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Enhanced Graph Theoretic Modeling for Estimating Node Localization and Reachability in WSN

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Abstract

A graph based approximation is developed for calculating the localization, reachability and sensing the node connectivity with randomly positioned nodes in Wireless Sensor Networks (WSNs). This approximation is achieved by taking into account the graph property in which edge appears between any vertices that denote sensors in the neighboring communication area. The key analysis is to create the communication area request enclosed by the minimum one node with the predicted amount of nodes in the specified network. The probability of connectivity of specified node is completely calculated and approximated here. The approximation results in the collaboration of connected node density for transmitting data. The relationship amongst the nodes and the region of coverage by the sensors is also investigated. This helps in designing any application related to sensor network effectively and to calculate the energy for transmission.

Keywords: *Coverage, geometric graph, networks, sensor, localization, reachability, and connectivity*

1. Introduction

WSNs has recently emerged as a new paradigm for providing multiple connectivity to the nodes seeking request. It senses certain specific physical quantity, like humidity, temperature, pressure or vibration. It collects and transfers sensed data to one node at least, typically through many wireless hops. To guarantee sensing coverage, WSN must sense essential physical quantity over complete area being observed—while performing this, both energy and reachability of nodes [1] are fundamentally considerations. WSN is desirable to multi-mode network since it removes the perfect links to schedule accordingly for allocation and facilitates several nodes for accessing different services even when there is a growth in demand. However, despite that WSN offers huge opportunities for efficient network deployment, as well with many issues still to be addressed.

Consider perfect links where every node has specified by the coverage range; but practically, it is executed to specific amount as of physical problems. The analysis may be complete to aid with specific scenarios where node's communication range is depending on atmosphere; the results in this article conversely follows the practical inference for different applications. It is powerful while requiring node density or estimating the node's likelihood. It is considered that nodes allocation over communication region is characterized by the localization and reachability [2], recommending that estimations are the most suitable to applications using randomly scattered nodes.

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It makes many links for creating the cluster that achieves powerful transfer. Combining the nodes for achieving the localization is an entire dynamic computing system. It may arrange, assign or reassign resource dynamically and forecast the resource uses at every time. Normally, WSN has scattered basis model and forecast the nodes linked to the network for accomplishing effective network access. It doesn't depend on certain data center, however it is the expected source to compute efficiently. But, it is simple to expand as compared with the common network and has an easiest controlling modes. Also, it offers a control scheme and accesses for several clients concurrently.

Nowadays, there has been a broad interactive in the network analysis due to the complicated devices. Graph theoretic equipment's [3] have been broadly applied in evaluating the WSNs and helpful for detecting the nodes which can cooperate with multiple adjacent and calculate the nearness or localization among nodes. This article proposes a graph theoretical framework for encouraging the network access [4]-[5] for localization and applied centrality for measuring the polar co-ordinates via the WSN's reachability.

The coverage issue [6] for WSNs is investigated in this work; mathematical methods using graph theory have been developed for estimation or calculation of sensing coverage. Even though node connectivity offers useful way of estimating overall coverage, the proposition provided here using graph concept is also directly related to analyze local connectivity information to determine the coverage extent.

This paper anticipates node's importance in WSNs according to the power model, localization, reachability for evaluating the node's importance via data transfer status with connected nodes in WSN. Based on the graph field theory [7], it investigates the alterations accounted in WSN node from view of power and network topology which may modify because of additional nodes to improve the exactness in practical application [8]. Some nodes with superior importance may become lesser significant after topological change. As a result, this method provides complete consideration to dynamic change of nodes for analysis [9].

2. Related Works

In [10], Jianping Dou, [2009] proposed a two-stage optimization approach is to handle the configuration generation problem. The first stage is to generate K-best solutions by solving a constrained K-shortest paths problem on a combined augmented machine graph derived from the precedence graph for a specific part. The second stage is to find p distinctive ones out of K configurations using the algorithms for p-dispersion problem. These p alternatives would be helpful to system designer in selecting the best configuration at both initial design and reconfiguration stages.

In [11], Xiaoyun Li, [2012] used the theory of tri-coverage for measuring the fraction of sensing coverage in WSN, considering the 2D Poisson procedure as a node localization framework. The analysis needs no hypotheses about the complete region and decide with the simulations efficiently with a variance of few ratio for network density. It achieves the correlation between tri-coverage and non-coverage defined via the likelihood of a trivial hole.

