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David C. Wyld
Jan Zizka
Dhinaharan Nagamalai (Eds.)

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Preface

The Second International Conference on Computer Science, Engineering and Applications (ICCSEA-2012) was held in Delhi, India, during May 25–27, 2012. ICCSEA-2012 attracted many local and international delegates, presenting a balanced mixture of intellect from the East and from the West. The goal of this conference series is to bring together researchers and practitioners from academia and industry to focus on understanding computer science and information technology and to establish new collaborations in these areas. Authors are invited to contribute to the conference by submitting articles that illustrate research results, projects, survey work and industrial experiences describing significant advances in all areas of computer science and information technology.

The ICCSEA-2012 Committees rigorously invited submissions for many months from researchers, scientists, engineers, students and practitioners related to the relevant themes and tracks of the conference. This effort guaranteed submissions from an unparalleled number of internationally recognized top-level researchers. All the submissions underwent a strenuous peer-review process which comprised expert reviewers. These reviewers were selected from a talented pool of Technical Committee members and external reviewers on the basis of their expertise. The papers were then reviewed based on their contributions, technical content, originality and clarity. The entire process, which includes the submission, review and acceptance processes, was done electronically. All these efforts undertaken by the Organizing and Technical Committees led to an exciting, rich and a high quality technical conference program, which featured high-impact presentations for all attendees to enjoy, appreciate and expand their expertise in the latest developments in computer Science and Engineering research.

In closing, ICCSEA-2012 brought together researchers, scientists, engineers, students and practitioners to exchange and share their experiences, new ideas and research results in all aspects of the main workshop themes and tracks, and to discuss the practical challenges encountered and the solutions adopted. We would like to thank the General and Program Chairs, organization staff, the members of the Technical Program Committees and external reviewers for their excellent and tireless work. We sincerely wish that all attendees benefited scientifically from the conference and wish them every success in their research.

It is the humble wish of the conference organizers that the professional dialogue among the researchers, scientists, engineers, students and educators continues beyond the event and that the friendships and collaborations forged will linger and prosper for many years to come. We hope that you will benefit from the fine papers from the ICCSEA-2012 conference that are in this volume and will join us at the next ICCSEA conference.

David C. Wyld
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Networks and Communications

Communications Security and Information Assurance

Partitioning and Internetworking Wireless Mesh Network with Wired Network for Delivery Maximization and QoS Provisioning

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Abstract. Wireless mesh architecture is a first step towards providing high-bandwidth network coverage. This architecture has major drawback of losing the bandwidth over multiple hops thereby resulting in poor quality of service (QoS) at nodes separated by more than two hops. This paper proposes a three step approach to guarantee bandwidth demand at each node of the network thereby providing high quality of service even to nodes separated by large distances from each other. The authors have presented a novel method for clustering the nodes and load sharing amongst the clusters based on graph partitioning approach. This work also presents a system and method of integrating Wireless Mesh Networks (WMN) with wired network for further increase in the QoS.

Keywords: Partitioning, Internetworking, Wireless mesh network, IEEE 802.11s.

1 Introduction

The wireless mesh network (WMN) is an emerging technology to extend the use of wireless communication. Mesh architecture sustains signal strength by breaking long distances into a series of shorter hops. Intermediate nodes not only boost the signal, but cooperatively make the forwarding decisions based on their knowledge of the network. Such architecture provides high network coverage, spectral efficiency, and economic advantage. Throughout the paper we use the IEEE 802.11s standard for infrastructure mode WMN. The authors have chosen IEEE802.11s as the WMN because major part of this work focuses on providing a wired backup to mesh nodes, and this standard already has a protocol defined for internetworking between the 802.11 and non 802.11 networks. But this work can be generalized to optimize any infrastructure based wireless mesh network. For this reason this work does not differentiate between a Mesh Point (MP) and Mesh Access Point (MAP) as separate entities as both are sources of bandwidth demand. Therefore hereafter both these entities will be called nodes whereas the Mesh Portal Point (MPP) will be called the gateway node.

