Energy Efficient Topology Control based on Sociological Cluster in Wireless Sensor Networks

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Abstract

The network topology for a wide area sensor network has to support connectivity and a prolonged lifetime for the many applications used within it. The concepts of structure and group in sociology are similar to the concept of cluster in wireless sensor networks. The clustering method is one of the preferred ways to produce a topology for reduced electrical energy consumption. We herein propose a cluster topology method based on sociological structures and concepts. The proposed sociological clustering topology (SOCT) is a method that forms a network in two phases. The first phase, which from a sociological perspective is similar to forming a state within a nation, involves using nodes with large transmission capacity to set up the global area for the cluster. The second phase, which is similar to forming a city inside the state, involves using nodes with small transmission capacity to create regional clusters inside the global cluster to provide connectivity within the network. The experimental results show that the proposed method outperforms other methods in terms of energy efficiency and network lifetime.

Keywords: Clustering method, energy efficiency, self-organization network, sensor networks, sociological topology, topology control

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1. Introduction

In social sciences, the social group refers to a body of people formed by two or more persons where the individuals interact with one another, accept expectations and duties as a group member, and share a common identity [1]. Sociologist C.H. Cooley classified social groups into two categories: *primary* and *secondary* groups [2]. Members of a social group are interdependent but their range and mode of action are restricted by the defined social structure, which has a functional and spatial arrangement [3]. According to Louis Wirth, ancient society involved individuals being spread over a wide area but participating in group activities, unlike modern society which forms gigantic integrated groups centered around political, religious, economic, or cultural centers [4].

There are similarities between sociology and wireless sensor networks, including a membership requirement, shared awareness and values, sense of belonging, interaction, connectivity, bond formation, and so on. There are also differences between wireless sensor networks and sociology or ecology including judgment of members, ability to reproduce, limitations of possessed energy, and so on. In **Table 1**, most functions show a similarity except factors of reproductivity and resource. Even though physical individuals are different, in the overall design philosophy they still perform the same logical functions.

Table 1. Common features between sociology and wireless sensor network

Function	Sociology	Wireless sensor network
Members	Two or more	Minimum one
Shared values	Need	Need
Belonging	Need	Need
Interaction	Need	Need
Connectivity	Need	Need
Proximity	Need	Need
Common experience	Need	Optional
Reproductivity	Natural	Artificial
Harmony	Need	Need
Resource	Long	Short

If sensor nodes are widely deployed and the nodes interact with one another and fulfill their role and duty as a member of a group, a group in a wireless sensor networks is similar to a group in social sciences. Groups for regulation and communication are similar to clusters in wireless sensor networks. The concept of groups or clusters is not needed when a single group is performing a duty or is moving. However, when multiple groups form a single culture, their interactions can be compared to topology. Early theories on network routing such as Bellman Ford or Dijkstra's algorithm are appropriate for wired routing and provide fundamental concepts for ad-hoc or WLAN design. One of the fundamental methods for designing topology in cases such as ubiquitous environments or wireless sensor networks is to observe, or more importantly, to apply the form of naturally occurring phenomenon.

In this paper, we present the SOCT method that creates network topology by taking a sociological perspective. In sociology, given an environment in which many individuals with similar abilities are widely distributed, an individual with powerful leadership may unify the whole as a single nation or minority groups with similar ideology may combine to create a whole society.

Similarly in wireless sensor networks, there exists a centralized scheme similar to an autocracy in which a single powerful node continuously controls the whole network. A distributed scheme is similar to democracy in which the power to govern is passed around. A scheme that hybridizes the central and democratic distributed schemes may also exist. It is analogous to a form in which central and local governments coexist. With a focus on how a single nation or political party is formed in the beginning and continues to maintain its form. Traditional clustering methods were focused on layered grouping. SOCT is, however, based on the regional area , adopting urban sociology approach.

We also present a method for forming a single-hop clustered network by using nodes with two different transmission ranges for clustering. The presented second order method involves first defining the boundary of a wide area using powerful elite nodes, then defining and managing specific regions based on the global boundary set by the elite nodes.

First, nodes with a large transmission range (hereafter referred to as alpha node) are used for primary clustering of the global area. Then nodes with a small transmission range (hereafter referred to as beta node) are placed inside each alpha node cluster to create secondary clusters. This method can reduce energy consumption per node, lessen interference and hidden nodes that appear during network configuration, and manage the energy of the whole network efficiently by using an appropriate hop-count.

This paper is organized as follows: In Section 2, we first describes some brief background in terms of clustering algorithms in wireless networks. In Section 3, the operation of the social clustering topology procedures are presented. In Section 4, the information structure and frame examples of the proposed SOCT algorithm are discussed. In Section 5 we show the numerical results of a performance evaluation obtained using an analytical energy model. Finally, concluding remarks are discussed in Section 6 and Section 7.

