

ABSTRACT

The increasing crime rate in smart cities demands a “smart” way to handle the situation. The objective of this article is to propose a methodology to strategically place a minimum number of police patrollers at road junctions such that positioning of the patrollers will achieve maximum visibility of the given geographical command efficiently. The notion of dominating set is applied to find the strategical locations at which the patrollers have to be placed. Also to allocate given patrollers optimally on these strategical locations we employ a priority based allocation to allocate them on the nodes that demand a higher importance. To experiment, the proposed model is tested for a place in Chennai, Tamilnadu, India. The results show that by only placing the patrollers on 1/3 of the total number of junctions, spatial visibility of all the junctions in the geographic command can be achieved. If provided with the number of patrollers available to be allocated, then the algorithm can optimally allocate the given patrollers

I. INTRODUCTION

One of the main objectives of the police patrols is to be omnipresent. The other roles they play in a community are maintaining public relations, investigating accidents, stopping crimes, and responding to the emergency calls. Police patrols play a significant role in preventing the crime rate. To achieve the maximum visibility of a geographic command, it is necessary for the patrollers to be physically or virtually present at almost all the road junctions. But, allocating the patrollers at each road intersection is not feasible. This can be attributed to various reasons like lack of human resource, financial constraints etc. Hence, a mechanism is required to strategically allocate the patrollers only at specific locations to cover the whole geographic space. Typically, police patrols are allocated at locations where a significant crime activity is observed in the past and based on the crime trend forecasted statistically.

Since 1960's the need for computer system in efficient allocation of police patrol is recognized. Extensive research has been carried out and several computer tools and algorithms have also been developed. The most widely known computer system is the Law Enforcement Manpower Resource Allocation System (LEMNAS) that was developed based on the St. Louis resource allocation system developed for St. Louis Police Department [1]. An alternative model is the Patrol Car Allocation Model (PCAM), by [2], is a computer program that helps police department to allocate police patrol based on work load analysis, call for service (CFS), and response time for the service requested on specific geographic command. The system expects suitable constraints and objective functions framed by the police department as its input and determines the total number of patrol officers a department needs to meet specified performance level. PCAM analyzes the problem primarily based on overlay tours that patrol cars take in a precinct, which was a unique technical feature compared to other existing tools of that time. The PCAM is insensitive to location.

Recently, [Curtin et.al] modelled the patrol allocation problem as a Maximal Coverage Location Problem (MCLP) [3]. Their proposed model Police Patrol Area Covering (PPAC) seeks to find the solution to the problem of locating facilities (patrol cars) to the crime incident locations, as the set of locations that should be maximally covered within a given acceptable service distance. The PPAC model is based on two main assumptions 1) Response time of the police to a service is a measure of performance. 2) Patrol cars are dispatched from a central location to service a call. One of the drawbacks of the system is the constant interaction of user to the system for querying, custom selection, and several exports and imports to switch between multiple softwares.

A network in general is a connection of individual components which interact with each other to allow flow of information in a certain form. Network theory, a part of graph theory, is the study of networks and the nature of connectivity between the components in the network. It is very useful in modelling problems like rumor spread in a network to find the actual source [4], interdependency of biological diseases in a human body [5] etc. It is also widely applied in natural language engineering [6], epidemiology [7], routing in ad-hoc networks [8], social sciences [9] etc.

In this article, we propose a network theory based approach to optimally select the locations for positioning the patrollers to achieve maximum visibility by using the concept of dominating set and a priority based allocation method. The rest of the article is organized as follows. The formal definition and explanation of dominating set and dominating set problem is described in Section 2. Section 3 describes the proposed methodology to allocate police patrollers. Section 4 presents the experiments and results.

II. DOMINATING SETS

The Dominating Set or Dominating vertices of a given graph G having vertex set V and edge set E denoted as $G(V, E)$, can be defined as the subset of vertices denoted as DS such that every vertex not in the set DS is adjacent to at least one of the vertex in the set DS . A given graph can have a different set of dominating vertices. A dominating set with minimum number of vertices is called minimum dominating set and the number of vertices in the minimum dominating set is called domination number. The problem of finding dominating vertices for a given graph with dominating set size less than or equal to given constant K is a classical NP-Complete problem. There exists no polynomial time algorithm to find the exact solution but a near optimal solution to the problem can be found using approximation algorithms.

