSN. Additionally, there are various other network design issues which require significant attention when designing an efficient routing method for WSN. These issues involve the following main aspects [13]:

- **Node Deployment:**

In WSN, sensor nodes are usually deployed randomly and without careful pre-planning (e. g. airdrop deployment by helicopters over forests and deserts, or by ships over lakes and seas) since most of the WSN applications operate in dangerous zones[6]. Additionally, sending engineers to carry out precise node placement is also not preferable. Also the network topology continuously changes with time due to several other exterior forces such as explosions and movements.

- **Limited Power:**

A typical sensor node is equipped with two AA batteries whose power supply is very limited[3]. Since most operations of a sensor nodes for instance, data sending and processing are energy consuming, the energy of node is drained quickly during the network operation. This issue gets more prominent by the fact that nodes in some applications of WSNs are left unattended. For instance, in the field surveillance application, sensor nodes are distributed in an inaccessible and dangerous territory. Recharging or replacement of the battery of node is difficult or impossible and can be expensive and unrealistic. Therefore limited energy of a node is the most crucial challenge for the design of a routing algorithm in WSN.

- **Small Storage Capacity:**

Sensor nodes being resource constrained in nature have a very small storage size as compared with those of traditional networks [11]. This constraint limits the applicability of WSN to the applications that require big data storage capacity. Furthermore, less storage results in limited computation capabilities for data communication and data processing.

- **Limited Transmission Range:**

Sensor nodes have limited communication range due to the small battery life and limited antenna capability[13]. Although, some nodes (like Crossbow mica nodes[11]) have the ability to adjust the power level according to the application requirements. The maximum communication range of a sensor node is comparatively smaller as compared to the traditional networks[5]. Hence, in several applications sensor nodes are deployed on large scale to provide sufficient network coverage. Additionally, the limited range of nodes requires high node deployment for the sake of maintaining reliable connection between nodes.

Therefore, employing energy-efficient communication techniques, taking into account multi-hop ability, scalability and reliability, is highly desired. As a direct result, the lifetime of the network will be improved.

2.4. Literature Review

In order to overcome the constraints of WSNs and to solve the design and application issues, a large number of research have been carried out[13],[14]. Several routing protocols are proposed and designed to overcome the challenges and cover the issues of power consumption, scalability, fault tolerance, productive cost, connectivity, data aggregation, quality of service and fusion, node mobility, security, congestion, latency, etc. [14], [15]. Routing protocols for WSN can be categorized according to the nature of the WSN operation and its network architecture [15]. This gives two main categories; network architecture (structure) based routing protocols and operation (property) based routing protocols [15]. Fig. 4 shows the two categories and the sub-categories for each. Hierarchical based routing protocols (from architecture based protocols) are the best option when scalability and efficient communication is the main goal of the network [15]. Hierarchical based protocols also known as cluster based routing protocols work well to contribute to network scalability, lifetime and energy efficiency [15], [17]. Energy conservation is considered the most important QoS requirement in most applications as energy is directly related to network lifetime [16].

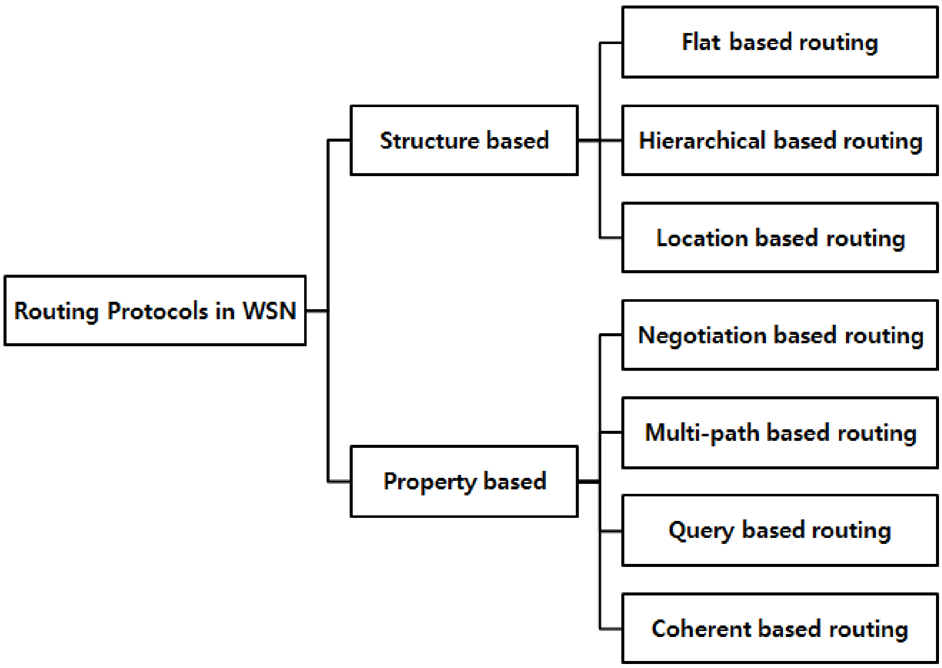

Figure 4. Classification of Routing Protocols in WSN

Cluster based routing protocols use hierarchical architecture which involves network division into various layers each performing its unique function[12]. The protocols work by grouping nodes into clusters. Each cluster consists of a leader node called cluster head and member nodes called cluster members[18]. Nodes with higher energy act as cluster heads and are responsible for the task of data aggregation and transmit information to the sink. The remaining nodes (member nodes) with lower energy perform the task of information sensing and sending the information to cluster head [18], [20]. Data is transmitted in the network in a form of multi-hop communication which reduces the number of transmitted information to the sink and drastically minimizes energy consumption of the sensor nodes [19]. The multi-hop communication property of cluster based routing protocols also contributes to network scalability and lifetime maximization [18], [20].