2. Related Works

The hierarchical tree structure is normally used to connect sensor nodes that have limited function and electrical energy into a network and send data to a desired node. In a hierarchical tree structure, the number of nodes in the upper and lower layers of the sensor nodes that have been spread to desired application areas is obtained, and the nodes are managed by assigning a logical ID to each node. Such a procedure is partially justified as it adheres to the IEEE802.15.4 standards. However, the form of a hierarchical tree is only appropriate for managing a limited area or small number of nodes. In cases with many nodes distributed over a wide area, mutual ID assignment or beacon period and duty time configuration becomes difficult due to transmission collision between nodes. Other methods such as peer-to-peer topology and star topology exist but are not suitable when large numbers of sensor nodes are deployed.

A central sink node that collects and manages data is required for sensor nodes deployed over a large area in order to set up a global sensor node network at an application level. Base station and access points usually perform the role of central nodes. To activate the sensor network in a sensor node cluster topology, the following nodes are required: a central node that manages the topology and data aggregation, a relay node that transfers data between the upper and lower layers, and a general sensor node that performs respective sensing missions and data transfer. Each node performs data sensing and network communication functions.

There are many studies on grouping sensor nodes and operating them as a single cluster [5][6][7][8][9][10][11]. Also, [12] presents many methods related to topology while many methods, including [13][14], and [15], use engineering theories, wireless routing and ad-hoc methods to present diverse ways to improve electrical energy efficiency. Each of these methods of cluster topology have advantages and disadvantages depending on the assumptions, conditions and circumstances. Normally, most clusters select a cluster-head internally and the cluster network develops around the selected cluster-head. There are studies on the selection of a proper cluster-head, connection methods for neighboring cluster nodes, avoidance of overlapping, transmission range and location management, and so on. However, in these methods a cluster is formed by communication between nodes within a regional scope, and each node transfers its information to neighboring sensor nodes or clusters. Such a format, from a wider, multi-faceted perspective, will encounter situations in which logical management is difficult, e.g. allocating logical clusters and avoiding transmission interferences between the nodes.

Within the group of interactive communication methods with fixed transmission ranges, there are multi-hop and single-hop methods. In the multi-hop method, energy consumption increases with transmission range size, making the method inefficient for large transmission ranges. The tree structure used in the single-hop method reduces energy consumption of individual nodes but has limitations with respect to network throughput [16][17]. There have been studies which look into reducing the network-handled traffic and efficiently managing the hop-count by setting a node transmission range as a common static variable [18], or dynamic variable [19]. However, a variable transmission power method that changes the transmission range depending on the situation reduces energy efficiency of the nodes, since the energy efficiency of a sensor node is decreased when the transmission power is changed.

In theory, a protocol that dynamically varies the transmission range of a node may be a good topology for establishing optimal communication between neighboring nodes. In reality, however, it is difficult to use a small sensor node to set up a network for companies that produce communication nodes or equipment with different maxpower levels that then have to take into account the throughput of the correspondent node. Most communication modules limit their transmission range and may only select between several static output levels. Although optimization of communication and connectivity is still important, there arises a need for a sociological analysis of energy management and network survival period as sensor nodes become miniaturized and standardized and are deployed over a wide range to form a wireless sensor networks.

3. Operation of Sociological Clustering Topology (SOCT)

3.1 Basic Procedure

In social sciences, to control a wide area the land is segmented into states and cities, which are the units of segmentation at a national level. Our classification is based on the scale criteria used in urban sociology [20]. In the clustering topology method for wireless sensor networks, nodes are clustered to set up a network in order to allow an individual within a group to transmit information regarding its mission to the group and to a global control node. Dividing the distributed wireless sensor networks clusters into global and regional domains creates a layered and distributed network topology which is a consilient background of SOCT.

The cluster-head configuration in each cluster is similar to a temporary boss. The global network is formed by generating temporary bosses to secure the network's global connectivity and optimizing for the intended application. For example, in the case of a clustering algorithm for the efficient usage of energy in a wireless network, which is one of main issues in wireless network, the temporary boss is used to configure and define duty time and transmission-target nodes from the member nodes in each cluster for basic network formation and efficient usage of energy. In the next round within the same cluster, data collection, transmission and reception become independent from the temporary boss. Clustering methods typically have layers, possibly multi-level. In sociology, a nation has hierarchical structure such as states, cities, and so on. Therefore, most clustering methods including SOCT function are performed with parameters such as number of nodes.

In this paper, to implement SOCT we suggest forming a primary cluster with a large area, and then establishing a secondary cluster with a smaller area within the primary large-area cluster. Also, to define the role of the nodes in each phase, nodes in the primary cluster and secondary cluster are defined separately, adopting the *Alpha-girls* concept that creates a powerful and elite group. This idea was developed by D. Kindlon [21]. The transmission range of the alpha nodes is set to be twice the distance of beta nodes. In the first phase, the alpha nodes are used to create a global cluster. The beta nodes participate in the second phase to create regional clusters within the alpha node cluster.