III. PROPOSED METHODOLOGY

The proposed allocation model is carried out in two phases. Firstly, a naïve greedy based approach [10] is employed to find the minimum dominating locations from the given road network map. Secondly, to allocate the given number of patrollers to certain specific dominating locations, a priority based allocation method is proposed. The schematic diagram of the proposed patrol allocation model is shown in Fig. I

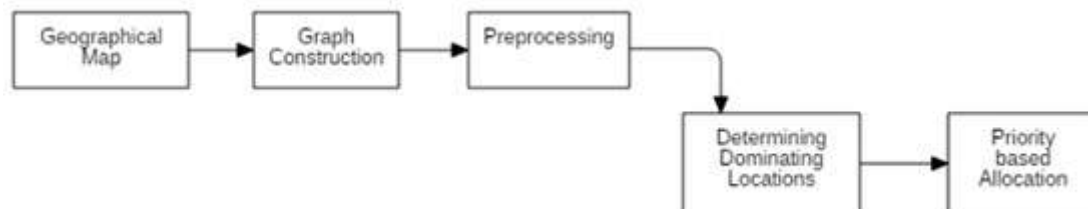


Fig. I Schematic diagram of the proposed system

The allocation system accepts the geographical map of the area, where patrollers have to be allocated, as the primary input for the model. A graph is then constructed from the map with the road intersection as nodes/vertices and the roads as edges. Since, the geographical map of an area includes information about all transport networks such as railway lines, airways etc., preprocessing the graph is necessary to extract only the road network and eliminate information about other mode of transport. The adjacency matrix of the preprocessed graph, a square matrix which represents and preserves the actual interconnection between nodes in the graph, is used for computation. A sample graph and its adjacency matrix are shown in Fig. II.

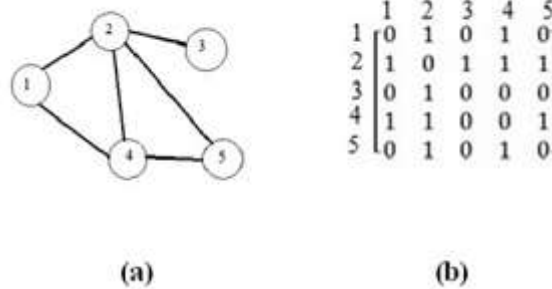


Fig. II Sample graph (a) and its corresponding adjacency matrix (b)

PHASE 1

Given the adjacency matrix of a graph $G(V, E)$ with V vertices and E edges, an empty array *status* of size equal to the number of vertices is defined to store the current status of each vertex in the graph. For a particular node in the graph, status 0 indicates that it is not visited; 1 indicates that it is visited or it is adjacent to a dominating vertex and 2 indicate that it is a dominating vertex.

$$status = \begin{cases} 0, & \text{Not Visited} \\ 1, & \text{Visited} \\ 2, & \text{Dominating vertex} \end{cases}$$

Initially the status of all the vertices is assigned to 0. A vertex is said to be dominating if it has the maximum connectivity among the entire vertex set V in the graph. Since, the degree of a vertex is a proper illustration of connectivity it can be said that the vertex is dominating if it has maximum degree or maximum degree centrality. When such a dominating vertex is found, the status of the vertex is assigned 2 indicating a dominating vertex and the status of the neighboring vertices connected to it is given status 1. A sub graph is generated by eliminating the dominating vertex (vertices) and its edges incident on it from the given graph. Further dominating vertices are found from the generated sub graph. The process continues until no more vertices has its status assigned to 0. Finally, all the vertices with its status marked 2 contribute to the minimum dominating set for the given graph.

The minimum dominating set obtained for the sample network is shown in Fig. III. The vertices labelled 2 and 4 encircled in blue are the dominating locations after applying the greedy algorithm whose status value is 2. The nodes encircled in yellow are the visited nodes whose status value is 1.