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At Layer 2 of WMN the crucial QoS parameter that can be delivered is the bandwidth demand of a node. It is a well known fact that wireless networks yield low throughput and poor QoS because they are bandwidth starved due to radio spectrum limitations. The authors suggest that if bandwidth demand at a node can be met; QoS constraints can be satisfied.

In subsequent sections the authors use a graph model of WMN to present a novel method of QoS provisioning in WMN. This work provides a three step approach to satisfy the bandwidth demand of all the nodes in a WMN.

- **Step I:** In order to share the load amongst gateways there has to be well defined clusters around the gateways. In [5] the authors have already provided a partitioning mechanism to create well defined clusters around gateways. This paper moves further and maps these partitions on to the Adjacency matrix of the graph model of WMN
- **Step II:** Using the concept of '*Supergraphs*' authors proceed to share the load amongst the partitions dynamically. The load sharing algorithm ensures that the under loaded partitions share the load of their neighboring overloaded partitions under certain mathematically validated constraints. This algorithm also ensures that there is no need to re-compute the partitions every time a node transits to a neighboring partition for load sharing.
- **Step III:** In case the constraints defined for load sharing in step II are not satisfied and nodes are still bandwidth starved, then the authors provide the partitions with a wired network backup. This step defines the set of constraints to be observed while transiting a node to the wired network. Although the authors' choice of network is Broadband over Powerline (BPL) but this work is not limited to BPL and is applicable to any wired Internet Protocol (IP) network. For more on BPL-WMN internetworking refer [12]

Note: Due to space limitations the authors have kept the contents of this paper limited to defining the mathematical constraints and presenting an algorithm for partitioning, load sharing and wired network interworking. In their coming paper authors have presented a detailed protocol between the gateways, core router and Dynamic Host Configuration Protocol (DHCP) server which is to be observed while implementing these algorithms. The authors have presented a centralized protocol to implement these algorithms

2 Motivation and Related Work

WMN suffer from the limitation of throughput drop and bandwidth loss over multiple hops, Li et al. [4]. Reducing the distance between nodes in the WMN loses the very purpose of mesh networking which is to provide wider coverage area with minimal infrastructure. Robinson et al.[2] and Aoun et al. [3] propose to increase throughput by introducing multiple gateways . Placement of multiple gateways throughout the mesh does not always result in more throughput as proved by [5]. In previous literature Xie et al.,[7] and Bejerano et al.,[8] have suggested to improve this shortcoming by creating clusters around each gateway and then make provisions for load sharing amongst these clusters. Nandiraju et al.,[6] and Bejerano et al., [8] have pointed out that by clustering the nodes in to non overlapping clique increases the throughput of networks. But partitioning the graphs in itself is an NP hard problem. With every change in load or transition of nodes amongst partitions, there is need to re-compute the partitions. This situation gets worse when nodes move to another network rather than another partition as the nodes are no longer a part of the same WMN. This is called 'loss of wireless neighborhood' problem. Current literature addresses this by emphasizing on the spanning tree computation periodically, thereby identifying all the nodes belonging to the same network. Partitioning the network every time with a changing load and node scenario is a serious problem as the whole network remains non-operational throughout this computation thereby reducing the network throughput. In this paper, authors have made a novel attempt to represent the network graph model in its adjacency matrix form. The adjacency matrix representation of the graph model of WMN preserves the neighborhood of each and every node, irrespective of whether it moves to a neighboring partition or to another network. The adjacency matrix representation eliminates the need to recreate partitions, even when the WMN is interworked with another network. This method increases the network throughput because it creates the partitions only once during the network design phase. Once the partitions are created, they are simply mapped onto the adjacency matrix of the graph model of WMN, which is done by our graph partitioning algorithm. Thereafter there is no need to continuously partition the network with changing load as in [7] and [8].