3.2 Formation of Sociological Cluster

In the first phase, the alpha node is used to create a primary global cluster that takes into account the transmission range between cluster-heads with respect to the central sink node. The transmission range of alpha nodes is set to be greater than the transmission range of beta nodes. The form of alpha node clustering is depicted in **Fig. 1**.

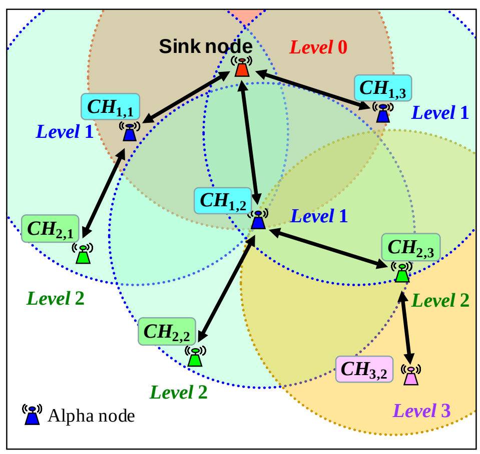

Fig. 1. Clustering formation in the first phase

The level number in **Fig. 1** is the hop-count from the sink node, and the hop-count difference between the upper and lower level is one.

In the second phase, a secondary cluster network is formed, this takes into account the transmission range between beta nodes (slash pattern nodes) with respect to the cluster-head of each alpha node (solid pattern node). The global cluster-heads that have been configured in the first phase are comparable to a temporary boss or an intermediate sink node. The beta nodes within the transmission range of a central intermediate boss node create a regional cluster. Regional clusters formed from the beta nodes transmit data under the control of the temporary boss, which is an alpha node generated in the first phase. In this figure, $CH_{l,m,n}$ is the logical cluster ID which is given by the administrating node such as a sink node, where l is the number of levels, m is the sequencial node ID from the first phase, and n is the ID from the second phase.

Fig. 2 shows the clusters and cluster-heads formed in the second phase. $CH_{1,2}$ is the first level cluster-head acting as the intermediate sink node in the second phase, and $CH_{1,2,1}$ is the regional cluster-head that has been generated after the formation of regional clusters. If a cluster formation is required for nodes that have an overlapping transmission range and the same hop-count from the upper layer nodes, the following rules should be applied. Nodes with the same transmission range and hop-count level form a logical tree structure relative to the topmost node. And when forming a cluster around a given node, proper grouping procedure is required since overlapping occurs between neighboring nodes. The set of neighboring nodes is calculated with respect to each node on the same hop-count level, and this set is used to form a cluster.

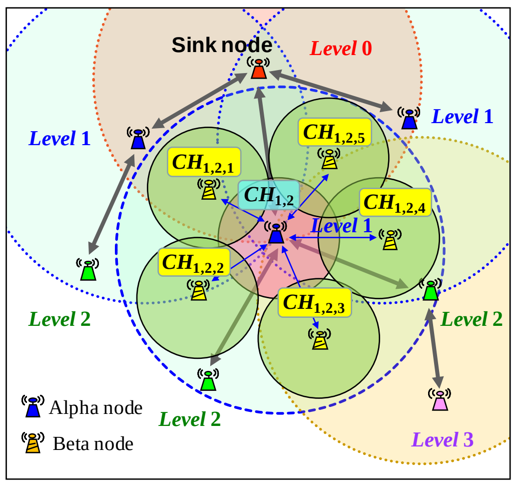

Fig. 2. Clustering formation in the second phase

Within a group with the same hop-count, each node has the same transmission range and is assigned a unique ID that has a value in the logical sequence. The upper-level nodes use the information received from the lower-level nodes to recognize the status of neighboring nodes in the lower-level. The upper-level node can use this information to sequentially arrange the neighboring nodes of the lower-level node. In other words, a neighboring node set $S(n_i)$, a subset of the universal set S_l, which is centered around a given node n_i can be expressed as:

$$S_l = \{n_0, n_1, n_2, n_3, \ldots, n_n\} \tag{1}$$

$$S(n_i) = \{n_{min}, \ldots, n_i, \ldots, n_{max}\} \tag{2}$$

where n_{min} is the logical minimum element node of the set $S(n_i)$ and n_{max} is the logical maximum element node of the set, i.e. $min \leq i \leq max$. In sequential order, the first cluster $C_0(n_{CH0})$ has the minimum node n_{min} as its element and n_{CH0}, sequentially the maximum element of the first set $S(n_0)$, as its cluster-head node ID which defines the cluster.

$$C_0(n_{CH\,0}) = \{\text{neighbor nodes of } n_{CH\,0} \mid n_{CH\,0} = \max S(n_0)\} \quad = S(n_{CH\,0}) \tag{3}$$

where max$S(n_0)$ means the relative maximum node ID in the temporary set $S(n_0)$ which defines the cluster nodes.