LEACH is a cluster based routing protocol which is proposed in [21]. This protocol provides local control for data transmission, includes randomized adaptive cluster formation, and application specific data processing. Conversely, TEEN protocol is proposed in [22] which is the first reactive protocol using hard and soft threshold values to trigger data transmission in sensor nodes. In order to increase the efficiency of the system, these threshold values should be carefully selected depending on the target application. The limitation of this algorithm is that if the values assigned as threshold are too high or too low, then nodes will never communicate or will utilize all there energy communicating unnecessarily respectively. In [23], Dijkstra-based Weighted Sum Minimization (DWSM) algorithm is proposed to analyze the impact of introducing a multiobjective function as the link cost between nodes. It takes path capacity and delay into account to minimize a weighted metric sum through Dijkstra algorithm. Moreover, ESRAD routing protocol is proposed to enhance energy efficiency of WSN in [24]. It takes into account the electronics energy consumption along the energy consumption during data transmission phase to select the least energy path. Then, Dijkstra algorithm is used to determine the path with least energy consumption from source to sink. this introduces additional overhead in the system which results in enhanced consumption of node energy.

Moreover, K-Hop Overlapping Clustering Algorithm(KOCA) is discussed in [25], which deals with the idea of overcoming the problem of overlapping in multihop clustering for WSN. Authors in this paper propose an algorithm which uses a specific degree of average overlapping to generate overlapping clusters to cover the entire network field. Cluster based Event Driven Routing Protocol (CERP) is proposed in [26]. It is an algorithm which deals with cluster formation based on different events. The limitations of this study is that it considers distance as a link cost between the neighboring nodes during shortest path calculation. Cluster are formed on the basis of event occurrence which due to random in nature, requires the selection of nodes with less energy and can result in isolation of nodes in particular area of network.

Optimal Path and Energy Efficient Aware Sensor (OPEAS) was proposed in [28], which uses different parameters to reduce the number of messages broadcasted during relay node selection phase. This technique helps in less power consumption in the network but increases packet loss rates. Furthermore, energy efficient multi-hop techniques for routing in WSN are proposed in [29]. In this protocol, a centralized approach is used where BS assigns a weight matrix to the underlying network and then uses the Dijkstra algorithm to calculate optimal data path from source to sink node. As a result, it becomes applicable to the network scenarios which involve periodic or query-based data reporting. Additionally, another protocol is proposed which involves an optimal path selection method using Dijkstra's algorithm in existing LEACH protocol [30]. In this study, the load and Dijkstra algorithm is used to find optimal path for data routing. However, it does not consider nodes residual energy while selecting the relay nodes during the data transmission phase.

Moreover, in [31] an improvement of LEACH protocol for wireless sensor network (LEACH-R) is presented. It proposes a cluster head reappointment algorithm in which the current cluster head continues to be a cluster head until a threshold value is reached. This technique leads to energy conservation by reducing the broadcasting and receiving of control messages per round. The disadvantage of this algorithm is that like LEACH protocol it does not considers the influence of surplus energy, density and geographic location of nodes when electing cluster heads. In [32], a study on energy-saving routing algorithm for wireless sensor network (LEACH-DT) is proposed. It uses a dynamic energy threshold to reduce the energy consumption during cluster head selection and rotation phase. In addition to this, it solves the problem of reallocating time slots for each round by exchanging the time slot information between current cluster head and the candidate cluster head. Furthermore, a study was documented on optimizing relay nodes in wireless sensor networks (TCBSP) in [33]. It organizes nodes in the form of a tree cluster structure to ensure proper connectivity among each cluster member node. This approach increases the lifespan of the nodes in the network as it first aggregates data in cluster form and then transmits it to another cluster in the form of a tree. The main drawback of this proposed algorithm is that it does not considers the residual energy of individual nodes while selecting cluster head as each node has equal probability of becoming a cluster head. This method might choose a node with less energy as a cluster head which will result in the network failure and critical data loss.

However, the above discussed protocols are well suited for periodic sensing and/or query-based data reporting. The proposed scheme is a multiobjective weighted sum function which considers residual energy of the node along its distance from the original source node during route selection using Dijkstra algorithm. This approach results in reduced overhead and the selection of node which has sufficient energy and is located at a minimum distance from the source node as compared to other neighboring nodes. The node with maximum energy and less distance is selected as data relaying node until data reaches final node.

III. ENERGY-EFFICIENT ROUTING PROTOCOL FOR WSN

This section presents a new energy-efficient routing protocol. It consists of a cluster formation method, cluster head selection algorithm by using optimal fixed packet size and a dijkstra-based weighted sum approach to obtain efficient routing path.

3.1. System Model

A description of system model is provided which includes network assumptions and energy model, considered in the proposed protocol.

3.1.1. Network Model

The network model provides the network environment that consists of N sensor nodes as $S_i(i=1,2,......,N)$ and one base station. Nodes are randomly deployed in an F x F network field with the base station located outside the network area. Sensor nodes are classified into clusters each having a cluster head and cluster members. This is a centralized clustering protocol which involves selection of cluster head in the BS and the selected cluster heads are announced to all the cluster members of the cluster. Once set-up phase is completed, nodes stay idle until an event occurs. Cluster members located in the vicinity of the event will sense and report the data to CH. CH integrates the gathered data to transmit it to the BS with the help of weight function using Dijkstra algorithm. This technique helps in efficient transfer of data packets from cluster head to base station. Fig. 5 illustrates the aforementioned wireless sensor network model. Further, the data received by base station is presented to the end-user when required.

