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GCCT: A Graph-Based Coverage and Connectivity Technique for Enhanced Quality of Service in WSN

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Abstract The area of wireless sensor network has been a constant source of attention in the research community owing to its potential remote sensing application as well as significant issues associated with almost every applications. Out of various types of issues, coverage and connectivity is one of the unsolved issues till date in wireless sensor network that potentially degrade the efficient performance capability of the applications in wireless sensor network. This paper introduces a graph based coverage and connectivity technique (GCCT) that is aimed to attain better optimization of coverage and connectivity issues in large scale wireless sensor network considering the issues of energy depletion factor. A model is developed considering the radio and energy model of hierarchical routing protocol and a new module is introduced called as super-leader node, which aims to attain energy efficiency at a same time. Simulation results shows substantial energy conservation of GCCT compared to conventional protocols.

Keywords Wireless sensor network · Connectivity · Coverage · Graph theory · Energy efficiency

1 Introduction

The area of wireless sensor network (WSN) has recently drawn the attention of researchers for various issues starting from quality of service (QoS) to security aspects. WSN consists of large quantum of sensor motes, an electronic device that has the potential to sense/perceive the physical data e.g. air, motion, moisture, temperature, smoke etc. [1]. Usually such sensor

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motes are very small in dimension and have very limited computational capabilities. Each sensor motes basically formulates connections with other sensor motes in the network and performs communications. Usually, a sensor mote adopts multi-hop network in order to perform communication when they are dispersed in much shorter communication range and evaluates the perceived data in highly distributed manner [2]. Another prominent issues in such sensor mote is power consumption or commonly known as battery lifetime. Once deployed in the field for tracking resources by the sensor motes, the batteries cannot be changed or recharged because of the massive quantity of the deployed sensor motes or dispersed location of motes are unapproachable by the human beings.

Usually, after deployment, a sensor mote formulating a network is expected to be highly functional for weeks and sometimes months. This fact will mean that connectivity and coverage also relates to the performance of the WSN systems. Connectivity is usually related to the sensor motes location coordinates which is random in majority of deployment cases. Connectivity and coverage plays a crucial role in the performance of cumulative sensor network effectively. If the motes are depleted of power or the motes are found with erroneous hardware design, connectivity highly suffers and thereby resulting its adverse effect on coverage too. In theory of deployment of WSN, it was explored with dual categories of deployment e.g. grid and random. In grid deployment strategies, the sensor motes are placed in predetermined area which is targeted for monitoring. In random deployment strategies, the sensor motes are deployed arbitrarily in the bigger area with unknown/undetermined location of sensor motes. In grid strategy, the network is seriously provisioned and sensor motes are placed in that specified area. In case of unawareness of node specification, relay nodes are introduced in order to retain connectivity and coverage. Unfortunately, grid deployment strategy has higher installation cost and therefore random deployment strategy is preferred for larger area to be monitored. Due to random deployment strategies, the analysis of connectivity and coverage requires a special representation of random network. Therefore, for the inclusion of mobility or preliminary random distribution, reliability of the connectivity cannot be guaranteed.

Various significant research contribution have been introduced in past decade focusing on coverage and connectivity issues (illustrated in Sect. 2); however, a significant research gap is identified as witnessing a few mathematical or scientific model for representing the optimization principle to be adopted for enhancing connectivity and coverage issues in WSN. Evaluation of network coverage will assist to analyze the loopholes in the WSN system. Working towards the enhancement on connectivity and coverage issues in random deployment environment in WSN will target to enhance the cost involve in transmitting data packets, sensor management system, possible extent of optimization of storage system in WSN, and finally little push in computing capabilities. The proposed system introduces a novel model termed as GCCT that uses the potential features of graph theory and energy efficiency to attain highly optimize coverage and connectivity. Section 2 discusses review of literatures followed by evolution of study in Sect. 3. Section 4 discusses about GCCT model followed by implementation and result discussion in Sect. 5. Finally, Sect. 6 summarizes the complete contribution of the study as conclusion.

2 Related Work

Ammari and Das [3] have proposed a framework that characterizes the coverage and connectivity considering the minimal spatial density of the sensor motes. The uniqueness in the study is that it focuses on three dimensional wireless sensor networks. The authors have designed a communication model considering heterogeneous wireless sensor network with a case study of underwater sensor network. The outcome of the study was evaluated with degree of coverage.

Khanjary et al. [4] have also investigated on coverage and connectivity issues in wireless sensor network especially focusing on directional sensor network. The design principle consists of spatial Poisson Point process to simulate the critical density for coverage area. The outcome of the study was evaluated by percentile of percolation for both coverage and connectivity. Chen et al. [5] have introduced an algorithm that ensures optimal coverage and connectivity using tree-concept. The secondary aim of the study was also to incorporate load-balancing to ensure better coverage in wireless sensor network. The introduced algorithm uses recursive heuristics for coverage and probabilistic strategy for load balancing. The outcome of the study was evaluated with network lifetime as well as expected load factor.

Senel et al. [6] have presented a framework for enhancing the coverage and connectivity for three dimensional wireless sensor networks. The outcome of the study was compared with graph coloring approach to find their work outperforms with respect to percentile of coverage and number of connected components. Coverage issues were also investigated with respect to energy harvesting WSN. The work presented by Ren et al. [7] has proposed a maximal criterion of quality of coverage under various time scales. The design of harvesting sensor network is done using standard graph theory.

Dezun et al. [8] demonstrated a practical graph theoretical framework for connectivity-based coverage problem in wireless ad hoc and sensor networks. They take the first attempt toward designing a distributed coverage algorithm to achieve configurable coverage requirements with using merely connectivity information. Khalil et al. [9] proposed a solution to solve the problem of coverage and connectivity, called Connected Cover Set based on IDentity of node (CCSID). The idea was to adapt a concept from graph theory of connected dominating sets having minimum cardinality MCDS, to build cover sets. The solution CCSID divides the set of deployed nodes into subsets.

Masoudi et al. [10] have also investigated on k-coverage in WSN for ensuring fault tolerance of the nodes to ensure better sustenance in the network. The work was found to substantially focus on energy efficiency with optimistic outcomes of network lifetime along with coverage. Khan et al [11] demonstrated the integration of connectivity and coverage in wireless sensor networks. They moreover demonstrated a method to repositioning multi-nodes based on a novel dynamic load, at this point by involving one or multiple neighbors of the simultaneously failed node to recover network from failure. This approach includes Recovery through Inward Motion or popularly called as RIM and Nearest Neighbor or known as NN algorithm when simultaneous node failure occurs. Woehrle et al. [12] presented novel models for the deployment of a WSN and proposes constraints and objectives to formulate the optimization problem. The authors have proposed a radio model by amalgamating the established models of the transitional region and the directional irregularity in wireless communication for WSNs.