In [12], Hui Kang, [2013] describes a graph colouring based TDMA scheduling algorithm for WSN clustering. This algorithm consists of two phases. In the colouring phase, a DVC algorithm, which is a distance-2 colouring algorithm, is presented. Its result and performance are analyzed in theory, and then it is proved that DVC has well scalability as well as stability by simulations. The number of

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colours used by DVC algorithm is close to (δ +1). In scheduling phase, the communication of intra-cluster is scheduled based on the characteristics of network structure.

In [13], Qindong Sun, [2016] investigated the node connectivity according to the effect of data transfer in WSNs and observed that the conventional frameworks have challenges in defining the dynamic procedure in WSN. Initially, these procedures were not applied in the data transfer protocols and transfer likelihood affects the analysis of nodes. Then, the node failures and other factors frequently affect the network topology, and these procedures can't adapt for analyzing the node's influence. After, these procedures have a rough classification of the nodes in WSN and can't detect the nodes having high traffic, however having adequate influence in the network.

In [14], TolgaEren, [2011] observed the graphical criteria on specific localization in cooperative networks with hybrid space and bearing evaluations. Also, it offers additional criteria sets in the networks fulfilling these graphical properties, so that the related computational difficulty can be linear.

3. Proposed Methodology

The significant idea of this investigation is to consider the connectivity graph or the distances between neighbouring sensor nodes as input. One major challenge of this approach is localization ambiguity i.e., when there exists multiple, diverse localization solutions that convince all distance constraints but not for nodes far from each other [15]. Instead of that, using distance information, local optimization such as ant colony optimization techniques may get stuck at local minima. The crisis of whether a graph is provided edge length constraints admit a unique embedding in the plane. A graph is usually rigid in its plane if it does not continuously deform the graph shape without altering the edge lengths. A graph is globally rigid if it accepts unique embedding in polar coordinates of its plane.

The graph theory rigidity in its two dimensions is relatively well understood. There is also an efficient way to test whether a graph is generically rigid in time O (nm). Where,

$n \rightarrow$ amount of nodes; $m \rightarrow$ amount of edges.

Given a graph with edge lengths specified, finding valid graph realization for a fixed dimension d is an NP-complete problem. The pioneering work of using fuzzy logic theory in network localization focuses on identifying special graphs that do admit efficient localization.

Various localization methods use global optimization tools. These algorithms in general have the best accuracy but the drawback is that they require the global network topology and thus are centralized methods, besides being computationally high cost.

3.1. Network Model

The WSN is depicted as a directed graph by taken into account nodes and Cluster Head (CH) as vertices and the communication link as route. The graph is designed as a random graph because the nodes can be attached to any existing nodes. As communication between the nodes is most important, we use node graph 'N' which is a connected clustering for data transmission as in Figure 1 whereas B is a graph node with to analyze the localization among network connectivity nodes as in Figure 2.

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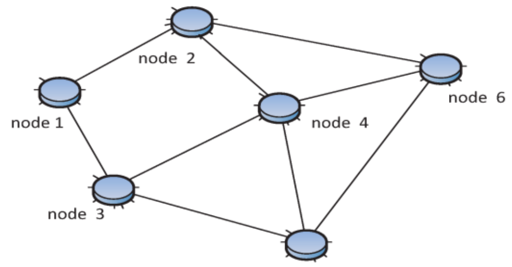

Figure 1. Connectivity node 'N'

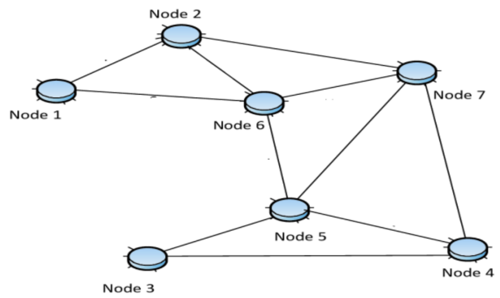

Figure 2. Node searching for localization

3.2. Prerequisites

This work explains the definition and notations that is cast off in graph theory. In n-dimensional graphical structure of sensor nodes, vertices are pairs (x,y), in which 'x' is the binary string with the length 'n' and y is an integer with a range between 0 and n. Also, the directed edges of the nodes are (x,y) to (x, y+1) if $x^1$is equal to x in each node with the promising delay of $(y + 1)^{th}$node used for clustering. The n-dimensional graph comprises 2^n (n +1) vertices and 2^{n+1}n edges.

