Implicit domain of i, j is the set of nodes including gateways (W) but excluding the source s and sink t.

Nodes, Links, Backbone nodes and links. Let x_i be a node and e_{ij} be an edge (incident with nodes x_i and x_j) in the original input network. The backbone-graph is a subgraph of this graph, and is denoted by node set $\{y_i\}$ and edge-set $\{b_{ij}\}$.

$$\forall i, \qquad 0 \leq x_i \leq 1 \tag{1}$$
$$\forall i, j, \qquad 0 \leq e_{ij} \leq 1 \tag{2}$$
$$\forall (i, j) \notin \text{LOS}, \qquad e_{ij} = 0 \tag{3}$$
$$\forall i, \qquad 0 \leq y_i \leq x_i \tag{4}$$
$$\forall i, j, \qquad 0 \leq b_{ij} \leq e_{ij} \tag{5}$$
$$\forall i, j, \qquad e_{ij} = e_{ji} \tag{6}$$
$$\forall i, j, \qquad b_{ij} = b_{ji} \tag{7}$$
$$\forall i, j, \qquad e_{ij} \leq \frac{1}{2}(x_i + x_j) \tag{8}$$
$$\forall i, j, \qquad b_{ij} \leq \frac{1}{2}(y_i + y_j) \tag{9}$$
$$\forall w \in W, \qquad x_w = y_w = 1 \tag{10}$$

Coverage. Each area is covered by at least one node in the backbone, here T_{ij} is 1 if target j is covered by a node i. Two alternate equations:

$$\forall \text{ target } j, \qquad \sum_{i \mid T_{ij}=1} y_i \geq 1 \tag{11}$$
$$\forall \text{ target } j, \qquad \sum_{i} (T_{ij} \times y_i) \geq 1 \tag{12}$$

Backbone Connectivity Test. Each node in the backbone graph must be connected to some gateway in W. To enforce connectivity, we set up a flow problem as follows: we add two nodes, a super-source node s connected to all the backbone nodes (except the gateways) and a supersink node t connected to all the gateways. There should be non-zero flow from s to every backbone node.

$$\forall i, j \qquad 0 \leq f_{ij} \leq b_{ij} \text{ for ``internal'' links} \tag{13}$$

$$\forall i \notin W, \qquad \frac{y_i}{N} \leq f_{si} \leq N y_i \text{ for source to nonGateway links} \tag{14}$$

$$\forall i \in W, \qquad f_{sw} = 0 \text{ for source to gateway links} \tag{15}$$

$$\forall w \in W, \qquad 0 \leq f_{wt} \leq N \text{ for gateway to sink links} \tag{16}$$

$$\forall i \notin W, \qquad f_{it} = 0 \text{ for nongateway to sink links} \tag{17}$$

$$\forall j, \qquad \sum_{i \cup \{s\}} f_{ij} = \sum_{i \cup \{t\}} f_{ji} \text{ flow conservation} \tag{18}$$

$$\sum_{i} f_{si} = \sum_{j} f_{jt} \text{ flow conservation} \tag{19}$$

Backbone Constraints. The number of node in the network graph is bounded by a given parameter. The node degree (except for the **gateway nodes**) of the backbone graph is also bounded by a given parameter.

$$\sum_{i \notin W} x_i \leq n_{max} + \tag{20}$$

$$\forall i \mid i \notin W \qquad \sum_{j} b_{ij} \leq d_{max} \tag{21}$$

Objective Function Flow. Maximize the total flow from the supersource to the supersink in the network graph. Let the flow in link e_{ij} be g_{ij}. The flow constraint equations can be formulated as follows.

$$\forall i, j \qquad 0 \leq g_{ij} \leq e_{ij} \text{ for ``internal'' links} \tag{22}$$

$$\forall i \notin W, \qquad 0 \leq g_{si} \leq N x_i \text{ for source to nonGateway links} \tag{23}$$

$$\forall i \in W, \qquad g_{sw} = 0 \text{ for source to gateway links} \tag{24}$$

$$\forall w \in W, \qquad 0 \leq g_{wt} \leq N \text{ for gateway to sink links} \tag{25}$$

$$\forall i \notin W, \qquad g_{it} = 0 \text{ for nongateway to sink links} \tag{26}$$

$$\forall j, \qquad \sum_{i \cup \{s\}} g_{ij} = \sum_{i \cup \{t\}} g_{ji} \tag{27}$$

$$\sum_{i} g_{si} = \sum_{j} g_{jt} \tag{28}$$

$$\tag{29}$$

The objective function is:

$$\mathbf{max}: \sum_{i} g_{si} \tag{30}$$