Kim et al. [13] demonstrates the WSN connectivity issues and the regular sensor deployment patterns to achieve coverage and connectivity under different ratios of sensor nodes communication range to their sensing range for wireless sensor networks. The information will be retrieved by using the inverse method of the proposed theorems which estimate the coverage level of the target region when sensors are deployed. He et al. [14] have focused on minimum weight sub-modular set cover issue in coverage of wireless sensor network, where the author has provided solution using greedy algorithm. The experiments have been carried out considering both real-time and simulation study considering lifetime factor of nodes and prediction error.

Wawryszczuk et al. [15] depicted about the control mechanism in wireless sensor network for particular specific topology such that it reduces the energy consumption without affecting the networks connectivity and coverage. The network shaped by this method capable of detecting object moving on ground and the coverage consistency is guaranteed. Gupta and Roy [16] presented an overview of WSN and some strategies of energy efficient target coverage in WSN. The author scheduled the set cover in such a way that at a time only one set cover is responsible for sensing the target, while other set covers are in sleep mode. The challenge in the above discussed joint scheduling issue is that the sensing range is not dependent on its radio transmission range.

Jedda et al. [17] have focused on coverage issue of RFID that are equally applicable to sensor networks. The outcomes were evaluated using amount of non-redundant RF readers considering 500 RF tags scattered randomly over dense graph. The results shows better coverage and connectivity, but was not found to be benchmarked. Kim et al. [18] demonstrates the WSN connectivity issues and the regular sensor deployment patterns to achieve coverage and connectivity under different ratios of sensor nodes communication range to their sensing range for wireless sensor networks. The information will be retrieved by using the inverse method of the proposed theorems which estimate the coverage level of the target region when sensors are deployed. Erdelj et al. [19] have considering the extensive mobility scenario, where the study has integrated location of interest with the maximized coverage and connectivity sustenance of the observational area under surveillance. The evaluation is done considering time factor for coverage in multiple mobility scenario. Balamurugan et al. [20] presented a notion of Integer Programmed Sensor Deployment (IPSD) scheme considering relay nodes as a triangular lattice that is designed based on the grid deployment strategies in order to enhance connectivity and coverage issues. The work has considered using Integer Linear Programming (ILP) for the purpose of discarding the idle relay nodes and in that way improves the connectivity and coverage with smallest amount number of relay nodes.

3 Evolution of Study

The coverage issues have been studied extensively by us. Particularly the coverage with respect to connectivity and network lifetime effectiveness is emphasized. Constructing a connected, absolutely encapsulated and energy efficient sensor network is efficacious for real time applications attributable to the restricted resources of sensor nodes. Our first study has highlighted the recent research analysis and their respective approaches on coverage of wireless sensor networks [21].

Our second study has presented a framework for enhancing connectivity and coverage simulated over random based topology. The performance is checked by observing the results derived from pattern based topology and random based topology with respect to packet delivery ratio, packet generated and packet drop. The prime aim of the study was to design a model/framework that can guarantee optimal connectivity and coverage in the transmission range of wireless sensor network considering that the sensor motes are randomly distributed. Such case usually happens in the large area where human beings are not easily accessible. The proposed system is compared with pattern based topology like Voronoi Polygon, 4-Connectivity network, Diamond pattern, Double Strip Pattern, Square

Pattern, and Angular Technique. Various Analytical as well as and simulation results demonstrate the effectiveness of our joint connectivity and coverage method [22].

Our 3rd study [23] has introduced a protocol termed as Multi-hop-Point Enhancing Coverage/Connectivity with Network Lifetime (MP-ECCNL) that address the best possible provisioning and routing the precise information using multi-hop transmission pattern. The protocol extracts the higher dimensionality of route sustainment for the network lifetime, furnishes better routing and higher exploitation of network resources, and also optimizes the utilization of power facilitated on the sensor nodes. The results are accomplished after performing the experiments; by comparing MP-ECCNL with LEACH algorithm, MP-ECCNL found to be highly successful in maintaining coverage and connectivity to a higher extent in large scale WSN environment. The study has considered the cost of the route as the summation of the cost of the link associated in that routes and it closely relates to the issue that which sensor node should the ECCNL selects for prolonging the network lifetime. Using the similar mechanism, if the active sensor node can be seen to cover the whole area, the process is repeated to find N wireless sensor nodes for the next cycle of data transmission. The entire process is repeated until the battery of the sensor nodes becomes dead. Hence, the process of MP-ECCNL confirms a visualization of the enhancement of coverage and connectivity with improvement of network lifetime. However, it has been experienced still that coverage and connectivity issues could be possible enhance if the energy model considering the real time hardware constraints are considered. Hence, in this paper, experimentation has been carried out to introduce new modules (super leader node) when the anticipated result should show less duration time for establishing optimal coverage and connectivity.

4 Proposed Model

The prime purpose of the proposed study is to perform conceptualization of optimization of coverage and connectivity aspect by means of data gathering, routing and balancing energy utilization and QoS parameters and finally comparing it with the standards of energy efficient algorithms in wireless sensor network.

It is known that in a fixed pattern deployment, the importance is given for maximizing leg connectivity and node density optimization. The proposed system targets in evaluating the large scale wireless sensor network, where in random deployment is achieved for fulfilling the objective of optimized coverage and connectivity by means of optimal data gathering strategy along with energy and QoS parameter consideration. Figure 1 shows the block diagram of the proposed study. The elementary goal of the study is to accomplish potential energy efficiency while enhancing the coverage and connectivity in the data from the member motes to the core leader node in wireless sensor network. The proposed mechanism is also responsible for assigning the core leader node and evaluates their judgment making tactics for energy efficient coverage and connectivity in wireless sensor network. In the current work, a novel schema is introduced that will incorporate the capabilities of a core leader node to enhance and ensure the energy effectiveness. The uniqueness of the proposed design formulation is the inclusion of super-leader node, which are usually not found in any conventional approach of data dissemination process. The conventional data dissemination process consists of member nodes and cluster heads only (apart from base station). The proposed system have added an extra node type called super-leader node for further balancing the load of data dissemination process. A graph theory

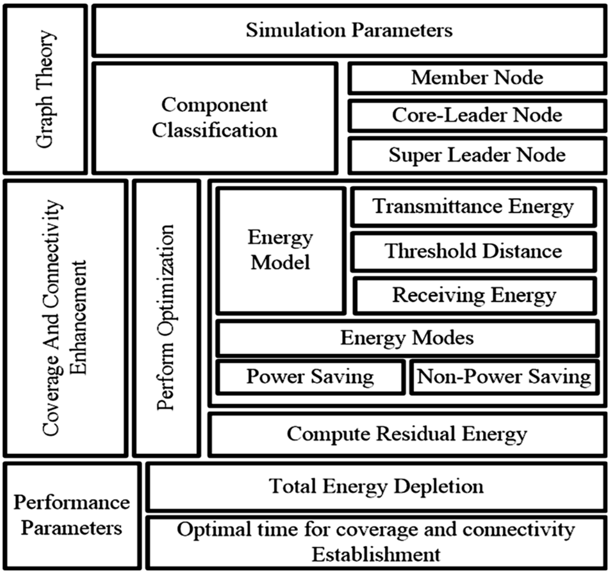

Fig. 1 Block diagram of the proposed study

based technique is considered for designing the effective coverage and connectivity technique that ensures energy efficiency within less duration and more computational capability. The proposed system discusses about the graph based-coverage and connectivity technique (GCCT) where the nodes are managed into numerous single layer assembly of multiple size for the purpose that group can communicate with the algorithm. Consider a WSN topology, considering α as a group with N_{sen} as total number of sensor motes.