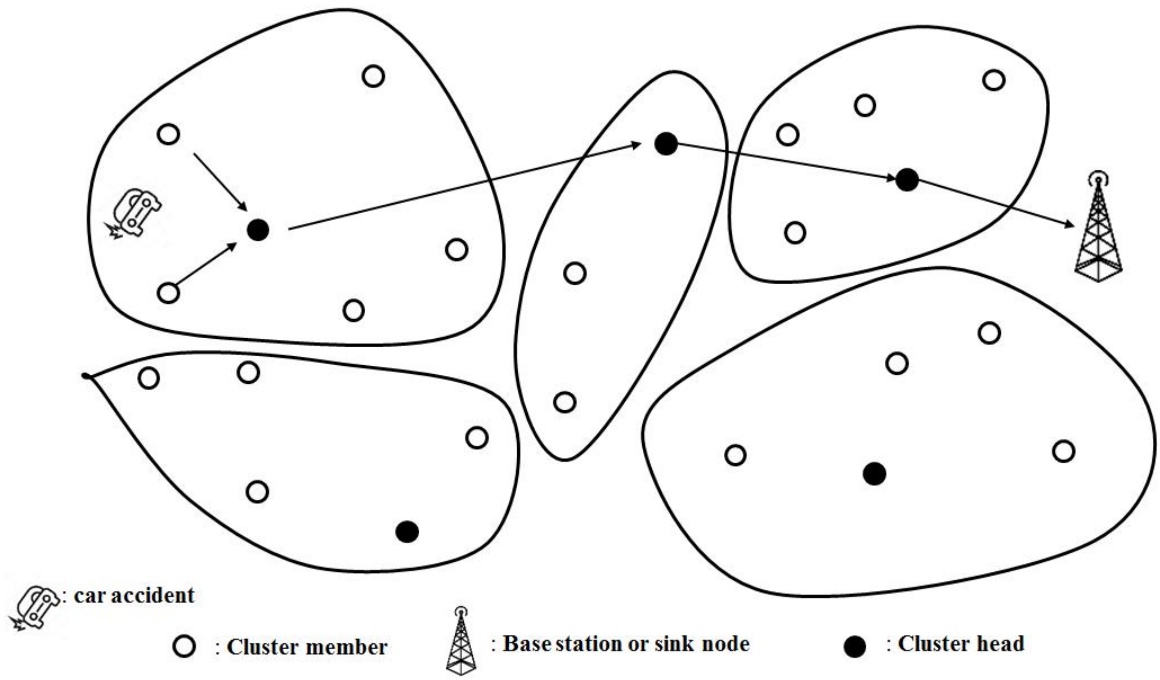

Figure 5. Network model for the proposed scheme

The network model for the proposed scheme comprises of some network assumptions which are stated as follows:

- Sensor nodes are homogeneous having same initial energy and computational capabilities such as sensing, processing and communication.
- Base station is located far from the sensing region and has no energy constraint.

- The sensor nodes and base station are static after deployment.
- The cluster head gathers all the information in a cluster and forwards it to the base station.

3.1.2. Energy Model

The energy model used in the proposed scheme is the first order radio model presented in[24]to measure the energy dissipation of nodes. The radio model includes three main components such as the transmitter, the power amplifier and the receiver as shown in fig. 6. The transmitter and receiver dissipates the energy to run the electronic circuitry for transmitting and receiving data respectively whereas the power amplifier amplifies the signal power for transmitting data[24].

In wireless sensor networks, relatively large amount of energy is utilized in the data communications phase. This consumption of energy can be controlled by using fixed optimal packet size [11] as:

$$P_{opt} = \frac{\sqrt{C_o^2 - \frac{4C_o}{\ln(1-p)}} - C_o}{2} \qquad (1)$$

where, $C_o = \alpha + \frac{K_2}{K_1}$ and α represents header bits in the packet. K_1 and K_2 are the amounts of energy used in communication of payload and startup energy consumption of transceiver respectively. p is the channel bit error rate (BER).

The energy dissipation for transmitting a P_{opt} bit packet from the transmitter to the receiver located at the distance d is formulated as:

$$E_{TX}(P_{opt}, d) = P_{opt} * E_{elec} + P_{opt} * \varepsilon_{amp} \ , \tag{2}$$

$$E_{RX}(P_{opt}) = P_{opt} * E_{elec} \ , \tag{3}$$

where, d represents the distance between transmitter and receiver, E_{TX} and E_{RX} represents the energy consumption of transmitter and receiver respectively, E_{elec} indicates the transceiver electronics energy consumption, and ε_{amp} shows the energy consumption of amplifier electronics installed in transmitter of sensor nodes, which can be defined as:

$$\varepsilon_{amp} = \begin{cases} \varepsilon_{fs} * d^2 \ \text{for}\, d \leq d_{th} \\ \varepsilon_{mp} * d^4 \ \text{for}\, d > d_{th} \end{cases} \tag{4}$$

where, $$d_{th} = \sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}} \ , \tag{5}$$

where, d_{th} is the cross-over distance, ε_{fs} and ε_{mp} are amplification energy propagation models as free space propagation model and multipath propagation model respectively. the free space propagation indicates that there is a direct, line-of-sight(LOS), between the transceiver. Conversely, the multipath propagation model represents the indirect propagation of electromagnetic wave from different paths at different times after reflection from the ground. The propagation loss in free space model for transmitting power is formulated as inversely proportional to d^2. Whereas, the propagation loss in multipath propagation model for transmitting power is modelled as inversely proportional to d^4,where d is the distance between transceiver.

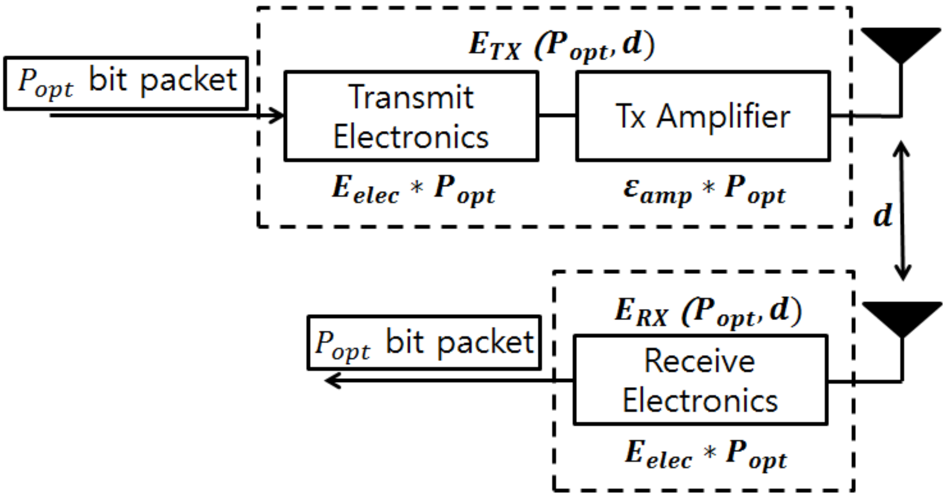

Figure 6. Radio energy dissipation model

In addition, the total amount of energy required for an optimal fixed packet transmission can be calculated as:

$$E_{total} = E_{TX} + E_{RX} + E_{DA} \tag{6}$$

$$E_{total} = P_{opt}(2 * E_{elec} + \varepsilon_{amp}) + E_{DA} \tag{7}$$

Let, d_{CH} be the distance from cluster member to cluster head and d_{BS} is the distance from cluster head to base station. Energy consumed by a cluster member for transmission of P bits to its cluster head is given by:

$$E_{CM} = E_{init} - E_{TX}(P_{opt}, d_{CH}) \tag{8}$$

Furthermore, the energy consumption by a cluster head in data aggregation and date transmission to base station can be calculated as:

$$E_{CH} = E_{init} - E_{RX}(P_{opt}) - E_{DA} - E_{TX}(P_{opt}, d_{BS}) \quad (9)$$

where, E_{CM} is the energy consumption of each cluster member, E_{CH} is the energy consumed by cluster head and E_{init} represents the initial node energy.

3.2. Problem Statement

The number of nodes deployed in a WSN application network field is usually very large. Thus the overall data flow in the network is considerable and incurs significant energy dissipation for sensor nodes. Moreover, the data is highly correlated as the nodes are deployed densely. Since the nodes are energy constrained, the routing scheme should be energy efficient. In addition, it is a known fact that big packets experience higher loss rates whereas short packets suffer from greater overhead. The condition of transmission channel has a significant impact on the network throughput[11]. On the other hand, variable packet sizes offer overheads and resource management cost for the underlying resource-constrained networks. Therefore, an optimal packet size should be considered to reduce energy consumption and maximize the lifetime of the sensor nodes in WSN [11]. Furthermore, the routing protocol also computes an efficient path to minimize the route cost such as energy consumption amid data transmission from nodes to the base station. In general, the problems that need to be addressed in the design of a routing protocol for WSN can be summarized as:

- How to efficiently organize numerous nodes in the network in order to maximize energy conservation.
- How to provide balance energy consumption of the nodes in the network.
- How to efficiently select a path and then route data from sensing nodes to the BS to ensure enhanced network lifetime.

3.3. Proposed Solution to the Energy Efficiency Problem

The main idea behind the problems discussed above is to improve energy efficiency in a WSN where the data is highly correlated and the end-user only needs a sophisticated form of the data describing the key attributes and events occurred in the environment. The clustering approach is a sensible solution for a large network. It can efficiently organize numerous nodes, aggregate data, and reduce energy consumption of the nodes [5].

Furthermore, the protocols which use centralized clustering, where the base station utilize the global information of the network for cluster formation and cluster head selection, can enhance network lifetime collectively. Additionally, the cluster head aggregates data and forwards it to base station on long distance. Using an optimal packet size and finding an efficient shortest path between the nodes and base station can reduce energy dissipation of the nodes and will result in increased throughput of the overall system [34,35].The efficient performance of these methods lead to the development of a centralized clustering, energy-efficient routing protocol for WSN. The proposed scheme addresses the aforementioned problems and consists of following features:

- Considering channel conditions and radio parameters, to calculate a fixed optimal packet size.
- A cluster formation and cluster head selection algorithm to ensure balanced energy consumption of nodes in the network area.
- A Dijkstra-based weighted sum method to calculate shortest route from the source node to the base station.

3.4. Proposed Scheme

This section includes detailed description of the proposed scheme. In the proposed algorithm, cluster formation technique known as K-means clustering is studied along the consideration of fixed optimal packet size to maximize the energy conservation of the nodes and increase system efficiency in the network. The proposed algorithm consists of two phases as set-up phase and steady state phase. These phases are explained below in detail as:

3.4.1. Set-up Phase

The set-up phase comprises of three different phases namely network deployment phase, cluster formation phase and cluster head selection phase. These phases are discussed as follows:

3.4.1.1. Network Deployment Phase

In this phase, a message is broadcast in the network by the BS which is termed as initialization request (IRQ). Once IRQ message is received by each sensor node, an initialization reply message (IRP) is sent back to the BS. This reply message comprises of residual energy of sensor nodes and their current location [35].

3.4.1.2. Cluster Formation Phase

This section explains the clustering algorithm used in the proposed algorithm. K-means clustering algorithm is the most popular and the simplest unsupervised learning algorithm used for organizing the data into K clusters. The value of K is calculated using equation 10. This algorithm consists of several iterations and steps which are explained below:

STEP 1: Calculation of value of K (initial cluster centers) [35] with the help of following formula:

$$K=\sqrt{\frac{N}{2\pi}}\sqrt{\frac{\varepsilon_{fs}}{\varepsilon_{mp}}}\frac{F}{d_{BS}^2}\ , \tag{10}$$

where, N presents the number of nodes in the network, F shows the network area of node deployment, and d_{BS}^2 is the average node distance to the BS.

Note that K represents the required number of clusters in the network.

STEP 2: The distance of each sensor node to each cluster center is calculated with the help of Euclidean distance as illustrated in equation 11, and assigning each node to the closest cluster center.

$$d_{N2C} = \sqrt{\sum_{i=1}^{N} (XY_i - XY_C)} \quad , \qquad (11)$$

where, d_{N2C} indicates the distance between the each cluster node and the respective cluster center, XY_i shows the coordinates of ith sensor node and XY_C represents the coordinate of the cluster center.

STEP 3: The mean value of all the sensor nodes in a particular cluster will be calculated to determine the position of new cluster centers.

STEP 4: Once new cluster centers are obtained, step 2 will be executed with the new centers. If the sensor node changes its position according to new cluster centers, step 3 will be executed otherwise the algorithm will be stop.