Definition:

1. A node graph is a graph 'N' = *(V,U)* with vertex V= V_1 U V_2 and edge set E = E_1 U E_2, where V_1 = {B_i/B_i} indicates the node exploring for localization, V_2 = {N_j/N_j} indicates the linked node and E1 and E2 are the group of nodes linked such that $E_1 \subseteq V_1$ X V_2 and E2 $\subseteq V_2$ X V_1.
2. A node graph B is a graph for node localization B = (V,U) with vertex V = {Bi/Bi and edge E ⊆ V × V.

Centrality is applied to discover dominant vertices/edges in graphs. In WSN, the (vertices) nodes are CHs and the edges are polar coordination/links between the CH and other member nodes.

3.3. Localization

It is the principle idea which uses more useful data about the network infrastructure. For directed WSN, it is normally based on in-degree or out-degree. The network ability is determined by measuring the communicability (Connectivity Point (CP)) amongst nodes. The CP measure is the amount of nodes reachable from X_k (i.e., CH),

$$B(X_k) = \sum_{i=1}^{n} r\,(X_{k,}X_1) \text{ where } (X_k, X_1) = \begin{cases} 1, & \text{if nodes is reachable from } X_k \\ 0, & \text{otherwise} \end{cases}$$

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B (X_k) is high if X_k is attained high amount of nodes and less if X_k is removed from such neighbourhood. Whilst the highest value is obtained for each node only while the graph is robustly linked and is 1.

Network localization usually comprises of two steps: measurement and location estimation. In general, network localization relies on estimation of neighbouring nodes location. In measurement step, packets are exchanged in neighbouring nodes and the distance is determined via estimating one or many transfer metrics related to the packets. In location estimation step, measured values are combined and cast off as inputs for executing the localization.

Lemma 1: Let 'N' is the network connectivity. Ncr (x) = n ∀ x ε V (N) if N is robustly linked for achieving effective communication.

Proof: Ncr = n, ∀x ε V (N) if each node can successfully interact with the rest n − 1 nodes and itself for each couple of node x and y, there is a (x, y) bidirectional route in N if N is robustly linked.

Nodes sensing specified characteristics of their dimension for estimating their locality. Determining the locality data with distance via node's ability helps to estimate the packet arrival time, time variance, and received signal strength.

Lemma 2:N_{cr} is 1, if $d^+(x) = 0$ as in Figure 3.

Proof: Consider x ε V. Ncr = 1, if 'x' can attain only itself, i.e., $d^+(x) = 0$

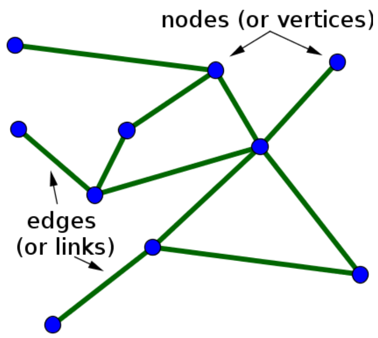

Figure 3. Pictorial representation of edges and vertices in WSNs

Lemma 3: Consider N is the route created from network graph with node group V (N) = {x_1, x_2. . . x_n}. Ncr(x1) = n and Ncr(xi) = Ncr(x_{i-1}) − 1 ∀i = 2, 3, . . . n.

Proof: Because 'N' is a route graph with node group V (N) = {x_1, x_2. . . x_n} and the network connectivity A(N) = {(x_i, x_{i+1})/i = 1 to n}. Route is created from node x_1 to nodes x_1, x_2. . . x_n and node x_2 to x_2, x_3.. .,x_n. Likewise, node x_{n-1} to nodes x_{n-1}, x_n. Node x_n reach x_n only. The node traversing route reachability is minimized by 1 in every forward direction. So, $N_{cr}(x_1)$ = n and $N_{cr}(x_i) = N_{cr}(x_{i-1}) - 1$ ∀i = 2, 3, . . . n.

Lemma 4: Consider 'N' is a cyclic graph with node group V (N) = {x_1, x_2. . . x_n}. After, $N_{cr}(x_i)$ = n ∀i.

Proof: Because cyclic graph is strongly interacted according to the proposition 1.