In the calculation of the second cluster $C_1(n_{CH1})$ with the same hop-count level, another n_{min} index is chosen that is different from the previous n_{max} used in $C_0(n_{CH0})$. The set $S(n_{CH1})$ has the n_{min}, which is the maximum element of the set $S(n_{CH0})$, as its first element. The cluster $C_1(n_{CH1})$ forms a cluster with node n_{CH1} as its cluster-head.

$$C_1(n_{CH\,1}) = \{\text{neighbor nodes of } n_j \mid \min S(n_j) = \max S(n_{CH\,0})\} \tag{4}$$

where min$S(n_j)$ means the relative minimum ID of the logical node in the set $S(n_j)$, $1 \le j \le n$, n_{CHk} is cluster-head node.

The cluster formation for the third cluster $C_2(n_{CH2})$ and the remaining clusters of the same level is the same as the cluster formation of the second cluster described above.

$$C_k(n_{CH\,k}) = \{\text{neighbor nodes of } n_j \mid \min S(n_j) = \max S(n_{CH\,k-1})\} \quad = S(n_{CH\,k}) \quad \text{where } 1 \le k \le n \tag{5}$$

3.3 Basic Rule of Balanced Clustering

The upper-level node has the set information of the lower-level nodes, and preferentially becomes the cluster-head if it is the only higher level node connected to a certain lower-level node. At the same hop-count level, each node has information about neighboring nodes within transmission range, this information is calculated in the form of a set, and common nodes are sequentially eliminated from the reference node to minimize the number of clusters.

When forming a cluster, a weight is calculated and an average value is found in order to calculate balanced cluster node. Weights are based on 1) number of nodes in the area, 2) energy possessed by the node, 3) amount of data possessed by the node, and so on. An appropriate weight is selected for each application to create a balanced cluster. For example, if a neighboring node set at a given second hop-count level is defined with respect to the transmission range as follows:

$$\begin{aligned} S(n_{2,1}) &= \{n_{2,1}, n_{2,2}\} \\ S(n_{2,2}) &= \{n_{2,1}, n_{2,2}, n_{2,3}\} \\ S(n_{2,3}) &= \{n_{2,2}, n_{2,3}, n_{2,4}\} \\ S(n_{2,4}) &= \{n_{2,3}, n_{2,4}, n_{2,5}\} \\ S(n_{2,5}) &= \{n_{2,4}, n_{2,5}\} \end{aligned} \tag{6}$$

As a basic rule for clustering, the set for each neighboring node is calculated and a cluster is formed by comparing the set information of reference and neighboring node. In this paper, a node with an element node still present after eliminating common nodes from the neighboring node set of the same hop-count level is selected as the central node of the cluster. In Eq. 6, $S(n_{2,2})$ and $S(n_{2,4})$ are left after eliminating common nodes and they respectively become central nodes $n_{2,2}$ and $n_{2,4}$, while $n_{2,1}$, $n_{2,3}$, and $n_{2,5}$ perform the duties of a cluster member node. In the case of having a single lower-level node or having a singular connection and not multiple connections to a neighboring nodes, $S(n_{2,1})$ and $S(n_{2,5})$ preferentially become cluster-heads and clustering is performed using the common element elimination method excluding the central nodes $n_{2,1}$ and $n_{2,5}$. Then, $n_{2,3}$ becomes the central node of the cluster of the remaining equal hop-count level nodes in the example above.

4. Information Structure

4.1 Information Acquisition Flow

To create a network between cluster-heads, each cluster-head node uses a transmission power with large range to acquire information about the lower-level nodes. If there are two or more upper-level nodes overlapping at a given hop-count level, a node selects the upper-level node and transmits information using one of the listed methods:

- Select node with more energy
- Select node with fewer internal nodes
- Select node with specified QoS
- Sequentially select a node
- Select a node with higher or lower ID

In addition, we describe the data acquisition process, and its contents, between cluster-heads or alpha nodes. The upper-level node broadcasts information about its own node ID and cumulative hop-count from the top node (the initial hop-count is zero) to the lower-level nodes, and the lower-level nodes delivers their ID to the upper-level node after acquiring the broadcasted information from the upper-level node.

The top node manages node information from the lower-level nodes in the form of a table, which contains hop-count, ID, and neighboring node information of each lower-level node. The lower-level node adds 1 to the hop-count delivered from the upper-level node and saves it to the table, then broadcasts this information to find its lower-level nodes. During the topology setup, each node ignores the acquired data packet if it is from a node with hop-count smaller than its own cumulative hop-count. An example of the essential contents among nodes with a one hop-count level are given in **Table 2**.