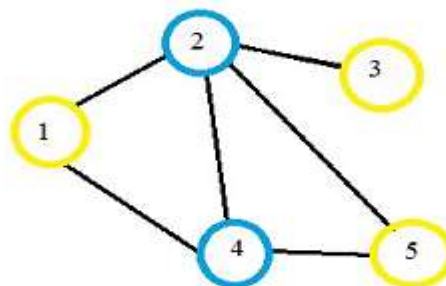


Fig.III Dominating vertices encircled in blue color and visited nodes encircled in yellow color for the sample graph.

PHASE 2

If the number of vertices in the minimum dominating set denoted as l obtained from the greedy algorithm is equal to the number of given patrollers k then the patrollers are positioned at all the dominating locations. If the value of l is greater than the number of patrollers k which is to be allocated, then a mechanism is required to select only k number of locations from the dominating set. To select these locations a priority based allocation is employed. Initially, for each individual road in the network a numerical priority is assigned. The priority for a

road is determined based on different features that a road exhibit in the network. For instance, a road with considerable civilization activity; that have schools, apartments, hospitals are some potential candidate for higher priority roads and a road like highway or main road; which have minimal civilization activities but with significant transport activities are some potential candidate for lower priority roads. Table1 describes the category of roads and their corresponding priorities used for allocation. The highways that are classified as Living Street is given maximum priority and the roads classified as Primary is given minimum priority.

Table 1: Classification of Roads and Their Respective Priorities.

S.no	Category	Priority
1	Primary Highway	1
2	Secondary Highway	2
3	Tertiary Highway	3
4	Road	4
5	Service roads	5
6	Pedestrian/footway	6
7	Living street	7

For each vertex in DS, the weighted sum of priorities of all its incident edges is calculated. Let the number of dominating vertices in DS be n each having $m > 1$ edges e_j incident to it, then the weighted sum of priorities of all the edges for each dominating vertices w_i can be formulated as:

$$w_i = \sum_{j=1}^m \text{priority}(e_j), \quad i = 1, 2, 3, \dots, n \quad (1)$$

The calculated sum of weights is a better illustration of connectivity and the importance of that junction in the network. The weights of the dominating vertices are sorted in descending order and first k vertices are chosen as the potential nodes/junctions which require significant attention as compared to other junctions.

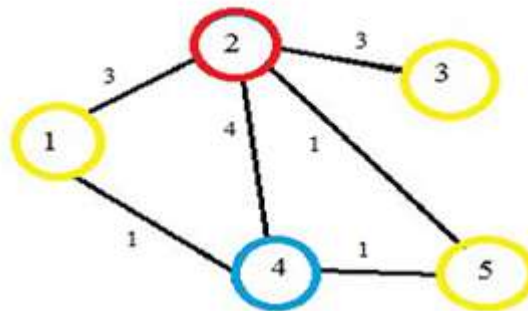


Fig. IV Highest priority nodes for given $k (=1)$ to be allocated

For the sample graph, it is found that the domination number l is 2. If the value of k is chosen as 1, then we have to choose one among the two dominating vertices. Arbitrarily the priorities are assigned to the edges as shown in Fig. IV and the priority based allocation is carried out. If the weighted sum of priorities of edges are calculated for each dominating vertex, then $w_2 = 11$ and $w_4 = 6$. Clearly, $w_2 > w_4$ hence, the vertex labelled 2 is the optimal allocation for given k shown in Fig. IV.

Following is the complete pseudo code of the proposed allocation algorithm:

```

N= No_of_Vertices;
E= No_of_Edges;
K= No_of_Patrollers_to_be_allocated;
G= Adjacency Matrix (N X N);
Status= [ ];
W=[ ];
P=[ ];
    
```



```
// Phase 1
while (exists(Status)){
    D= central (G);
    Status [D] =2;
    DS=DS+D;
    Status [neighbors (D)] =1;
    G=G-{D};
}
//Phase 2
foreach vertex p in DS{
    wp =  $\sum_{j=1}^m$  priority(ej);
}
sort(w, desc);
choose_top_k_vertices (w,k);
```

The variables *Status* and *P* are the arrays to store the current status and priority of each node in the graph and variable *W* denotes the array to store the weighted sum of priorities of incident edges of each dominating vertex. The function *exists*() will return true if there exists a node with status 0 in the graph G. The function *central*() returns the index node which has maximum degree or maximum degree centrality measure and function *priority*() returns the priority of a particular edge.