Contributions of this paper are

- One time partitioning of WMN.
- System and method to map partitions of a WMN on to the adjacency matrix of its graph model.
- System and method to transit nodes amongst these partitions directly using the adjacency matrix.
- System and method to interwork the WMN with another wired network and mapping the same onto the global adjacency matrix.
- Defining a set of mathematical bounds and constraints for load sharing and node transitions amongst partitions.
- A locally recursive algorithm for node selection and transition to the BPL or any other wired network.
- Nodes continue to remain part of WMN with their neighborhood preserved in the adjacency matrix, irrespective of whether they transit to another partition or to another wired network.

3 Notations and Assumptions

Let undirected planar Graph $\mathcal{G} = (\mathcal{V}, \mathcal{E})$ represent a WMN '*W*' with *n* number of nodes and gateways. The graph nodes and gateways represent the vertices and wireless links are represented by edges between the nodes. Self loops are not permitted. Let $\mathcal{V}$ be the set of vertices $v_1, v_2, \cdots, v_n$ such that $|\mathcal{V}| = \mathrm{n}$ and $\mathcal{E}$ be the set of edges $e_1, e_2, \cdots, e_m$ such that $|\mathcal{E}| = \mathrm{m}$. Total number of gateways/MPP is assumed to be k. Then, $\mathcal{G}_1, \mathcal{G}_2, \cdots, \mathcal{G}_k$ will be the k distinct partitions of graph $\mathcal{G}$, each with one gateway.

Let P_i denote a node corresponding to the contracted subgraph $\mathcal{G}_i$ in the supergraph of the partitioned $\mathcal{G}$. Let n_i be the number of vertices in $\mathcal{G}_i$. Let $\mathcal{V}_i$ be vertex set for $\mathcal{G}_i$ $\forall\, i = 1 \dots k$. . Let $\mathcal{A}(\mathcal{G})$ be the Adjacency matrix corresponding to graph $\mathcal{G}$ and $\mathcal{A}(\mathcal{G}_i)$ be the adjacency matrix for partition $\mathcal{G}_i$.

$\mathcal{B}(\mathcal{G})$: Incidence matrix corresponding to graph $\mathcal{G}$
$\mathcal{B}(\mathcal{G}_i)$: Incidence matrix corresponding to the partition i of graph $\mathcal{G}$
$\mathcal{C}(\mathcal{G})$: Cycle matrix corresponding to graph $\mathcal{G}$
$\mathcal{C}(\mathcal{G}_i)$: Cycle matrix corresponding to the partition i of graph $\mathcal{G}$

Let C_i be the capacity of i^{th} gateway in partition i. $Q\{\mathcal{A}(\mathcal{G}_i)\}$ denotes QoS available at partition $\mathcal{G}_i$

R_i : current bandwidth demand (load) of partition $\mathcal{G}_i$
U_i : Upper working demand limit of QoS for partition $\mathcal{G}_i$
L_i : Lower working demand limit of QoS for partition $\mathcal{G}_i$

Under normal load conditions if demand of node n_i is d_i then total load of partition $\mathcal{G}_i$ with n_i number of nodes is

$$R_i = \sum_{j=1}^{n_i} d_j \ \forall\, i = 1, \dots, k$$

Overload of a partition is given by

$$overload(\mathcal{G}_i) = \begin{cases} 0, & if\ R_i < C_i \\ R_i - C_i, & Otherwise \end{cases}$$

4 Step I: Selective Partitioning

Selective Partitioning is called so because a graph is partitioned with certain constraints. The constraint in our case is that each partition must have exactly one gateway. This algorithm assumes that initial partitioning of WMN is already done. A WMN can be partitioned using any of the graph partitioning procedures available in literature [10]. Alternatively researchers can also use the node marking and partitioning algorithms presented by authors in [5] and [9]. First we present an observation on $\mathcal{A}$