The data contents and acquisition process between cluster-head and beta nodes are as follows.

The beta nodes that constitute the cluster receive topology information from the higher-level cluster-head to create the regional cluster. The cluster-head broadcasts the initial command, which includes its ID, to neighboring nodes using small transmission power.

Table 2. Information frame in different layer

< Frame-1a : cluster-head to alpha node >

ID	Acc. hop-count	Upper node	Lower node	Function	Data factor	Res. power
$CH_{1,0}$	1	$\{CH_{0,0}\}$	$\{S(CH_{2,1}), S(CH_{2,2}),\ldots\}$	CH	High	9.5

< Frame-2a : alpha node to cluster-head >

ID	Acc. hop-count	Upper node	Lower node	Function	Data factor	Res. power
$CH_{2,1}$	2	$\{CH_{1,0}\}$	$\{S(CH_{3,1}), S(CH_{3,2}),\ldots\}$	CH	Medium	9.2

- ID: Logical node identification
- Acc.hop-count: Accumulative hop-count from top node
- Upper node: Node ID in upper-level
- Lower node: Node ID in lower-level
- Function: Role of node in cluster
- Data factor: Degree of data
- Res.power: Residual power of node
- Neighbor CH: Cluster-head ID in neighbor area
- Neighbor node: Node ID in neighbor area
- Duty time(DT): Active-time allocated by cluster-head
- CH node: Cluster-head node in its cluster
- Attribute: Sensing attribute
- Reserved: Temporary used or preparation

The beta node analyzes the command packet broadcasted by the cluster-head, then sends a request for cluster participation, which includes its ID and information of neighboring nodes. The cluster-head analyzes and organizes participation request packets from the beta nodes, then broadcasts the beacon period and duty time of the beta nodes included in its cluster. Mutual data exchange information is shown in **Table 3**. The beta nodes of regional cluster are only activated during their duty time and enter sleep-mode during other times in order to conserve their energy.

Table 3. Information frame between cluster-head node and beta nodes

< Frame-1b : cluster-head to beta node >

ID	Acc. hop-count	Upper node	Neighbor CH	Duty time
Function	Attribute	Data factor	Residual power	Reserved

< Example of frame-1b >

$CH_{2,1}$	2	$\{CH_{1,0}\}$	$\{CH_{2,0}, CH_{2,2}, CH_{2,3},\ldots\}$	$\{DT(N_{2,1,0}), DT(N_{2,1,1}),\ldots\}$
CH	Temperature	High	9.1	

< Frame-2b : beta node to cluster-head >

ID	Acc. hop-count	CH node	Neighbor node	Duty time
Function	Attribute	Data Factor	Residual power	Reserved

< Example of frame-2b >

$N_{2,1,1}$	3	$\{CH_{2,1}\}$	$\{N_{2,1,0}, N_{2,1,2},\ldots\}$	$DT(N_{2,1,1})$
Ordinary	Temperature	Low	9.6	

4.2 Topology Initialization Procedure

After being globally installed, each sensor node calculates its own energy, and is either assigned to cluster-head and alpha node duties or beta node duties. **Fig. 3** shows the control command flow of clustering topology.

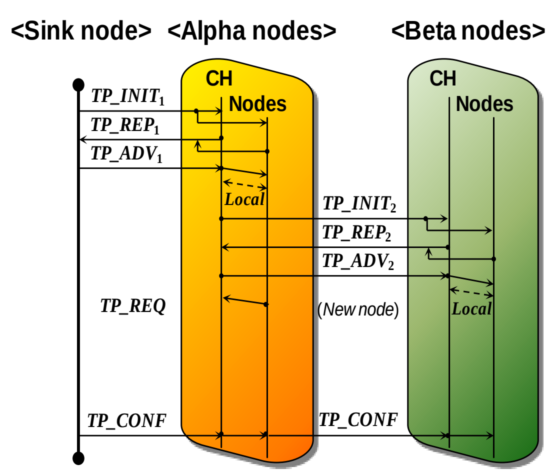

Fig. 3. Control command flow of clustering topology

At the beginning, every node listens for a TP_INT_1 command from the upper-level node. Each node accepts the TP_INT_1 command 2 to 3 times, then transmits a TP_REP_1 command to the upper-level node using the IEEE802.11 Mac mode of delivery. The upper-level node that receives the TP_REP_1 command then transmits a TP_ADV_1 command to each node that has sent a TP_REP_1 command. Information on cluster unit, logical ID, and cluster-head are included in the TP_ADV_1 command. Each cluster that has received a TP_ADV_1 command confirms the clustering around the cluster-head, then exchanges data. First level clusters that have completed clustering from the upper-level nodes start normal communication, then the upper-level nodes step-down their transmission power and range to initiate second level clustering with the beta nodes in the range.