Lemma 5 (Topology connectivity): Consider 'N' is the star network topology where every node interacts with every other in a node group V (N) = {y, x_1,x_2, . . . , x_r } where 'y' signifies the central node. After,

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$$N_{cr}(x) = \begin{cases} d^{+}(y) + 1, & \text{if 'x' is centre node} \\ 1, & \text{if } x \in N^{+}(y) \\ d^{+}(y) + 2, & \text{if } x \in N^{-}(y) \end{cases}$$

Proof: The centre node 'y' attains each node in $N^{+}(y)$ and itself. $N_{cr}(y) = |N+(y)|+1 = d^{+}(y) + 1$. For x ε $N^{-}(y)$, x reach y, itself and each node in $N^{+}(y)$. $Ncr(x) = |N^{+}(y)| + 2 = d^{+}(y) + 2$ ∀x ε $N^{-}(y)$.

The main goal of topology connectivity is to handle the graph topology with sustaining particular global graph property (e.g., connectivity), when minimizing the power use and intrusion related to the node's communication region.

Proposition 6: Assume 'N' is a n-dimensional butterfly-based network graph. After, Ncr((w, n)) = 1 and Ncr((w, n − k)) = Ncr((w, n − k + 1)) × 2 + 1, where k = 1, 2, . . . , n.

Proof: Because the out-of-range of each node at level n is 0, Ncr((w, n)) = 1. Because each node in 'i' level attains two nodes in 'i+1' where 'i' = 0 to n−1, Ncr((w, n−k)) = Ncr((w, n − k + 1)) × 2 + 1, where k = 1, 2, . . . , n.

3.4. Data transfer based on reachability

To discover the transfer capability of the constructed network, the link ratio is computed according to the major node to each secondary nodes. Assume 'n' is the node, n-1 is the node that can be found via the major node for creating the link whereas ∞ is the locality that can't be found via the major node. Then, a single index calculation is executed via summing each node ratio that is reachable with the considered distance and the suitable weight. The node that can't be reachable is assigned with the weight '0' and the node that is consecutive to the major node is assigned as 1. The node consecutive to the major node is not simply reachable and able to interact with every other efficiently.

Definition:

Consider x ε V. Describe $Nccr(x) = \frac{1}{\infty}.\frac{l_1}{n-1} + \frac{1}{1}.\frac{l_2}{n-1} + \frac{1}{2}.\frac{l_3}{n-1} + \cdots . + \frac{1}{n-1}.\frac{l_n}{n-1}$ where $l_i, i = 1, 2...n$ are sum amount of nodes at distance ∞, 1, 2, . . . , n−1, accordingly.

Observe: $0 \leq l_i \leq n - 1$, ∀i and $\sum_{i=2}^{n} l_i = C_{cr} - 1$.

Node labeling challenge may allow to determine the distance between any two nodes directly from their labels. Here, Nccr of every node is determined for finding the nearby network connectivity for cooperation.

Lemma 7: Consider '*N*' is the network graph. After, Nccr(x) = 1∀ x ε V (N) if d(x, y) = 1 ∀y.

Proof:N*ccr*(x) = 1, if $l_2 = n-1$, $l_1 = 0$, $l_3 = l_4 = ... = l_n = 0$, if x reach each n − 1 nodes through distance 1 if d(x, y) = 1 ∀y.

Lemma 8: For each N, N*ccr*(x) = 0, if $d^{+}(x) = 0$.

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Proof: Assume x ε V. N*ccr*(x) = 0, if x (major node to create path) can't reach any nodes if no route is created from origin to target, i.e. if $d^{+}(x) = 0$.

Lemma 9: Consider 'N' is a cyclic graph as in Figure 4 with node group V (N) = {x_1, x_2. . . x_n}. After, N*ccr*(x_i) = $\frac{1}{n-1}\sum_{i=1}^{n-1}\frac{1}{i}\,\forall i = 1,2,3 \ldots n-1$

Likewise, for N*ccr*(x_j) = $\frac{1}{n-1}\sum_{j=1}^{n-1}\frac{1}{j}\,\forall j = 1,2,3 \ldots n-1$.

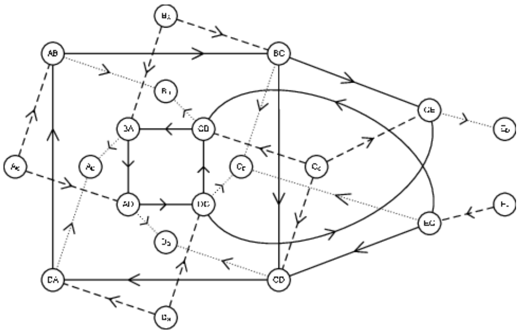

Figure 4. Pictorial representation of cyclic network topology

Proof: The N*ccr* index is equal for each cyclic graphs. For x_i ε V, x_i reach x_{i+1}, x_{i+2}. . . x_{i+n-1} by distances 1, 2, . . . , n − 1. So, $l_1 = 0$, $l_2 = l_3 = \ldots l_n = 1$.