$\mathcal{A}(\mathcal{G})$ can be written in block diagonal form as

$$\mathcal{A}(\mathcal{G}) = \begin{bmatrix} [\mathcal{A}(\mathcal{G}_1)] & \cdots & & 0 \\ \vdots & [\mathcal{A}(\mathcal{G}_2)] & & \vdots \\ & & \ddots & \\ 0 & \cdots & & [\mathcal{A}(\mathcal{G}_k)] \end{bmatrix}_{n\times n}$$

Based on this observation we present the Algorithm I for selective graph partition

1. From WMN create $\mathcal{G}(v, e)$ with one gateway
2. From $\mathcal{G}(v, e)$ construct $\mathcal{A}(\mathcal{G})$.
3. Now take $[\mathcal{A}(\mathcal{G})]_{n\times n}$ and identify the 1^{st} gateway of the WMN represented by $\mathcal{G}(v, e)$

4. Around the first gateway create a partition $[\mathcal{A}_{11}]_{\mathrm{n}_1\times\mathrm{n}_1}$by relabeling / visiting nodes and demand augmentation of nodes in $[\mathcal{A}(\mathcal{G})]$ against gateway capacity C_1. Refer authors' paper [9] for complete procedure on node marking and relabeling.
5. Now identify the second gateway in $\mathcal{A}_2 = [\mathcal{A}] - \begin{bmatrix}\mathcal{A}(\mathcal{G}_1) & 0\\ 0 & \ddots\end{bmatrix}$ now create $[\mathcal{A}_{22}]_{\mathrm{n}_2\times\mathrm{n}_2}$. Relabel $\mathcal{A}(\mathcal{G})$ such that all the nodes adjacent to the second gateway have their corresponding rows and columns next to the second gateway row and column thereby creating the second matrix $[\mathcal{A}_{22}]$.
6. Now get $\mathcal{A}_3 = [\mathcal{A}] - \begin{bmatrix}\mathcal{A}(\mathcal{G}_1) & \cdots & 0\\ \vdots & \mathcal{A}(\mathcal{G}_2) & \vdots\\ 0 & \cdots & \ddots\end{bmatrix}$and create$[\mathcal{A}_{33}]_{\mathrm{n}_3\times\mathrm{n}_3}$by relabeling / node visiting fundamental on $[\mathcal{A}_3]$
7. Repeat step 4 to 6 till the last partition$[\mathcal{A}_\mathrm{k}]$ is formed such that $\sum_{\mathrm{i}=1}^{\mathrm{k}} \mathrm{n}_\mathrm{i} = \mathrm{n}$, this leads to k disjoint initial partitions
8. Hence WMN in the initial partition looks like $\mathcal{A}(\mathcal{G}) = \begin{bmatrix}[\mathcal{A}(\mathcal{G}_1)] & \cdots & & \\ \vdots & [\mathcal{A}(\mathcal{G}_2)] & & \vdots\\ & & \ddots & \\ & \cdots & & [\mathcal{A}(\mathcal{G}_\mathrm{k})]\end{bmatrix}$obtained by relabeling and node visiting. Thus the adjacency matrix has all the partitions defined by their own adjacency matrix right across the diagonal. The other elements of the adjacency matrix are as before corresponding to the various rows and columns as in the initial adjacency matrix. Thus initial set of disjoint partitions in $\mathcal{A}$ matrix is created
9. End

Note: The partitioned adjacency matrix of step 8 has to be created only once

From Algorithm I we get the WMN partitioned in k partitions each having one gateway. We denote the i^{th} partition by subgraph $\mathcal{G}_\mathrm{i}$ and its adjacency matrix by $\mathcal{A}(\mathcal{G}_\mathrm{i})$. It can be seen that $\mathcal{V}_\mathrm{i} \cap \mathcal{V}_\mathrm{j} = \emptyset \forall \mathrm{i},\mathrm{j} \in [\,1 \ldots \mathrm{k}] \exists \mathrm{i} \neq \mathrm{j}$. Hence any vertex in $\mathcal{G}_\mathrm{i}$can be made as gateway. Each $\mathcal{G}_\mathrm{i}$ will have n_i number of nodes. All these partitioned matrices must satisfy the condition $\mathcal{B}(\mathcal{G}_i) \times [\mathcal{C}(\mathcal{G}_i)]^T = \mathcal{C}_i \times [\mathcal{B}(\mathcal{G}_i)]^T = 0 \ (mod\ 2)$ where superscript T denotes the transposed matrix [11].