$$\sum_{i=1}^{\alpha-1} \beta_i < N_{sen} \le \sum_{i=1}^{\alpha} \beta_i \tag{1}$$

In the above equation, β ($=2^{i-1}$) is acting as the maximum numbers of the sensor mote in the ith group that can be depicted the form of progression. Substituting the value of $i = 1, 2, 3,\ldots$, it can be seen that the β_i will generate the values of 1, 2, 4, 8 etc. as a progression. Therefore, Eq. (1) can be written as below,

$$2^{\alpha-1} - 1 < N_{sen} \le 2^{\alpha} - 1 \tag{2}$$

It is quite clear that a minimal degree of the group size can minimize the effort required for the process of coverage and connectivity technique. Therefore, the proposed system considers the αth group (last group) to be the last member to perform communication with the super-leader node. A super-leader node is a sensor node, which performs all the final dissemination of the data from all the others core-leader node. Hence, during the initial phase of set-up, the member nodes are assigned to $(\alpha - 1)$th groups initially coming down to αth group for member node assignment within that group. The system considers the time period required to establish efficient coverage and connectivity during data aggregation to be lower bound by the total number of sensor motes. Considering a topology with Eq. (1), it can be seen that the initial ($\alpha - 1$) groups are completely packed with the member nodes and needs a following cumulative timeslot for forwarding all the disseminated data to super-leader node as,

$$\sum_{i=1}^{\alpha} \beta_i = 2^{\alpha-1} - 1 \tag{3}$$

The last group (αth group) is assigned with $N_{sen} - 2^{\alpha-1}$ member nodes, which means that the core-leader node will use time period of $(2^{\alpha-1} - 1)$ to disseminate the physical data and $(N_{sen} - 2^{\alpha-1}+1)$ time period to transmit the disseminated data to the super leader node. Therefore the complete time slot (T_s) to perform an efficient coverage and connectivity among the nodes in one group as

$$\begin{aligned} T_s(N_{sen}) &= \left(2^{\alpha-1} - 1\right) + \left(N_{sen} - 2^{\alpha-1} + 1\right) \\ &= N_{sen}(\max) \end{aligned} \tag{4}$$

It should be noted that group size is highly reliable characteristic for the assessment of the time slot (T_s). Hence, the study formulates a condition of T_s as when αth group can establish coverage and connectivity with the super leader node only when ($\alpha - 1$)th group is done with communication. Therefore, T_s can be now represented as,

$$T_s = \sum_{j=1}^{\max} \left[\overline{T_s}(2^{\alpha-1} - 1), N_{sen} - 2^{\alpha-1}\right]^j + R^{N_{sen}-2^{\alpha-1}} + \sum_{j=1}^{N_{sen}-2^{\alpha-1}} R^j \tag{5}$$

$$\begin{aligned} \overline{T_p}(2^{\omega-1} - 1) &= \overline{T_p}(\eta_{\omega-1} - 1) \\ &= \eta_{\omega-1} - 1 + [R^{\eta_{C-1}-1} + \sum_{p=1}^{\eta_{\omega-1}-1} R^p \end{aligned} \tag{6}$$

In the above Eq. (5), $\overline{T_s}(2^{\alpha-1} - 1)$ is considered as cooperative time period by the initial ($\alpha - 1$) groups for disseminating the data from their member nodes and transmit the disseminated data to the super-leader node. It can also be seen that all these ($\alpha - 1$) groups are cumulatively assigned and so Eq (6) arises.

As the formulation of the proposed study is the critical implementation aiming at energy efficiency, hence better standards are considered to evaluate the effectiveness of the model. The proposed study considers the similar radio and energy model that has been used in standard hierarchical routing algorithm. The justification behind this logic is that although there were various formulations of design, algorithms, and mathematical model in the past that has totally focused on solving the energy issue in order to maximize the lifetime of the WSN. However, very few of the prior work have received recognition. Out of the majority of the work introduced in the past, Low Energy Adaptive Clustering Hierarchy protocol is considered as benchmarked formulation. Therefore, using the standard radio and energy model [24], the depletion of energy by the radio model in transmitting l bits of data over a distance d can be represented by,

$$\begin{aligned} E_{TX}(l, d) &= l.E_{elec} + l.\varepsilon_{FS}.d^2, \quad \text{if } d < d_o \\ &= l.E_{elec} + l.\varepsilon_{TR}.d^4, \quad \text{if } d \geq d_o \end{aligned} \tag{7}$$

where, threshold distance is represented as,

$$d_o = \sqrt{\frac{\varepsilon_{FS}}{\varepsilon_{TR}}}$$

In the above equation E_{elec} is the energy depleted per bit to operate the transmitter or the receiver circuit. ε_{FS} and ε_{TR} are the constant and is highly dependent on the transmitter amplifier model that is considered in the study and d_o is the threshold transmission distance.

The energy drainage on the receiver end to attain *l* bits of the data can be depicted as E_{RX} $(l) = l.$ $E_{elec.}$ The coverage and connectivity framework in this section of the study considers that the core-leader node would process (*n/2*). *l* bits of the data at the end of one frame, where *n* represents number of core-leader node. The formulation also considers the energy cost for performing better connectivity that is initialized as $E_{DA} = 6n$ J/bit. Considering the standard energy framework as exhibited in Eq. (7), the present network of $2^{\alpha-1} - 1 < N \leq 2^{\alpha-1}$ sensor nodes will be allocated in α groups. Hence, the total energy drainage can be represented as following,

$$E_o = \sum_{i=1}^{\alpha-1} \sum_{p=1}^{\beta_i-1} [E_{TX}.d_{pi} + E_{RX}] + \sum_{p=1}^{\eta_\alpha-1} [E_{TX}.d_{pc} + E_{RX}] + \sum_{i=1}^{\alpha-1} \beta_i.E_{TX}.d_{iRA} + \beta_\omega.E_{TX}.d_{\alpha SL} \tag{8}$$

In the above equation, d_{pi} is the distance between the pth member nodes to ith core-leader nodes, d_{pc} is the distance between pth member node and cth core-leader node. While d_{iRA} is the distance between the ith core-leader node to super-leader node and $d_{\alpha SL}$ is the distance between αth core leader node and super-leader node. In the above Eq. (8). The first two part of the equation are related to the energy drainage owing to internal transmission and reception within groups while the last two part of the equation are related to data forwarding operation from the core leader node to the super-leader node. Therefore, considering the upper limit for the E_{TX}, Eq. (8) is now amended as follows,

$$E_o^h = \sum_{i=1}^{\alpha-1} (\eta_i - 1)\left[E_{TX}^h + E_{RX}\right] + (\eta_i - 1)\left[E_{TX}^h + E_{RX}\right] + \sum_{i=1}^{\alpha-1} \eta_i.E_{TX}^h + \beta_i E_{TX}^h \tag{9}$$