3.4.1.3. Cluster Head Selection Phase

After the formation of the clusters is completed, cluster head selection phase takes place. In cluster head selection phase, two weight functions are calculated for each cluster. Each node calculates its own weight as:

$$W_i = A * E_i + B * D_{i2c} \quad , \qquad (12)$$

where $i = 1,2,......,m_c$ and m_c represents number of cluster member nodes, A and B are constants[35], W_i represents the weight of ith node within a cluster, D_{i2c}

is the distance of ith node to cluster center and E_i is the residual energy of ith node. In addition, a standard weight is also calculated for each cluster which is given as:

$$W_{std} = A * E_{total} + B * Avg(D_{i2c}) \quad , \tag{13}$$

where, W_{std} indicates the standard weight a node is supposed to have to become cluster head, $Avg(D_{i2c})$ shows average node distance of the nodes belonging to a particular cluster to its cluster center and E_{total} is the amount of energy required to transmit, receive and aggregate P_{opt}. These two weights are compared within a cluster and the cluster node with weight almost equal to standard weight is considered to be the cluster head for that particular cluster. Cluster head information is now broadcast to all sensor nodes in a cluster by base station and this way their routing tables are updated.

3.4.2. Steady State Phase

After cluster formation and cluster head selection are completed, steady state phase or data transmission phase starts. This phase is comprehensively described below.

3.4.2.1.Data Transmission Phase(DTP)

In data transmission phase, the shortest path from source node to destination node is calculated. The sensor nodes stay idle in the network until any event or activity is sensed. The event is referred to as any change in the sensed value exceeding a certain threshold level. When the event is occurred, the sensor nodes of that particular cluster will sense the values and send it to cluster head. Cluster head aggregates the collected data and transmits to BS using multi-hop communication. For this purpose, Dijkstra-based weighted sum algorithm is used to find optimal path from cluster head as a source node to base station as a destination node.

The Dijkstra algorithm finds the optimal route from the source to destination based on a link cost. This algorithm is explained below in detail:

STEP 1: A set of nodes (NL) is initialized which consists of the nodes participating in the route formation from source node to final node. Initially, this set consists of only the source node (N_i) which is equal to (N_S) for the first DTP iteration. A DTP iteration refers to the duration in which a source node identifies its neighbouring nodes and selects the link with minimum cost. Several iterations are performed to route data to final node via minimum route cost. The initial path cost (W) from source node to neighboring nodes (N_j) represents simply the link cost (L).

$$NL = \{N_S\}$$

$$L(N_i, N_j) = W(L_{ij}) \quad \text{for } N_j \neq N_i \,, \qquad (14)$$

Proposed scheme calculates a weight function as a link cost which is influenced by two network parameters such as the residual energy of the packet receiving node and its distance from the data sending node or source node in this case.

The weight function is formulated as:

$$W(L_{ij}) = \beta * E_j + (1-\beta) * D_{ij} \ , \quad (15)$$

where, $W(L_{ij})$ is the weight of the link between the source node (N_i) and the neighbouring node (N_j), D_{ij} is the distance between the source node and the neighbouring node and E_j is the residual energy of the neighbouring node. β is the tuneable parameter ranging from 0 to 1.

STEP 2: Calculate above mentioned weight function for each neighboring node (N_j) from node (N_i) .

STEP 3: The weights of the each links from neighbouring nodes (N_j) to source node (N_i) will be compared. After comparison the node along with the link with minimum cost (weights) is selected to forward the packet as shown in Fig. 7:

$$W(L_{ij}) = \min\left[L(N_i, N_j)\right] \ , \quad (16)$$

where, $j = 1,2,...,m$ and m is the number of neighbouring nodes to source node. $W(L_{ij})$ represents the link cost from source node to the neighboring node with the least link cost. Update the set (NL) with the node that has the least link cost from source node along with the link that is incident on that node.

STEP 4: The step (2) and (3) will be executed again until the final path is found between source node and destination node. The summation of minimum weights for each selected link will be performed using equation 17.

$$\sum_{i=1}^{f} W(L_{ij}) \ , \quad (17)$$

where, f represents the final node which is BS in this case.

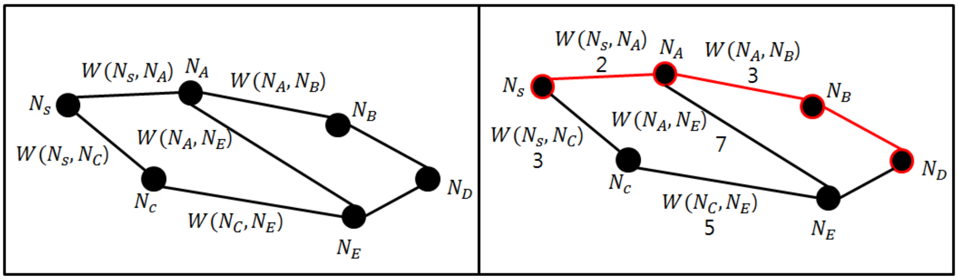

Figure 7. Dijkstra Algorithm. (a) weighted graph between source node (N_S) and destination node (N_D).(b) path with minimum weight is selected from N_S to N_D.

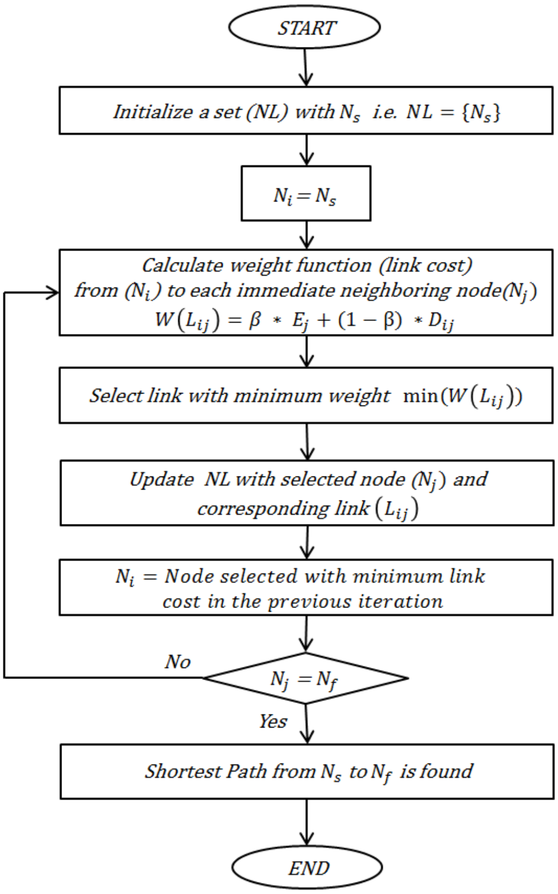

Figure 8. Flowchart of Data Transmission Phase.