Finally, the chosen *k* vertices/ junctions are allocated with the given patrollers.

IV. EXPERIMENTS AND RESULTS

The system is experimented by taking a place located in Chennai, Tamilnadu, India. The map used for analysis is extracted from OpenStreetMap [11] in .OSM format. The .OSM (XML) file is then converted into a network of nodes (road junctions) and edges (roads). The OpenStreetMap of the chosen area is shown in Fig. V highlighted in a white shaded rectangle.



Fig. V Geographical map of the chosen place highlighted in white shaded region

The graphical network with edges and nodes is constructed from the given OpenStreetMap using SUMO [12], a traffic modelling tool. The nodes and edges file of the resultant network is parsed carefully to eliminate railway fly-overs and crossings. The graph with only road lines will be taken as an input to this proposed allocation system. The graphical representation of the map after preprocessing is shown in Fig. VI. The circles filled with red color indicate the road junctions and the black lines represent the roads.

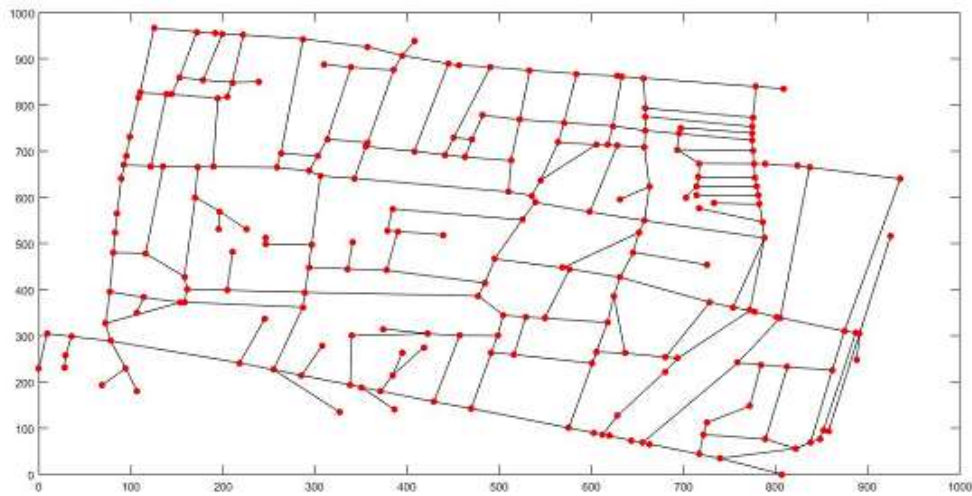


Fig. VI Graphical representation of the OpenStreetMap after preprocessing

After preprocessing, the graph shown in Fig. VI has 219 nodes (junctions) and 289 edges (including streets, roads, and highways) in total. The adjacency matrix for this graph is generated to find the dominating junctions. The first phase of the algorithm yields an output as shown in Fig. VII. The nodes marked with red colored '*' in the figure depicts the set of minimum dominating vertices. It can be seen that for the chosen graph of 219 vertices 72 are dominating which is approximately 1/3 (33%) of the total number of nodes.