Normalizing the above equation becomes,

$$\begin{aligned} E_o^h = & \sum_{i=1}^{\alpha-1} (\beta_i - 1)\left[E_{TX}^h + E_{RX}\right] + (\beta_i - 1)\left[E_{TX}^h + E_{RX}\right] \\ & + \sum_{i=1}^{\alpha-1} (R^{\beta_i-1} + \sum_{p=1}^{\beta_i-1} R^p).E_{TX}^h + (R^{\beta_i-1} + \sum_{p=1}^{\beta_i-1} R^p)E_{TX}^h \end{aligned} \tag{10}$$

The current study basically introduces super-leader node as a supplementary node for the purpose of optimizing the energy drainage factor in wireless sensor network and in order to do so the Overhead for coverage and connectivity of the current network management should be reduced. Hence, in order to carry out optimization, following techniques were adopted. The network is decided in the considered topology with $2^{\alpha-1} - 1 < N_{sen} \leq 2^{\alpha-1}$ sensor nodes. Then the system arranges the sensor nodes as per the residual energy in declining order and stored in a matrix of the form $M = [M_1, M_2,\ldots, M_{Nsen}]$ so that residual energy of M_1 is more than that of M_2 and continues. The system than chooses α elements in matrix M as the core-leader node. The transmission distance between the core leader node and the member nodes are optimized using the following,

$$\min \sum_{i=1}^{\alpha} \sum_{p=\alpha+1}^{N_{sen}} I_{ip}.d_{ip}^{2} \tag{11}$$

with a condition that

$$\sum_{p=1}^{\alpha} I_{ip} = 1, \quad \forall i \in [\alpha + 1, \ldots, N_{sen}] \tag{12}$$

$$\sum_{i=\alpha+1}^{N_{sen}} I_{ip} = \eta_{\alpha-p+1} - 1, \quad \forall p \in [1, \ldots, \alpha - 1] \tag{13}$$

$$\sum_{i=\alpha+1}^{N_{sen}} I_{ip} \leq \eta_{\alpha} \tag{14}$$

In the above conditions, d_{ip} is the coverage distance between the sensor node M_i and M_p, I_{ip} is the deployed indicator to exhibit the established connectivity between M_i and M_p. The dissemination of the physical data from the member is done by core-leader node and sends the notification of the disseminated data to the super-leader node. It is already known that core-leader node drains substantially higher energy as compared to member nodes in the process of establishing enhanced connectivity. Therefore, the coverage and connectivity optimization process in this study basically allocates the nodes with maximum residual energy to be core-leader node. However deploying Eq. (11) with its specified condition will enable the minimization of the transmission distance among every core-leader node and member nodes in the simulation environment. Equations (11) (12), and (13) discusses about the constraint-condition that need to be satisfied by I_{ip} of Eq. (11). The condition specified in Eq. (11) ensures that all the member nodes are connected to only one core-leader node, while the condition specified in Eqs. (15) and (13) guarantees that the ωth group is the ultimate group to be allocated by respective member nodes. Therefore, enhanced coverage and connectivity is achieved along with better energy efficiency of the cumulative network of WSN environment.

5 Implementation and Results

The implementation of the proposed research work is done on Windows 32-bit OS with 1.84 GHz dual core processor considering Matlab as programming language. The proposed system is compared to frequently used LEACH protocol [24]. LEACH [24] algorithm was originally formulated in the year 2000 in MIT for addressing energy dissipation in WSN and is usually considered as energy efficient as well as adaptive clustering protocol. The algorithm compresses the fused data for minimizing the energy depletion as well as for improving battery lifetime. The self-elected cluster heads acts a bridge of communication from member nodes and base station. One of the unique features of LEACH [24] is integration of lossy compression along with routing the data. Till date, there are various research works that has attempted to perform comparative study of energy efficient protocols, where it becomes the most challenging to decide, the best energy aware routing

Table 1 Existing energy efficient routing protocol in WSN

Protocol	Year	Cited by
LEACH [24]	2000	11,412
PEGASIS [25]	2002	3013
TEEN [26]	2001	2136
APTEEN [27]	2002	971

protocol, to consider for benchmarking. It was seen that basically energy efficient routing protocols in WSN are of 4 types mainly e.g. (1) LEACH [24], (2) PEGASIS [25], (3) TEEN [26], and (4) APTEEN [27]. A closer look into Table 2 will show the year of implementation of these energy efficient routing protocols and extents of citation performed by other researchers worldwide using Google Scholar. Table 1 highlights the most updated data for adoption of routing protocol observed on 24th December, 2014.

The above table highlights that LEACH [24] is the most frequently adopted algorithms for the purpose of benchmarking and in-depth investigation by existing research community for WSN. Although, there are various comparative study to draw variation conclusion about effectiveness about protocols mentioned in Table 1, but still in reality LEACH [24] is highly standardized. Although various studies e.g. [28]. have discussed that PEGASIS [25] is better version of LEACH [24], but the fact is completely not true as power consumption of PEGASIS [25] is more than LEACH [24] and PEGASIS [25] doesn't support extended data aggregation [28]. Various prior studies e.g. [29, 30] have the evidence that if there is an enhancement done towards LEACH, it can perform better than PEGASIS [25] with respect to energy and delay. Moreover, LEACH [24] is designed and evaluated on real-time Antenna theory considering significant channel properties. This design principle has yet not been subjected to revision owing to its potential features in any other variants of LEACH [24] algorithm till date [31]. Hence, LEACH [24] is considered to perform benchmarking standard for our study. The network simulation parameters considered are as shown below (Table 2):

The proposed framework considers that all the cumulative energy depletion are causing overheads as well as due to spontaneous receiving and transmitting of physical data. Another fact is different hardware components of a sensor node consumes different rate of energy. As a property of energy conservation protocol, whenever a sensor mote is in power saving mode, it will preserve the energy drainage rate of the different hardware components in a sensor node. Therefore, the energy depletion in the inactive stage of ith node can be represented as,

$$\mathrm{E}_{\text{power\_saving\_mode}} = \psi_i \Omega (\Lambda_1 + \Lambda_2 + \Lambda_3) \tag{15}$$

In the above Eq. (15), ψ_i is the time period of the power saving mode of ith sensor mote, Ω is the amount of the voltage supplied, while Λ_1, Λ_2, and Λ_3 are current used for the