Formation of second level clusters is similar to first level clustering. The lower-level node transmits a TP_REP_2 command to the upper-level node and the upper-level node uses a TP_ADV_2 command to transmit data to the lower-level cluster nodes. Depending on the level, the upper-level node uses a TP_INT_n, TP_REP_n, or TP_ADV_n commands to create clusters, and if there is no occurrence of the TP_REP_n command after a while, the upper-level node transmits a *TP_CONF* command to complete the clustering.

Normally, *TP_INT*, *TP_REP*, and *TP_ADV* commands are used in an open environment in order to create the network topology. However, there may be partial non-receipt of commands related to topology formation due to collisions between nodes, jamming due to the terrain, etc., or some nodes may even be left out of the clustering.

Similarly, new mobile nodes cannot directly enter an existing cluster within the network topology. Such nodes can register by periodically transmitting a command to neighboring nodes in the form of a beacon signal so that cluster-heads or alpha nodes within transmission range can recognize it. A cluster-head that recognizes a new node will first internally process the information of the new node, and then include information regarding the newly added node in a transmission of topology information to an upper-level node. Also, the cluster-head node will update the beacon period and the duty time within the cluster as well as adjusting the time schedule table.

5. Experimental Performance Evaluation

5.1 Evaluation Scenario

To evaluate the energy consumption of the network nodes and network lifetime through data aggregation, we used a method commonly used in cluster networks, the basic energy consumption model defined in [11].

$$E_{consum} = E_{Tx} + E_{Rx} + \beta d_{ij}^{\alpha} \tag{7}$$

where E_{Tx} is the energy cost at the transmitting circuits and status processing. E_{Rx} is the energy consumption when receiving the data, and βd_{ij}^{α} accounts for the radiated power necessary to communicate over a distance d_{ij} between node n_i and node n_j. To simplify the calculation of energy consumption in evaluation, we also assume that

$$E_{Tx} = E_{Rx} = E_{circuit} \tag{8}$$

So the expression for E_{consum} in Eq. 7, which we refer to as the link metric hereafter, simplifies to

$$E_{consum} = 2E_{circuit} + \beta d_{ij}^{\alpha} \tag{9}$$

We define the network lifetime of the configured network, T_{Lnet}, as the number of rounds until the first node is exhausted of its energy. The network lifetime is correlated to E_{remain}, the remaining energy of a given node, and R_f, the number of rounds of data aggregation between cluster-heads and cluster member nodes within each cluster. After R_f rounds, the amount of energy that a given node has is given in Eq. 10.

$$E_{remain}(R_f+1) = E_{remain}(R_f) - E_{consum} \tag{10}$$

The whole network process is terminated for evaluation when $E_{remain}(R_f)$ becomes zero and the R_f value of the final round is defined as the T_{Lnet}. We evaluate the energy performance of the proposed method using MATLAB. In our experiment, we set $\alpha = 2$, $\beta = 100pJ/bit/m^{\alpha}$, $E_{circuit} = 50pJ/bit$, the data packet sizes is $500bits/packet$. The initial energy of E_{remain} on each sensor node is $1J$. The node distribution for the simulation was uniform random distribution, and the results presented here are average values from 100 simulations.

The value of each parameter in the evaluation scenario model is shown in **Table 4**, where the term ratio is the proportion of the alpha node and beta node transmission range. We compare the energy level performance of our algorithm with that of other cluster network protocols such as PEGASIS [22] and CMLDA [23]. Simulation method for cluster networks come in various forms depending on the application, and results may vary depending on simulation parameters such as transmission ability and amount of energy per sensor node. However, for the purpose of evaluating the proposed algorithm we apply an existing sensor node model and specifications that are normally used.

Table 4. Parameters for the evaluation model

	Scenario 1	**Scenario 2**	**Scenario 3**	**Scenario 4**
Field	$50m \times 50m$	$100m \times 100m$	$50m \times 50m$	$50m \times 50m$
N	*variables*	*variables*	*variables*	50
TRi	$25m$	$50m$	*variables*	*variables*
Ratio	50%	50%	50%	*variables*

5.2 Experimental Result

SOCT in general displayed a superior lifetime compared to other protocols. In Scenario 1 for small number of network nodes, SOCT performed worse than CMLDA but better than the others. SOCT shows a 35 percent higher efficiency on average compared to LEACH in **Fig. 4**. When number of network nodes is increased, the SOCT lifetime is enhanced by 1 percent on average. However, the network lifetime efficiency is improved in an environment with a wider range such as in Scenario 2.