5 Step II QoS Provisioning by Load Sharing

Before moving to the load sharing algorithm we define a few terms and formulate some theorems.

Definition I: A 'Cut set' $\mathcal{E}_{ij}$ is set of all the edges between two partitioned subgraphs $\mathcal{G}_i$and $\mathcal{G}_j$of $\mathcal{G}$ such that for each edge both its incident vertices belong to two different partitions $\mathcal{G}_i$ and $\mathcal{G}_j$

Definition II: A 'Supergraph' $\mathcal{G}^2$ of $\mathcal{G}$ is the graph obtained such that each vertex $P_i$of $\mathcal{G}^2$represents the partition subgraph $\mathcal{G}_i$and edge e_i is the edge belonging to the cut set $\mathcal{E}_{ij}$. Fig1

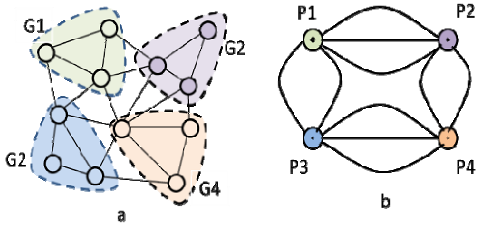

Fig. 1. a: A Graph G with its 4 partitions. **b:** Supergraph$\mathcal{G}^2$of$\mathcal{G}$.

We present following set of properties of the Supergraphs

Property I: Since a WMN with k gateways will have k partitions therefore number of vertices in $\mathcal{G}^2$will be k.

Property II:$\mathcal{G}^2$ will be a multigraph because there can be many edges for each pair of partition cut set.

Property III:$\mathcal{G}^2$ can also be a complete graph of k vertices i.e. K_k graph. Consequently the following proof is needed.

Lemma 1: *If $\mathcal{G}^2$ is a super graph of $\mathcal{G}$and if $\mathcal{G}$ is planar $\mathcal{G}^2$ will also be planar*

Proof: By contradiction let us assume that $\mathcal{G}^2$ is non planar. Then $\mathcal{G}^2$ will have intersecting edges. Now since $\mathcal{G}$ is contracted to $\mathcal{G}^2$. This implies that $\mathcal{G}$ also has intersecting edges. As a result $\mathcal{G}$ has to be non planar. Thus by contradiction since $\mathcal{G}(\mathrm{v,e})$is a planar therefore $\mathcal{G}^2 \cong \mathcal{G}(\mathrm{v,e})$is also planar. **(Q.E.D)**

The implication of the above lemma is for the reinforcement of fact that any node transition from one partition to another does not contradict the planar structure of the graph. The transition of nodes can happen from one partition to another if the two partitions are neighbors. Partition/node at one hop distance are called neighbors.

In $\mathcal{A}$ we retain only the partitions on the diagonal and replace remaining elements by 0. This matrix we call as $\mathcal{A}'$. Then,

$$\Rightarrow \mathcal{A}'(\mathcal{G}) = \overset{\quad\leftarrow n_1 \rightarrow\leftarrow n_2 \rightarrow \cdots \rightarrow n_k \leftarrow}{\begin{bmatrix} [\mathcal{A}(\mathcal{G}_1)] & & & \\ & [\mathcal{A}(\mathcal{G}_2)] & & \\ & & \ddots & \\ & & & [\mathcal{A}(\mathcal{G}_k)] \end{bmatrix}} \begin{matrix} n_1 \\ n_2 \\ \vdots \\ n_k \end{matrix}$$