Table 2 Simulation parameters

Total number of nodes	500
Size of network	1000×1000 m^2
Position of BS	(72, 140) m
Preliminary energy initialization	0.2 J
Feasibility of CL election	0.5
Size of packet	7000 bits

purpose of enhancing the connectivity, processing, and the amount of current in power saving mode (i.e. even in power saving mode stage, a mote depletes certain scale of energy) respectively. The proposed system considers the above mentioned parameter to depict much precise outcome of the energy efficiency owing to circuit design of the sensor mote. The super-leader node introduced in the model to ensure that the framework dynamically reconfigures the coverage and connectivity depending on the available nodes with sufficient residual energy. In the data dissemination mode, a sensor node will always turn on its radio model thereby performing computation of probable connectivity sources. Hence, the transmittance energy for a sensor node in this model with its final threshold energy E_{TH} in the maximum of Max level can be expressed as,

$$E_{TX}^{TH}(\mathrm{Max}) = E_1(\mathrm{Max}) + \psi_i\Omega(\Lambda_1(\mathrm{Max}) + \Lambda_2 + \Lambda_3) \tag{16}$$

In the above equation, $E_1(\mathrm{Max})$ represents cumulative overhead power drainage in the connectivity stage while switching to and from transmission to receiving phase, $\Lambda_1(\mathrm{Max})$ is the overall current needed to establish enhanced connectivity perform communication when the node is transmitting with its defined final threshold energy at the Maxth level and Λ_2 is the amount of the current required in the non-power saving mode. Similarly, the energy E_{RX} drained by the prime sensor node to receive the data packet from the member nodes is represented as,

$$E_{RX} = E_{RX\_1} + \psi_i\Omega(\Lambda_1 + \Lambda_2 + \Lambda_3) \tag{17}$$

In the above Eq. (17), E_{RX_1} is the overall overhead energy depleted by the connectivity establishment and frequent toggling of power saving and non-power saving mode of the sensor nodes. Equivalently, the energy needed for effective coverage and connectivity can be represented by,

$$E_{PRO} = E_{PRO\_1} + \psi_i\Omega(\Lambda_1 + \Lambda_2 + \Lambda_3) \tag{18}$$

Where E_{PRO_1} is the overall energy depleted due to overhead occur by recurrent toggling of power saving and non-power saving mode of the sensor nodes. Although the proposed work is completely a simulation study but in order to ensure better applicability of the outcomes in real-time scenario, the parameters discussed above are chosen based on MEMSIC nodes. The result evaluation of the study is divided into multiple single-layered groups. It is already known that networks designed using hierarchical routing protocol have fixed group nodes to cumulative number of nodes in many cases. Therefore, the simulation is being studied considering two attributes mainly i.e. (1) energy depletion and (2) overall time of data dissemination. Figure 2 represents the overall energy depletion in joules when Data Compression Ratio (DCR) is initialized to 0.5 J and the simulation is done considering 500 nodes. The result shows that energy depletion of proposed system is considerably less as compared to conventional hierarchical routing protocol.

In the next phase as exhibited in Figs. 3 and 4, when the compression ratio is increased to 0.75–1, equivalent trend is observed that shows that proposed system has better energy conservation as compared to standard hierarchical routing protocol with increased data compression ratio. One of the elementary reason behind this is the proposed graph-based technique doesn't permit the core-leader node to establish connectivity of data directly to the base station, but creates a better hoping strategy thereby mitigating the enough traffic load using the new module of super leader node, thereby enhancing coverage. Hence, super-leader node acts as better balancing mechanism towards data aggregation and energy

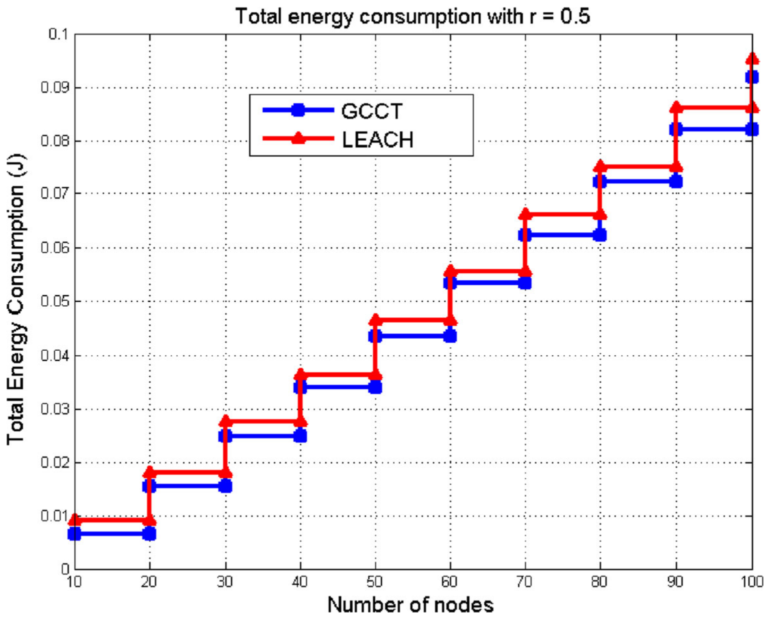

Fig. 2 Total energy consumption at DCR = 0.5

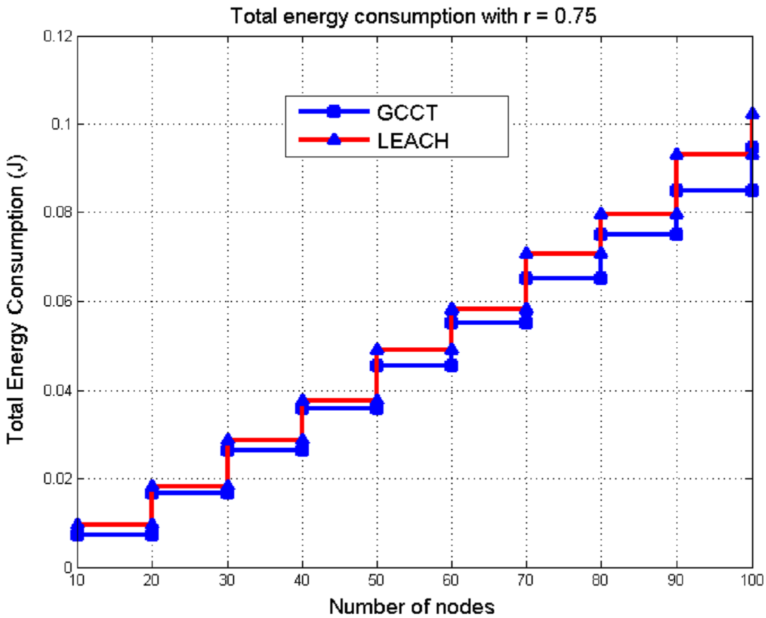

Fig. 3 Total energy consumption at DCR = 0.75

preservation in proposed system. If in the duration of extending coverage, the core leader node is about to deplete its residual energy below certain threshold value, the super-leader node performs selection of new super leader node even before the old core leader node