Nccr(x_i) = $\frac{1}{n-1}\sum_{j=1}^{n-1}\frac{1}{j}$

Lemma 10: Assume 'N' is a star network graph as in Figure 5 with node group V (N) = {y, x_1, x_2. . . x_r}, where 'y' is the centre node. After,

$$N_{ccr}(x) = \begin{cases} \frac{d^{+}(y)}{r} & \text{if x is the centre node} \\ 0 & \text{if } x \,\varepsilon\, N^{+}(y) \\ 1.\frac{1}{r} + \frac{1}{2}\frac{d^{+}(x)}{r} & \text{if } x \in N^{-}(y) \end{cases}$$

Proof: Centre node 'y' reaches each node in $N^{+}(y)$ by distance 1. For x ε $N^{+}(y)$, $d^{+}(x) = 0$, N*ccr*(x) = 0 ∀x ε $N^{+}(y)$. For x ε $N^{-}(y)$, reach 'y' by distance 1 and reach each node in $N^{+}(y)$ by distance 2. Hence, $l_2 = 1$, $l_3 = d+(y)$. $N_{ccr}(x)=\frac{1}{r} + \frac{1}{2}\frac{d^{+}(y)}{r}\forall x \,\varepsilon\, N^{-}(y)$.

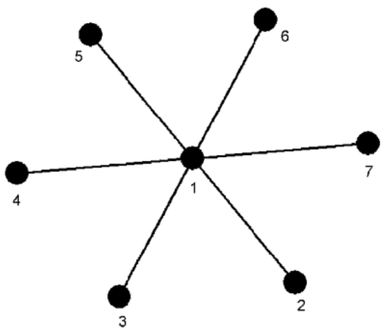

Figure 5. Pictorial representation of star network topology

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Lemma 11: Consider 'N' is n- dimensional mesh-based butterfly topology graph as in Figure 6 with |V| = N. After, $N_{ccr}((w, n)) = 0$ and $N_{ccr}((w, l)) = \frac{1}{N-1}\sum_{i=1}^{N-1}\frac{1}{i}2^{i}$

Proof: N*ccr*(w, n) = 0, because $d^{+}((w, n)) = 0$, ∀w. For i = 0 to n, each node in i level reaches 2 node in i + 1 by distance 1, reaches 2^2 nodes in i + 2 by distance 2, reaches 2^3 nodes in i + 3 by distance 3, …, reaches 2^{n-i} nodes in level n by distance n – I, accordingly.

Cccr((w, l)) = $\frac{1}{N-1}\sum_{j=1}^{n-1}\frac{2^{j}}{j}\ \forall\, l = 0,1,2,3,\ldots n$

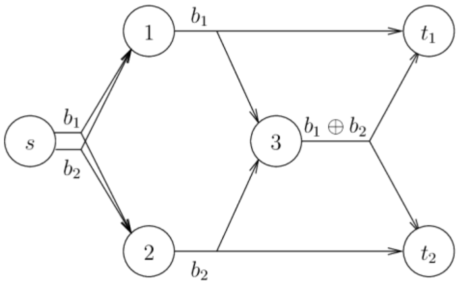

Figure 6. Pictorial representation of butterfly network topology

3.4. Communication establishment in network graph

Definition: Consider 'N' is the weighted network graph where weight w(i, j) of each connectivity (i, j) computes the amount of nodes reached via the link from i. w(i, j) = $|A_{ij}|$ where A_{ij} = {z/∃ directed connectivity begins from the node (i, j) and reaches z}. Choose the route with the highest length in N.

The data transfer through the node is computed as T(N) = $\sum_{i=1}^{n-1} w(i, i+1)$ where 1,2,3,....n is a route with the highest length of 'N'.

Lemma 12: For any connectivity (x, y) in N, w(x, y) = 1, if $d^{+}(y) = 0$.

Proof: w(x, y) = 1, if $|A_{xy}| = 1$, if A_{xy} = {y}, if $d^{+}(y) = 0$.