Here $\mathrm{n_i}$ is number of vertices in partition subgraph $\mathcal{G}_\mathrm{i}$. Let, $\mathcal{A}''(\mathcal{G}) = \mathcal{A}(\mathcal{G}) - \mathcal{A}'(\mathcal{G})$. Then,

$$\mathcal{A}''(\mathcal{G}) = \mathcal{A}(\mathcal{G}) - \mathcal{A}'(\mathcal{G}) = \begin{bmatrix} [0] & [\mathcal{A}]_{n_1\times n_2} & [\mathcal{A}]_{n_1\times n_3} & \cdots & [\mathcal{A}]_{n_1\times n_k} \\ [\mathcal{A}]^T{}_{n_1\times n_2} & [0] & \ddots & & \vdots \\ \vdots & & & \ddots & \\ [\mathcal{A}]^T{}_{n_1\times n_k} & & \cdots & [\mathcal{A}]_{n_{k-1}\times n_k} & [0] \end{bmatrix}$$

Proposition 1: *$\mathcal{P}_i$ has 'q' paths to $\mathcal{P}_j$ iff there are q number of non zero entries in $[\mathcal{A}]_{n_i \times n_j}$ of matrix $\mathcal{A}''(\mathcal{G})$*

Proof: The number of non zero entries in $[\mathcal{A}]_{n_i \times n_j}$ is the edge cut set of $\mathcal{P}_i$, and $\mathcal{P}_j$. Now without loss in generality, $\mathcal{P}_i$ can be termed as node, $\forall$ i = (1…k) and if $\mathcal{P}_i$ is neighbor of $\mathcal{P}_j$ then it can be joined by edges from their edge cut set.

If $\mathcal{A}(\mathcal{G}_i)$ is operating at its limit U_i then node need to be transited to $\mathcal{A}(\mathcal{G}_j)$ operating at limit L_j. In the next proposition we define the operation in order to balance the load on the $\mathcal{G}^2$ graph.

Proposition 2: For any partition $\mathcal{P}_i$ if the cumulative QOS requirements are not met then following operations can be performed

Transit the node to the neighboring partition.

Create a partition in the sub partition

Proof: Consider the k partitions as created earlier. These partitions operating under normal load must satisfy following condition

$$\lceil Q(\mathcal{A}(\mathcal{G}_i)\rceil_{n_i} \geq Q(\mathcal{A}(\mathcal{G}_i))|_{n_i} \geq \lfloor Q(\mathcal{A}(\mathcal{G}_i)\rfloor \qquad \forall i \in [i \ldots k]$$

This is same as $U_i \geq R_i \geq L_i$ (normal load constraint)

To satisfy the QoS requirement if a node is shifted to powerline network, then it is same as further partitioning of partition $\mathcal{A}(\mathcal{G}_i)$. Let us assume that $\mathcal{A}(\mathcal{G})_i^j$ is the j[th] partition of $\mathcal{G}_i$. Likewise, if there are ω sub partitions of $\mathcal{A}(\mathcal{G}_i)$ then the following condition holds good

$$\mathrm{Q}(\mathcal{A}(\mathcal{G}_i)) = \sum_{j=1}^{\omega} Q\left(\mathcal{A}(\mathcal{G}_i^j)\right)$$

where

$$\sum_{i=1}^{k} n_i = n = total\ number of nodes$$

Now if $Q(\mathcal{A}(\mathcal{G}_i))|_{n_i} \geq \lceil Q(\mathcal{A}(\mathcal{G}_i)\rceil_{n_i}$ then following can be carried out

1. Transiting q nodes of partition i to neighboring partition such that following condition holds good

$$Q(\mathcal{A}(\mathcal{G}_i)|_{n_i - q} \leq \lceil Q(\mathcal{A}(\mathcal{G}_i))\rceil_{n_i}$$

2. Create a partition in $\mathcal{G}_i$ on n_i nodes such that $\lceil Q(\mathcal{A}(\mathcal{G}_i))\rceil^{n_i} \geq Q\big(\mathcal{A}(\mathcal{G}_i)\big)|_{n_i - p}$ and $\left\lceil Q(\mathcal{A}(\mathcal{G}_i^p)\right\rceil > Q\big(\mathcal{A}(\mathcal{G}_i)\big)|_p$ (For example: This means p nodes in n_i partition are put on to power line network.)