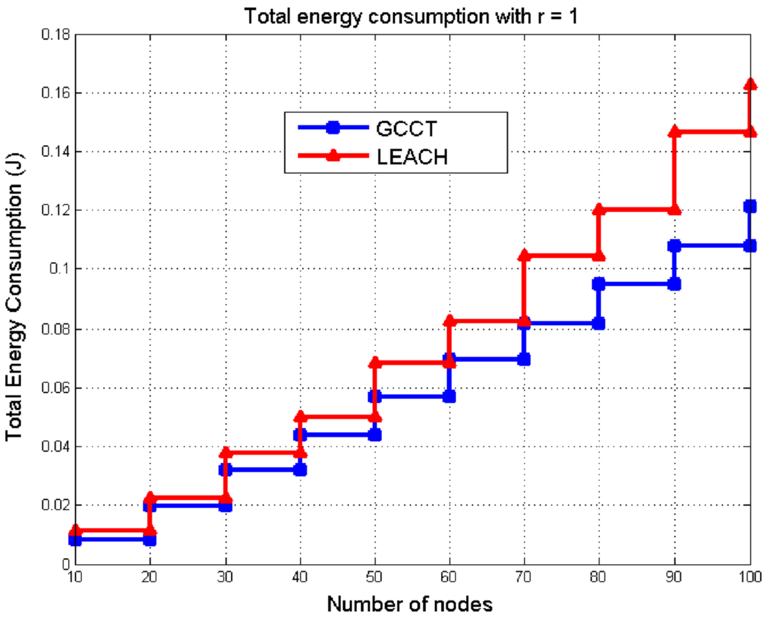

Fig. 4 Total energy consumption at DCR = 1

completely depletes its energy to zero joule. In this manner, the overall network's energy is highly preserved maintaining effectively coverage and connectivity. The system thereby ensures better energy optimization along with better balancing coverage and connectivity using traffic.

The performance evaluation of the current study is also considered for cumulative time for optimal coverage and connectivity. Figures 5, 6 and 7 shows that cumulative time for optimal coverage and connectivity for proposed system is higher compared to convention hierarchical routing protocol at data compression ratio 0.5, 0.75, and 1 respectively.

This increased dimension of the duration for the proposed system is basically due to the initial connectivity stage that attempts to perform preliminary connectivity within various groups after performing data dissemination. The prime reason here is although the system might experience a bit high latency in the preliminary simulation rounds, but the latency will be highly minimized in the consecutive cycle of data dissemination. However, when the data compression ratio is maximized to 0.75 from 0.5, the system is witnessed with increasing linearity in curves with maximizing number of sensor nodes. Hence, the optimal time for coverage and connectivity for proposed system is now found to be minimized as compared to preliminary outcome when data compression ratio was 0.5.

A closer look into the graph in Fig. 6 shows that duration for both conventional hierarchical routing protocol as well as proposed system exponentially differs with respect to performance as the current study provides a better routing schema that can direct its packets, minimizing its redundancies, and connecting them in proper direction (either base station or next hop) using super-leader node. Moreover, due to higher level of sustenance (owing to better energy conservation), the protocol can perform exponentially better than conventional hierarchical routing protocol in minimizing the duration of establishing coverage and connectivity. As the system is designed based on the radio and energy model

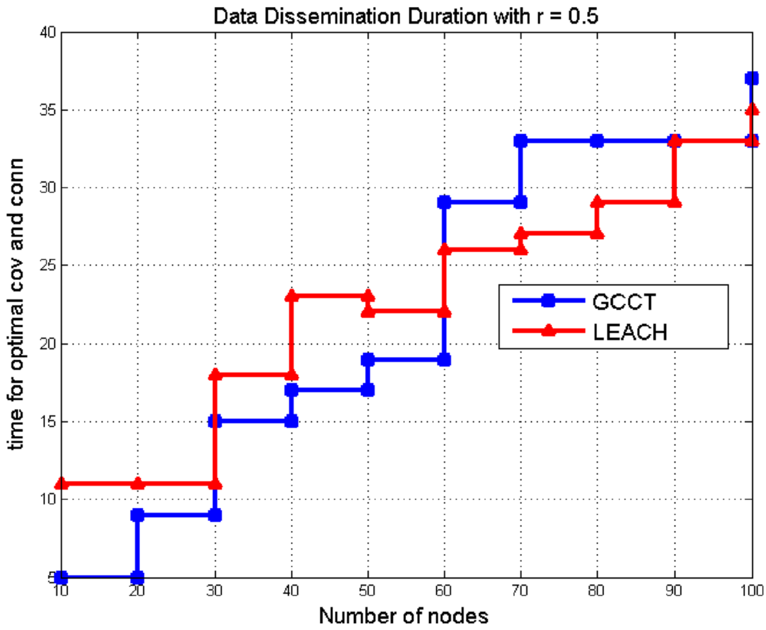

Fig. 5 Total time for optimal coverage and connectivity at DCR = 0.5

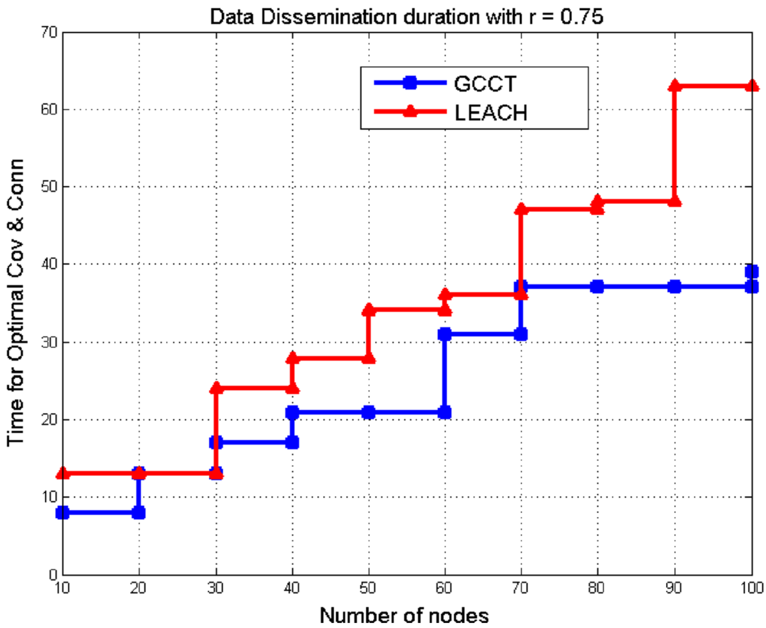

Fig. 6 Total time optimal coverage and connectivity at DCR = 0.75

using multiple layer grouping of nodes, the accomplished outcome is therefore easy to measure and hence scalable. With the increasing number of nodes, the number of group will possibly maximize; however, it is still not found with any significant effect in the