Lemma 13: Consider 'N' is node connectivity graph. After, T (N) = $\frac{n(n-1)}{2}$

Proof: Assume 'N' is the route with node group V (N) = {$x_1, x_2 . . . x_n$}. w (x_i, x_j) = $\frac{i+j}{2}$.

$$T(N) = \sum_{i=1}^{n-1} w\left(x_i, x_{i+1}\right) = 1 + 2 + \cdots + n - 1 = \frac{n(n-1)}{2}$$

Lemma 14: Consider 'N'is a cyclic graph. After, T (N) = n (n − 1).

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Proof: Consider 'N' is cyclic graph with node group V (N) = {x_1, x_2. . . x_n}. w(x_i, x_j) = n ∀(x_i, x_j) ε A(N). T (N) = $\sum_{i=1}^{n-1} w\left(x_i, x_{i_{+1}}\right) = 1 + 2 + \cdots + n - 1 = n(n-1)$

Lemma 15: Assume 'N' is the oriented star network graph and 'x' is centre node. After,

1. If $d^+(x) = 0$ or $d^-(x) = 0$ then I (C) = 1.
2. If $d^+(x) = l$ and $d^-(x) = m$ then I (C) = l + 2.

Proof: If $d^+(x) = 0$ or $d^-(x) = 0$, then w(x, y) = 1 or w(y, x) = 1, ∀y = x and route highest length is 1. So, T (N) = 1. If $d^+(x) = l$ and $d^-(x) = m$, then w (z, x) = l + 1 and w(x, y) = 1, ∀y, z = x and route z − y highest length is 2. So, T (N) = l + 2.

Lemma 16: Assume 'N' is n-dimensional based network graph. After, T (N) = 2(2n −1) − n.

Proof: Network connectivity from i to i + 1 where i = 0 to n, assigns weight $2^{n-i} - 1$. So, the highest length of route in n-dimensional butterfly network graph is n. Assume P = $x_0x_1 . . . x_n$ is the route. After, x_i ε i where i = 0 to n. So, T (N) = $(2^1 - 1) + (2^2 - 1) + . . . + (2^n - 1) = (2 + 2^2 + . . . + 2^n) - n = 2(2^n - 1)$.

Lemma 17: For each network graph N, 1 ≤ T (N) ≤ n (n − 1).

Proof: For (i, j) ε A (N), w (i, j) ≥ 1. So, T (N) ≥ 1. Assume P = (x_0, x_1. . . x_l) is the route of the highest l in N. T (N) = $\sum_{i=0}^{l-1} w(x_i, x_i + 1 \leq n + n + \_\ldots + nl \leq l.n \leq (n-1)\, n\ (\because l \leq n-1)$. So, 1 ≤ T (N) ≤ n (n − 1).

3.5. Power usage during network connectivity

Consider 'N' is the network graph. Assume six methods of power use functions on N during transfer and the resultant graphs to determine the expressions for power use of these graphs according to the power of N.

Lemma 18: Consider N_1 is the duplication node because of risk on N. Assume 'k' is the secluded nodes and link the duplicate node to every adjacent to every node of N.

Lemma 19: Create two groups X = {x_i} and Y = {y_i} related to the nodes of N. Build $x_i$neighboring to each node in G(v_i) and $y_i$neighboring to each node in $G^/(v_i)$ for every i = 1,2, ... ,p.

Lemma 20: Generate two groups X = {x_i} i = 1,2, ... ,p and Y = {y_j},j = 1, 2, ... , k. Create $x_i$neighboring to each node in $G^/(v_i)$ for every 'i' and each node of Y neighboring to each node of N.

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Lemma 21: Create two groups X = {x_i} and Y = {y_i} related to nodes of N. Provide x_i and $y_i$neighboring to each node in G(v_i) for every i=1,2, ... ,p.

Lemma 22: Generate two groups X = {x_i} and Y = {y_i} related to nodes of N. Generate $x_i$neighboring to every node in G(v_i) and $y_i$neighboring to every node in G(v_i) for every i = 1,2, ... ,p. After, remove the links of N.

Lemma 23: Create two groups X = {x_i} i = 1,2, ... ,p and Y = {y_j}, j = 1, 2, ... , k. Provide $x_i$neighboring to each node in G(v_i) for every i and each node of Y neighboring to every node of N. After, remove links of G.

4. Conclusion

Nowadays, the attention in analyzing the networks as frameworks of complicated structures has been robust. For studying economic and social networks, communication networks and technical systems, graph computational schemes have been broadly applied. It motivates us to identify the nodes that can communicate with several nodes and evaluate the network proximity. In this study, we modeled a graph theoretical framework for constructing WSN, localization and centrality for estimating the nearness via network reachability.

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