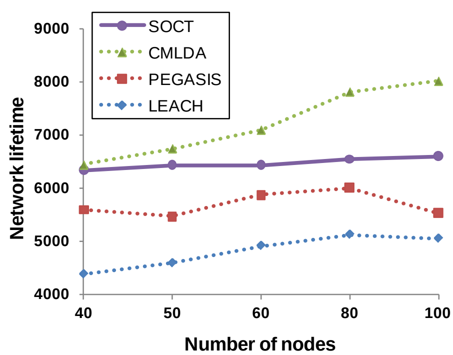

Fig. 4. Network lifetime in Scenario 1

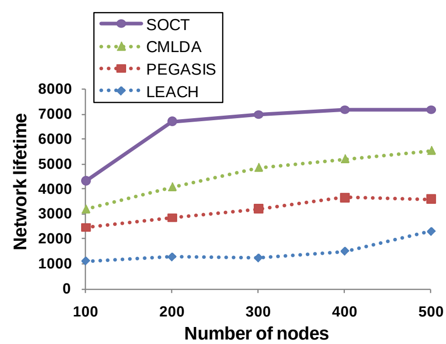

Fig. 5. Network lifetime in Scenario 2

In Scenario 2, the node distribution range was set to 100 meters square and the transmission range was twice the distance used in Scenario 1. **Fig. 5** indicates that as the number of nodes is increased, the lifetime for SOCT is enhanced compared to other protocols. Clustering method of SOCT establishing two kinds of areas differs from the traditional clustering methods searching for neighbor nodes. The simulation results of regional SOCT shows longer lifetime than other clustering methods in a large network. This is due to reduction of unnecessary communications by forming clusters based on area.

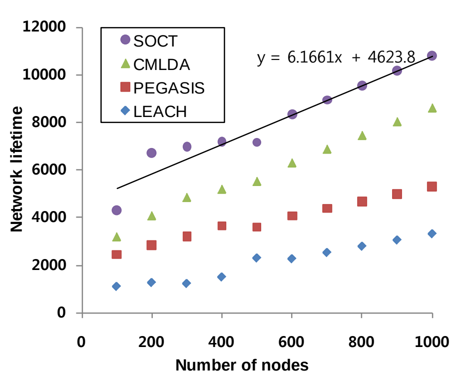

Fig. 6. Extended trend line of SOCT

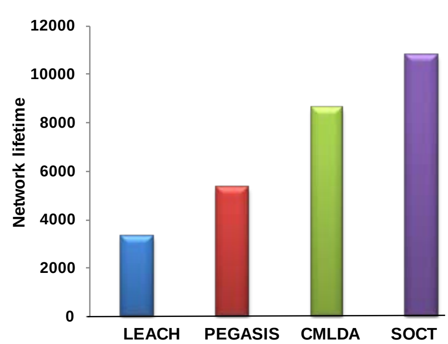

Fig. 7. Forecasted lifetime at N=1,000

On the other hand, traditional clustering methods may show a longer lifetime in a small network because they, compared to SOCT, have fewer clusters and do not experience the communication overhead needed to form global and regional clusters. SOCT showed at least 30 percent higher efficiency compared to other protocols, which was about twice the efficiency of PEGASIS. The lifetime of SOCT itself was improved by 16 percent on average.

When regression analysis was performed using results from node numbers 100 to 500, a linear trend line with a slope of 6.1661 and intercept of 4623.8 was found. **Fig. 6** describes the result forecast for a 1000 node system using this trend line. When the number of nodes was expanded to 1000, the SOCT lifetime was increased by 6.7 percent. **Fig. 7** shows that SOCT lifetime performance is increased by 50 percent when the number of nodes is doubled, and is 1.3 times higher than that of CMLDA.

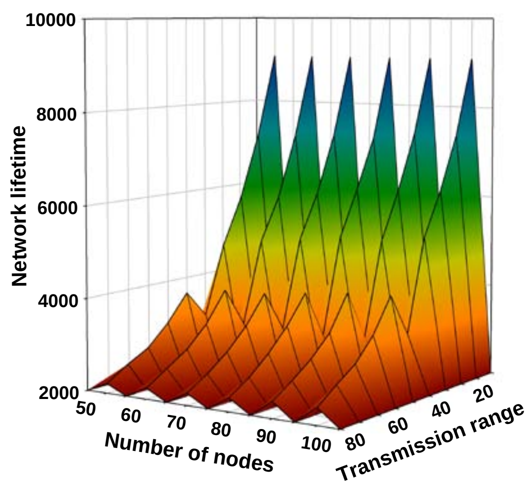

Fig. 8. Characteristics of lifetime in Scenario 3

Fig. 8 shows the results of the calculation of lifetime with a varying number of nodes and the transmission ranges. In Scenario 3, an experiment with a fixed transmission range, when the total number of nodes was increased, the average lifetime was enhanced by 3 percent, and the rate of average lifetime enhancement between the minimum and maximum number of nodes was about 7 percent. When the total number of nodes is fixed and the transmission range (TR) is increased, the average lifetime reduction is 13 percent. The lifetime decrease between TR values of 10 and 100, the maximum value, is 75 percent on average.