Fig. 8 shows the complete flow of explained data transmission phase. Eventually, the data route is found which has minimum route cost(weights) involved for data transmission. Fig. 9 represents the complete flow of proposed algorithm.

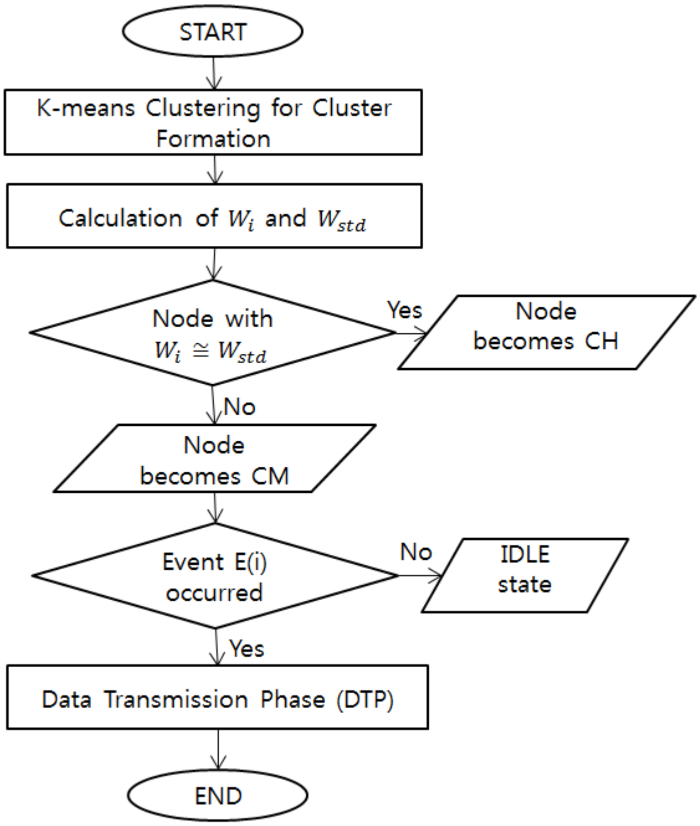

Figure 9. Flowchart of Proposed routing protocol.

IV. SIMULATION RESULTS AND ANALYSIS

In this section, the proposed routing protocol is evaluated on a simulation platform which is MATLAB. The proposed protocol is evaluated in terms of energy efficiency, system throughput and network lifetime with two existing protocols namely cluster based event-driven routing protocol (CERP)[25] and threshold sensitive energy efficient sensor network protocol(TEEN)[21]. These mentioned routing protocols are briefly discussed in the literature review section.

The proposed scheme assumes that a cluster occupies an area of $\frac{F}{K}$ in a field of $F \times F$ [20] where K is the number of clusters formed and F is the area of network field. The simulation parameters and values used in this paper are given in Table I [20].

Table I. Simulation Parameters and Values

Simulation Parameter	Value
Transceiver Electronics Energy (E_{elec})	$50\,nJ/bit$
Data Aggregation Energy (E_{DA})	$5\,nJ/bit/signal$
Node's Initial Energy (E_{init})	$0.5\,J$
Number of Nodes (N)	100
Position of Base station (X, Y)	$(100,175)$
Network Field (F)	$(100 \times 100\,m^2)$
Packet size (P_{size})	$1000\,bits$
Node's Transmission Range (r_t)	$7\,m$

Fig. 10 shows the average residual energy of the nodes as calculated for specific intervals. The results obtained were compared with CERP and TEEN. It shows that proposed scheme has better performance as compared to the CERP and TEEN protocol because the energy consumption of proposed scheme is much less than the above two. The reason for high energy consumption in TEEN is due to the continuos sensing of the environment for the threshold value to be reached. The energy consumption of CERP increases due to the reason that it does not considers energy of the relay nodes while in the proposed scheme the residual energy of the node and its distance to source node selects a node efficiently and increases the network energy conservation overall.

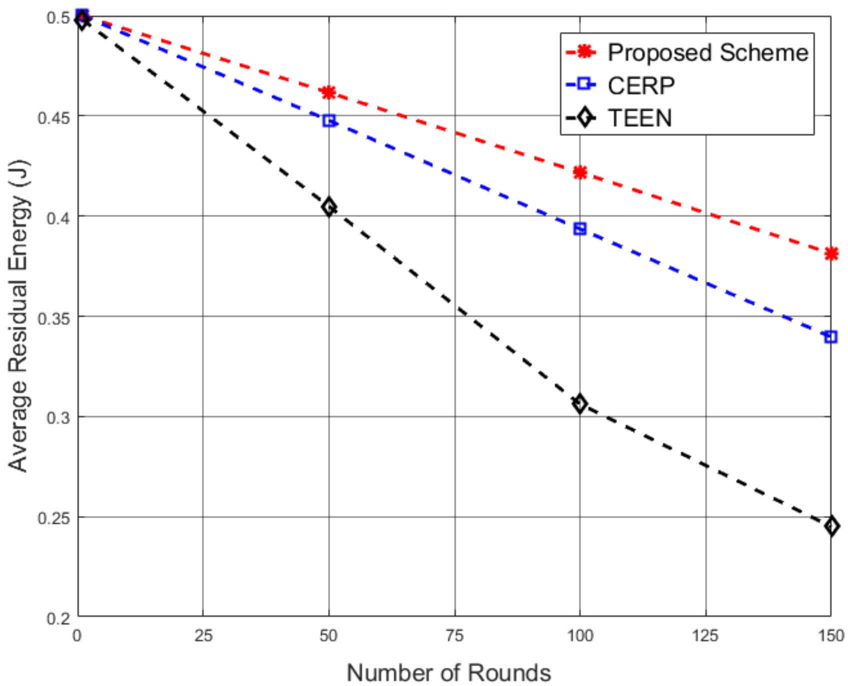

Figure 10. Average residual energy w. r. t to number of rounds.