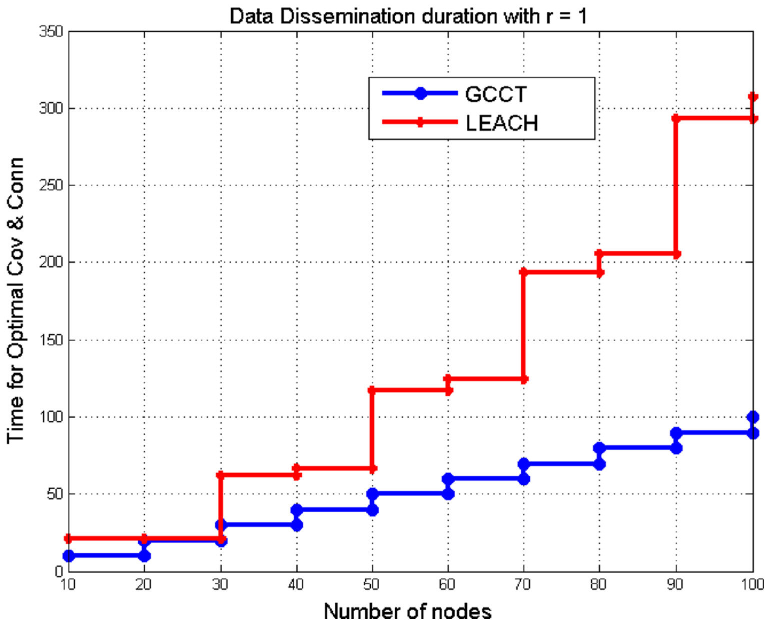

Fig. 7 Total time optimal coverage and connectivity at DCR = 1

establishment of optimal connectivity. The outcome shows that optimal coverage and connectivity duration of the proposed system is exponentially minimized to larger extent as compared to the standard hierarchical routing protocol in wireless sensor network. However, it has been opted to consider further extensive simulation to strengthen the outcomes.

For the purpose of extensive comparative analysis, PEGASIS [25] is considered, as it has certain characteristics of energy efficiency that was proven better than LEACH algorithm [24]. LEACH algorithm [24] was actually not meant for large scale WSN and moreover certain assumption in LEACH [24] can be marked as impractical e.g. all the nodes can become cluster head. Also LEACH [24] doesn't support multihop communication. However, PEGASIS [25] is discussed as superior version of LEACH [24] for improving energy in some significant studies e.g. [32]. The design principle of PEGASIS is based on chain-based approach that is completely different from LEACH (cluster-based approach) [24]. However, both are hierarchical routing protocol used in WSN. Hence, a comparative evaluation of proposed GCCT protocol with both LEACH [24] and PEGASIS [25] is performed. For testing in PEGASIS [25] environment, certain simulation environment and patterns are altered to render similar experimental test-bed. The study has used similar radio and energy model in PEGASIS [25]. PEGASIS [25] model is designed suitably for our implementation scenario where greedy technique is adopted for formulating chain.

An extra module was designed to perform data fusion for all the nodes in the chain and all the schema of data gathering process in PEGASIS [25] is designed on our simulation test-bed just like LEACH [24]. The comparative analysis is performed, considering the performance parameters of (1) amount of energy being preserved, (2) amount of energy being consumed per packet, (3) total time for optimal coverage and connectivity, and (4) processing time. Figure 8 shows the amount of energy being preserved with the increasing number of the nodes. It can be seen that extent of energy preservation for the LEACH algorithm [24] is quite poor as compared to PEGASIS [25]. The prime reason behind this is PEGASIS [25] attempts to restores energy at the stage of local data gathering and selection of leader node. However, with the adoption of greedy technique by LEACH [24], it will have slight overhead for performing computation to discard certain node to become leader nodes. For which reason, further optimization of PEGASIS [25] is not much possible as compared to LEACH [24]. However, in GCCT, the energy is conserved at every stages and moreover owing to fast switching of roles from existing aggregator node to new aggregator node (maintained by super-leader node), amount of energy conservation and delay is considerably less compared to PEGASIS [25]. Hence, the outcome exhibited in Fig. 8 shows superior energy conservation for GCCT as compared to LEACH [24] and PEGASIS [25]. In order to validate the outcomes exhibited in Fig. 8, it has been altered to get the simulation parameter from number of nodes to size of packets in bytes. Hence, Fig. 9 exhibit the outcomes of energy consumption per packets with respect to increasing number of packet size till 800 bytes. The outcome shows higher drain rate of energy for LEACH [24], whereas PEGASIS [25] has improved performance compared to LEACH [24]. A closer look into the outcomes also highlights that GCCT technique ensures less energy consumption with the increasing number of data packets. The prime reason behind this is that PEGASIS [25] formulates the construction of chain and selects aggregator nodes without any consideration of energy, whereas in proposed GCCT, the energy model highly comprehensive that can cater up any distance related factor to ensure proper transmission (routing) during and after data aggregation. Figure 10 highlights the total time required for ensuring optimal coverage and connectivity considering DCR value as 1. DCR value of 1 is selected as it shows discrete outcome in Fig. 7 when compared to DCR value of 0.5 and 0.75 in Figs. 5 and 6 respectively. An interesting outcome has been evolved here where it can be seen that although PEGASIS