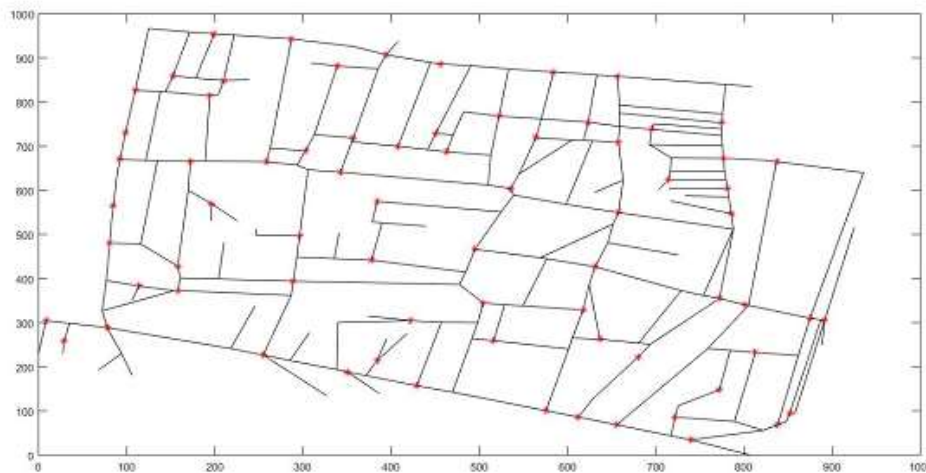


Fig. VII Dominating vertices highlighted with red colored '*'

If the given number of patrollers (=40) is equal to the number of vertices in the dominating junctions then the patrollers are allocated accordingly, else the dominating vertices are optimized based on the priority of each road to allocate the patrollers to the junctions. In this case, the number of vertices in the dominating sets is 72 which are greater than the number of patrollers (40) to be allocated. So, in the next phase each road in the network is assigned with a priority specified in Table 1. Then for each node in the dominating set, the weighted sum of priority of its incident edges is calculated using (1) and sorted in descending order.

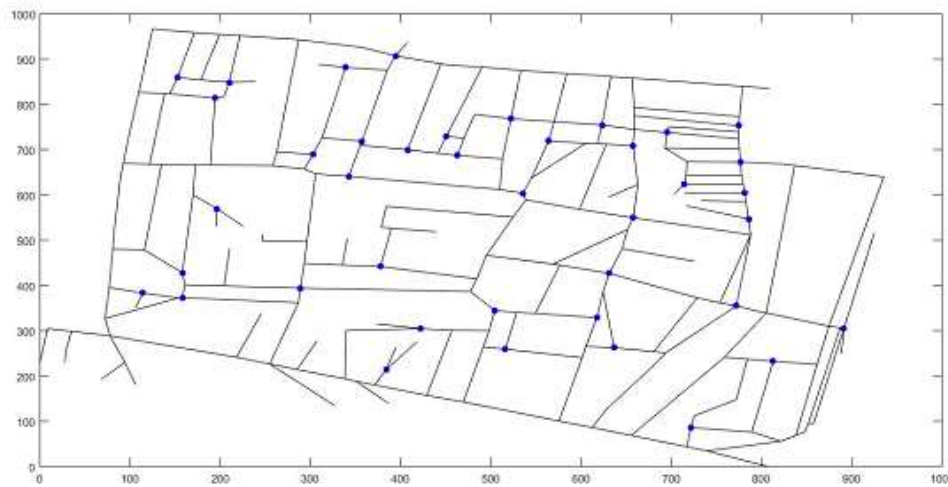


Fig. VIII Top 40 high priority optimal junctions where the given ($k=40$) patrollers will be allocated.

Since, only 40 patrollers are to be allocated the first 40 nodes with maximum weights are chosen to be the potential allocation junctions. Fig. VIII, shows the top 40 most dominating vertices in the given graph. The junctions marked with blue discs are the final patrol allocation centers.

V. CONCLUSION AND FUTURE WORK

In this article the problem of patrol allocation is studied and modelled from the view point of network theory using the notion of dominating sets and from the results it can be seen that it yields a feasible solution to the problem.

Though the proposed method offers optimal allocation of given patrollers, there are opportunities to improvise the algorithm in many aspects. Firstly, the greedy algorithm employed to find the minimum dominating set can be optimized further. Secondly, the assignment of priority in priority based allocation is merely based on the category of the road which is a static priority assignment. In addition to it if the priorities are assigned dynamically with respect to the crime rate observed in the particular geographic command, then the allocation of patrollers will be more efficient and dynamic

VI. REFERENCES

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