Figure 11 shows the amount of energy consumed for each routing scheme

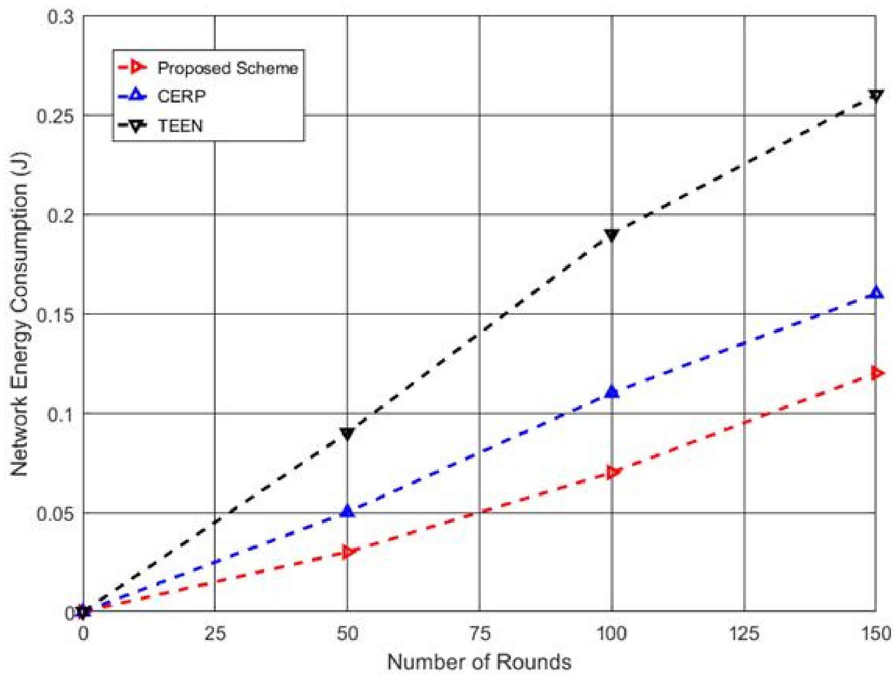

Figure 11. Network Energy Consumption w. r. t to number of rounds.

with respect to the number of rounds. It is evident that the proposed method has better performance as compared to the other two due to the consideration of residual energy of the data forwarding nodes. Moreover, it takes into account the distance of the node to the BS which ensures energy balancing throughout the network.

Figure 12 shows the performance of each routing protocol in terms of number of sensor nodes alive for each round. In the proposed scheme, the nodes are selected on the basis of residual energy level as cluster head which results in uniform load distribution among nodes in proposed scheme. In addition, the proposed scheme selects the nodes with adequate amount of energy during packet transmission to BS which promotes the balanced energy consumption in the network as compared to TEEN and CERP Conversely, the nodes die early due to increased energy consumption of node in the other routing schemes.

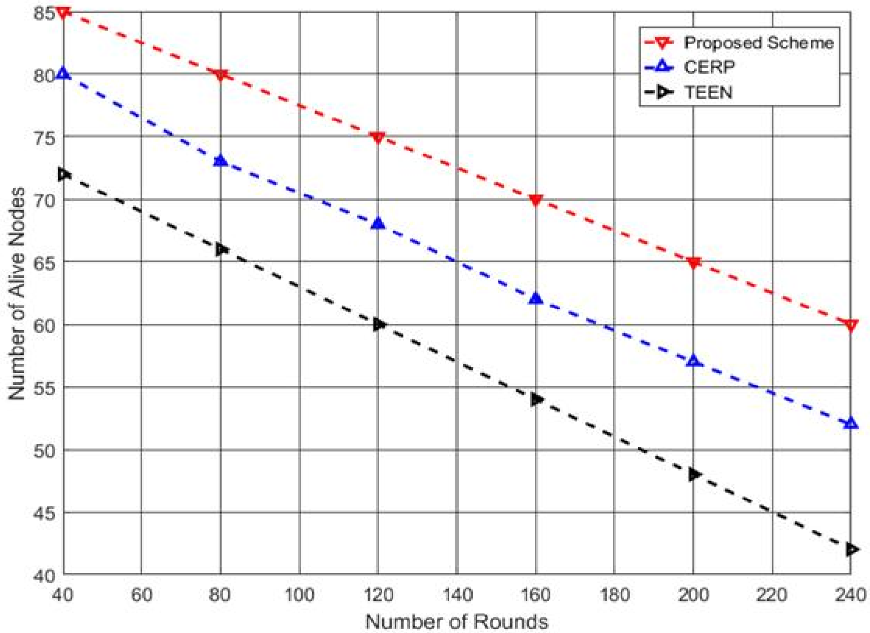

Figure 12. Number of nodes alive w. r. t number of rounds.