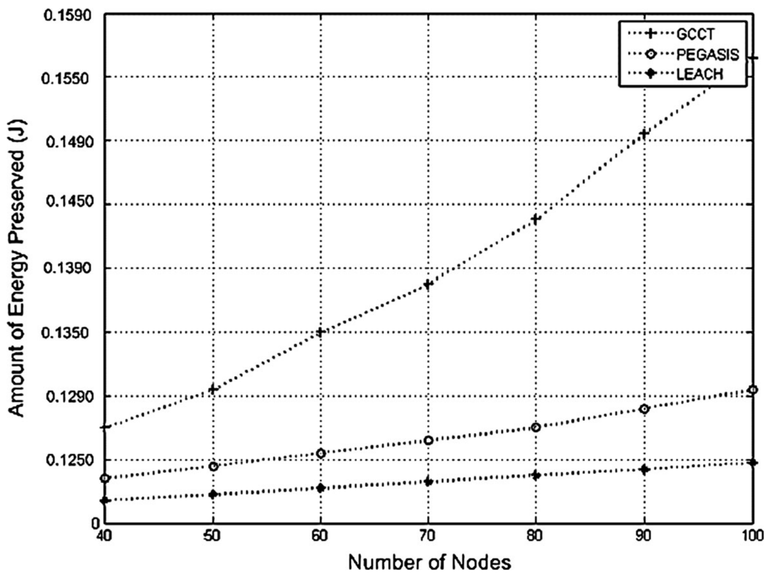

Fig. 8 Amount of energy preservation

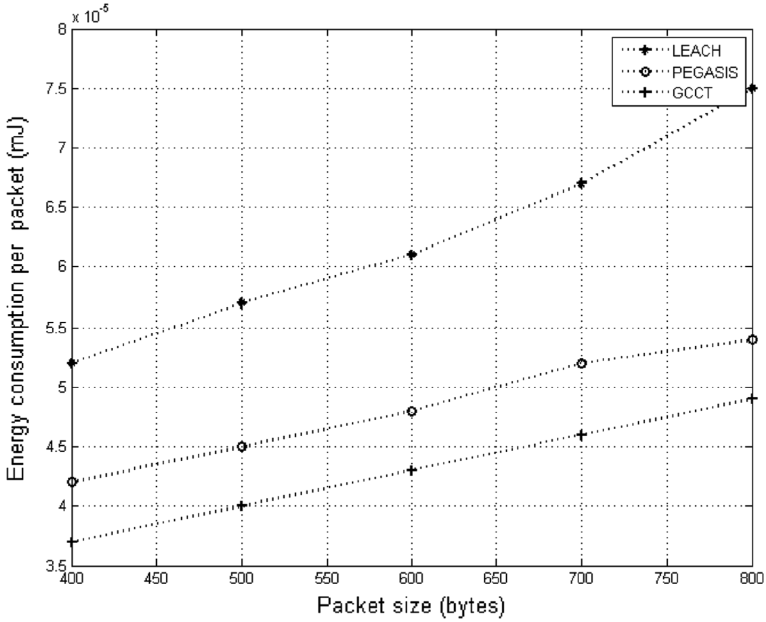

Fig. 9 Energy consumption per packet

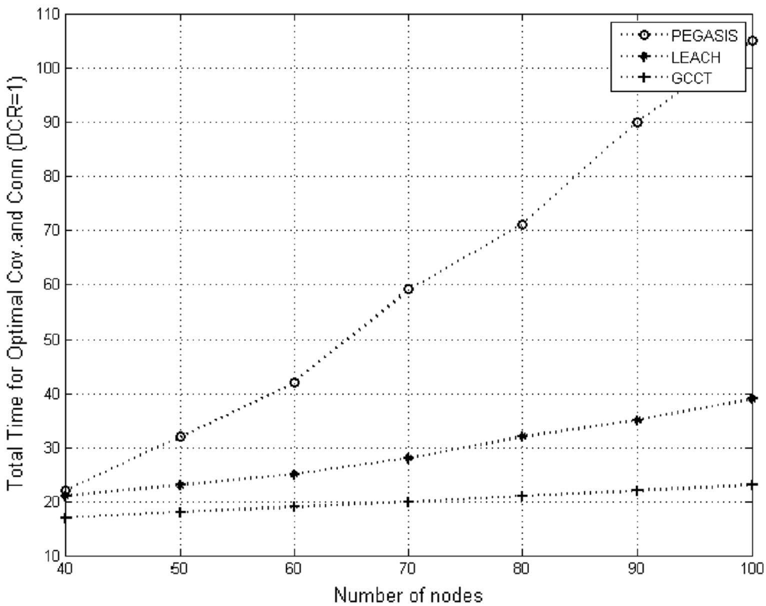

Fig. 10 Total time for optimal coverage and connectivity

[25] ensure energy effectively as compared to LEACH [24], but it cannot ensure optimal coverage and connectivity time. The curve for PEGASIS [25] is found to be increasing exponentially with increasing number of nodes. The prime reason behind this

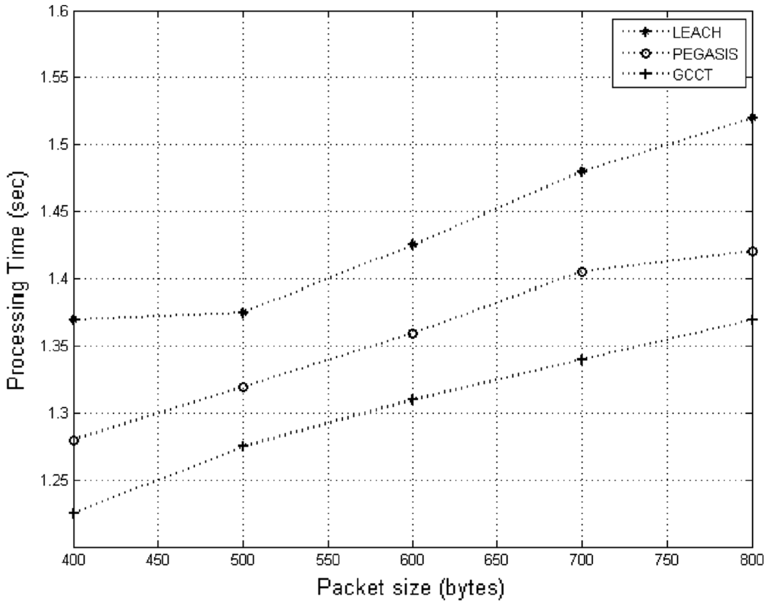

Fig. 11 Processing time analysis

is PEGASIS [25] only support electing one cluster leader which considerably increases the delay/time that is very much critical for establishing better coverage and connectivity. Hence, PEGASIS [25] cannot be recommended for being used in coverage and connectivity for mission critical applications. However, in terms of coverage and connectivity, LEACH [24] is found to have better acceptability. Still, LEACH [24] as well as PEGASIS [25] in their legacy version of design cannot be recommended to be used for large scale wireless sensor network. Hence, for energy efficient routing to ensure effective coverage and connectivity, the convention routing protocols should be subjected to extensive revision in their routing strategy before applying it to network.

The final factor of benchmarking of the proposed outcome is to check for the total processing time for GCCT, LEACH [24], and PEGASIS [25]. Figure 11 highlights the analysis of processing time, where it can be seen that GCCT is less computationally complex as compared to LEACH [24] and PEGASIS [25]. It was seen that computational time required for LEACH is directly proportional to number of sensor nodes as well as data packets being transmitted through them. Hence more the nodes, more is the processing time. It just increases linearly. In case of PEGASIS [25], it performs an extra computation while (1) formulating chains, (2) selection and elimination of leader node and finally select only one leader node (extra time is required in this process), and (3) highly redundant data transmission. Hence, PEGASIS [25] outperforms LEACH [24]. However, in case of GCCT, optimization has been performed for which, GCCT ensures (1) faster switching of leader nodes (older one with less residual energy to new one with high residual energy) without any delay in data aggregation process, (2) tree-technique allows the proper updates of dying node to the neighbor enhancing the optimal election of leader node. Therefore, the proposed technique offers an enhanced version of communication technique in WSN that ensure better coverage and connectivity along with energy efficiency.

6 Conclusion

The current paper has illustrated about a novel energy efficient framework for optimal coverage and connectivity establishment by introducing a module called as super leader node for the major purpose of accomplishing energy efficiency of cumulative lifetime of wireless sensor network. However, along with energy optimization, the system is also found to posse's better traffic management scheme due to its unique connectivity tactics. The prime responsibility of the new module is to collect the disseminated data and perform energy efficiencies task by taking the decision of forwarding the disseminated data to the base station or to the new hop. The outcome accomplished from the study is evaluated with respect to standard protocol, where it was seen that proposed network has better utilization of energy optimization leading to minimizing in duration time of coverage and connectivity. From the application viewpoint, the proposed system can be used for monitoring the urban traffic situation. Usually in traffic monitoring system, the sensors are exhausted in faster rate as compared to other applications of sensor network. Moreover, cost of traffic monitoring system can be reduced if less number of sensors are used without any significant impact on coverage and connectivity using proposed GCCT. The next suitable application of GCCT is in covert operation in defence.

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