Each node now can be represented in the $\mathcal{G}^2$ graph with k nodes as $\mathcal{P}_1, \ldots, \mathcal{P}_k$ and corresponding $\mathcal{A}$ matrix as $\mathcal{A}(\mathcal{G}_i)$ and dynamic load as $Q\ (\mathcal{A}(\mathcal{G}_i))$ where i = 1. . . k. This means that $Q\big(\mathcal{A}(\mathcal{G}_i)\big) = Q(\mathcal{P}_i)$. Now each $\mathcal{P}_i$ can either be underloaded or overloaded as mentioned before. So $\mathcal{P}_i$ belongs to either U_i or L_i hence in graph $\mathcal{G}^2(Q(\mathcal{P}_i) \in \{U_i, L_i\}$, e) $\forall i = \{1...k\}$

Theorem 1: *Consider Graph $\mathcal{G}^2$ ({U,L}, e), where U is set of vertices operating at overloaded condition and L is set of nodes operating at under load condition with $\mathcal{P}_1, \ldots, \mathcal{P}_k$ nodes and also consider that for $\mathcal{P}_1, \ldots, \mathcal{P}_k$, theorem 2 is satisfied; then with k partitions the load can be balanced by approach of node transition iff their bipartite graph with U and L exist for $\mathcal{G}^2$.*

Proof: If overloaded nodes (partitions) can transit nodes inside the partition such that the under loaded partition will have more to accommodate as compared to the loaded partition hence such condition becomes the necessary condition. The proof of sufficiency follows from the contradiction. Consider that $\mathcal{G}^2$ $(\{U,L\}, e)$ is not bipartite then it means that one of the overloaded partition nodes$\mathcal{P}_i$ is in neighborhood of another overloaded partition $\mathcal{P}_j$. Thus the transition of nodes from one overloaded partition (node) to the other overloaded partition can be expected. Hence ***Bipartite graph formation between U_i and L_i nodes is necessary and sufficient condition for node transitions in $\mathcal{G}^2$graph***.

5.1 Constraints to Be Followed for Node Transitions from One Partition to Another

There are three major constraints which must be followed to enable movement of a node from one partition $\mathcal{G}_i$ to another neighboring partition $\mathcal{G}_j$

1. $R_i \geq U_i$
2. $R_j \leq L_j$
3. $\mathcal{G}^2$ $(\{U,L\}, e)$ must be bipartite between U and L

Observation I: *A node p transiting from one partition i to another partition j needs only relabeling within the global adjacency matrix $\mathcal{A}$ such that row and column corresponding to node p in $\mathcal{A}$ moves from $\mathcal{A}(\mathcal{G}_i)$to $\mathcal{A}(\mathcal{G}_j)$. Since this transition is only affecting the active/passive table entries of partitions i and j gateways the whole network need not be defunct, only partitions i and j can stop their operations. There is also no need to re-compute the partitions as in earlier cases.*

6 Step III: Mathematical Constraints for Node Transition to Powerline

In this step we prove that introducing a powerline network to a node within the WMN is analogous to the partitioning procedure performed recursively. The introduction of the powerline network to any node within the WMN is defined as two part process. First we define constraints on identifying the node which can be moved to powerline. Secondly we explain how the node remains connected to the WMN and preserves its integrity even when it is on another wired network. This will ensure that the node can be recalled to exactly the same location within same neighborhood in spite of its association to a wired network which in this case is BPL.