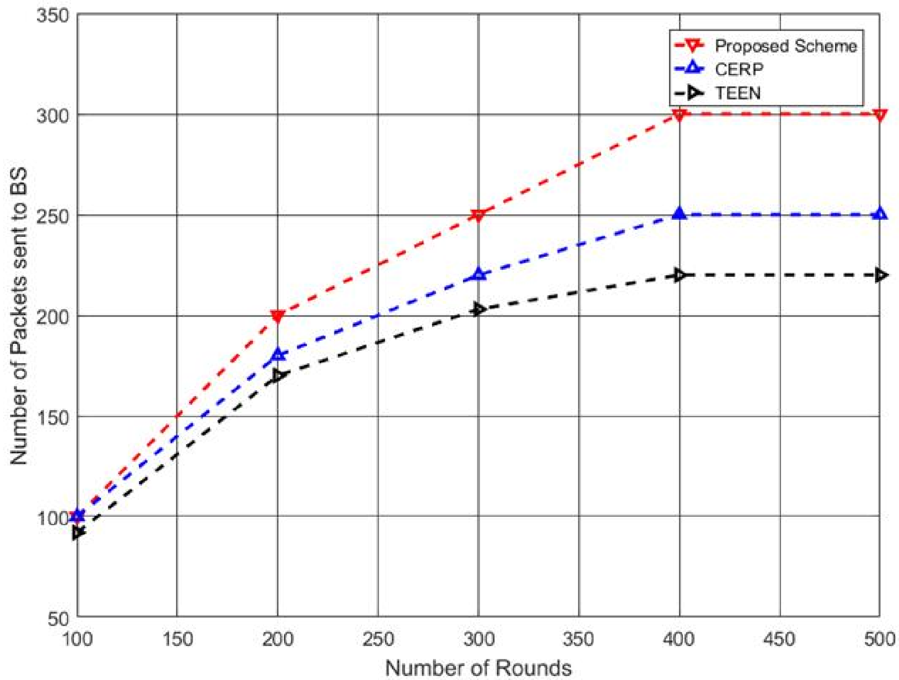

Figure 13. Network throughput w. r. t number of rounds.

Fig. 13 illustrates the throughput of the network in terms of packets sent to BS with respect to the number of rounds. The throughput of the system is defined as the number of data packets successfully received at BS after every round. Proposed algorithm outperforms the other routing algorithms and provides relatively higher network throughput. In CERP and TEEN, nodes die out early which results in less number of data relay nodes available for the packet transmission to BS. In addition to this, TEEN transmits least number of packets to the BS because until the sensing value does not reaches the threshold value, the nodes will never communicate.

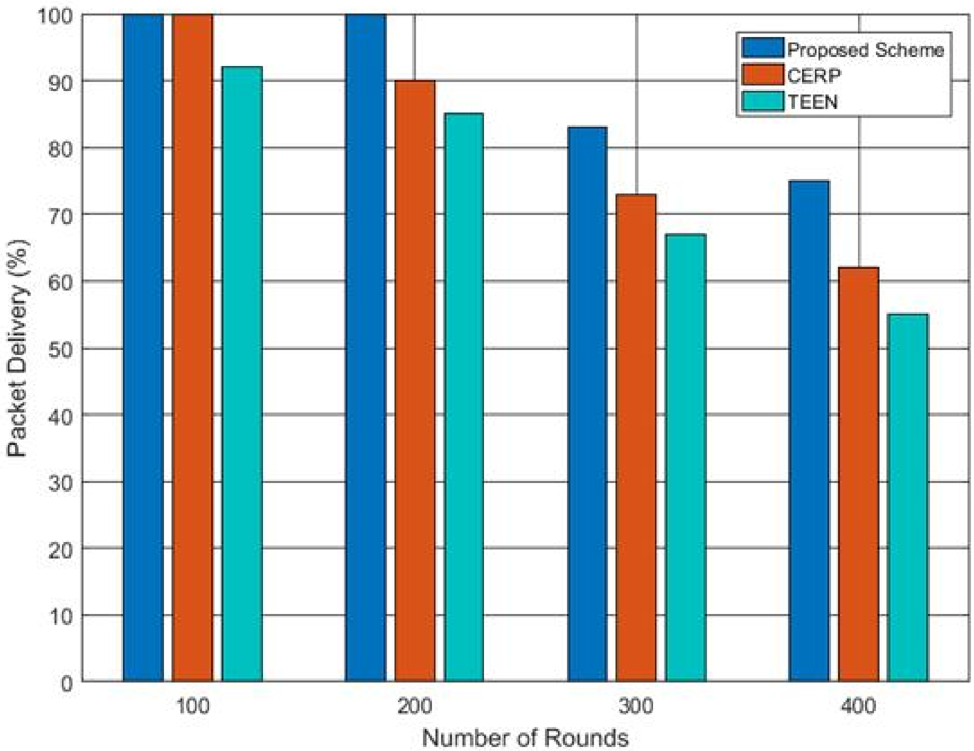

Figure 14. Packet Delivery (%) w. r. t number of rounds.

Fig. 14 shows the percentage of packets delivered to BS with respect to the number of rounds. The packet delivery refers to the amount of packets delivered successfully at the end of each interval of rounds. It can be noted that TEEN shows least packet delivery percentage in every interval due to reason that data transmission will occur only if the threshold value is reached. Overall, proposed algorithm outperforms the other routing algorithms and provides relatively higher packet delivery.

V. CONCLUSION

In wireless sensor network, sensing devices often termed as sensor nodes have limited battery power and deplete most of it in data transmission phase. K-means clustering algorithm is used in the proposed scheme to organize sensor nodes into clusters. Eventually, in the cluster head selection phase, node with highest amount of energy in the cluster is selected to perform transmit and aggregate data efficiently. Moreover, the proposed scheme calculates a weight function which is considered as a link cost for each link in the network using Dijkstra algorithm amidst data transmission. This weight function is influenced by two parameters i. e. nodes residual energy and its distance to the neighbouring node which ensures maximized network lifetime and the throughput of entire network.

The performance evaluation of the proposed algorithm is done using MATLAB. The performance metrics used to compare developed protocol with other existing routing algorithms are energy efficiency, energy distribution, and network lifetime. It is evident from the simulation results that the proposed scheme outperforms the existing routing protocols in terms of energy conservation and network lifetime. The proposed protocol can prolong network lifetime and enhance system throughput, therefore it can be applied to the applications in which network energy and throughput are primary considerations. As a future work this study will focus on the variation of control packet size from node to node and node to BS to offer a more realistic approach. Control packet generation will be monitored in a centralized routing environment to study the effect of control packet overhead on the network energy consumption and efficiency as a whole. Additionally, this study will consider the effect of node mobility on the energy efficiency of the system and will adopt the distributed clustering approach to set up a more efficient network environment.

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