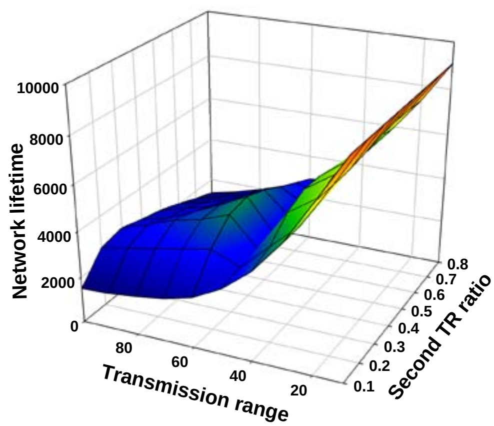

Fig. 9. Shape of lifetime by varying transmission range and second TR ratio in Scenario 4

Fig. 9 represents the lifetime by fixing the number of nodes at 50 and changing the ratio of the alpha node transmission range and beta node transmission range. The ratio of the alpha node and beta node transmission range was used for the second TR ratio in the figure. The average lifetime reduction between minimum and maximum TR ratio was about 16 percent. When the TR ratio is fixed and the transmission range is increased, lifetime was decreased by about 14 percent on average. Lifetime reduction between TR values of 10 and 100, the maximum value, is 76 percent on average. Applying log function to the simulation results with a TR ratio fixed at 0.2 to calculate a trend value when the TR value was doubled showed lifetime was decreased by 72 percent.

6. Discussion

In the evaluation, SOCT shows improvement in lifetime performance compared to conventional clustering methods when the number of nodes is increased. This efficiency can be observed even in forecasting that used a trend line. The energy efficiency of a clustering architecture depends generally on the number of member nodes in a cluster.

If the number of member nodes in a cluster is high, the energy consumption of each member node is small, but the clusterhead consumes large amounts of energy due to data receiving. It also takes a lot of time to elect a clusterhead in a local cluster causing a lot of energy to be consumed. Moreover, if the nodes change transmission power to form a cluster, this also consumes a lot of energy.

As mentioned in the evaluation, increases of transmission range drives the energy consumption of each node higher and affects the overall lifetime. In cases where the difference of transmission range between alpha node and beta nodes is large, lifetime is also decreased. In SOCT, which has sociological links to two areas, the overlap of transmission range between the alpha node and beta node should be minimized. In view of energy consumption being dependant on the transmission power, we recommend that the transmission ratio is set to 50 percent.

Table 5 summarizes the characteristics of the presented SOCT and conventional clustering methods. Some methods show advantages in terms of management such as resilience, scalability, and aggregation timing. In SOCT, however, we adopt another discipline, social science, to expand an idea of design and present the concept of divided clustering areas like those seen in urban sociology. Most clustering methods consist of a single-capacity node that has a role in clustering and a transmission range, or of other nodes that change their transmission range unpredictably to form clusters. Clustering nodes that have two roles can potentially improve the management of wireless sensor networks.

Table 5. Summarizes the characteristics of SOCT and conventional clustering methods.

Features	SOCT	LEACH	PEGASIS	CMLDA	CLUSTERPOW
Perspective	Sociology	Cluster	Energy	Energy	Connection
Main Focus	Division	Clustering	Near Chain	Gathering	Clustering
Area Configuration	Global, Regional	Layered	Chain	Heuristic	Non Uniform
Tradeoffs	Complexity	Efficiency	Routing Overhead	Complexity	Loop
Transmission Range	Dual	Mixed	Mixed	Mixed	Variable
Scalability	High	Low	Very Low	Low	Medium
Gateway	Multi	Single	Single	Single	Single

7. Conclusions

In this paper, we presented a novel clustering topology method to support long lifetime, wireless sensor networks. We applied the sociological concepts of structure and group to wireless sensor networks and presented a new topology model. This form of topology hybridizes the centralized and the distributed operating methods to support structural connectivity and controllability of sensor nodes that are standardized and widely distributed in a ubiquitous environment. Topology combines global and the regional structures, as in urban sociology. It shows better energy efficiency than existing clustering algorithms, depending on the number of member nodes and the transmission range. We expect that this form will become adaptive by having deployed nodes collect regionally unique data and select methods of communication with the upper-level nodes.

In the past, the science has limited itself to a single area of study, or in case disciplines have not been clearly divided. The domain of study has been significant so that the range of each field has been well-defined and partitioned. Since different disciplines are related in one way or another, science of the future will experience partial convergence or complementary consilience, and new methods will be produced that combine ecology, natural sciences and sociology with ubiquitous communication and computers. We expect that this method will be useful in the self organization of networks based on social structures that encourage network expandability and interactivity.

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