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COMMUNITY HEALTHCARE MESH NETWORK ENGINEERING IN WHITE SPACE FREQUENCIES

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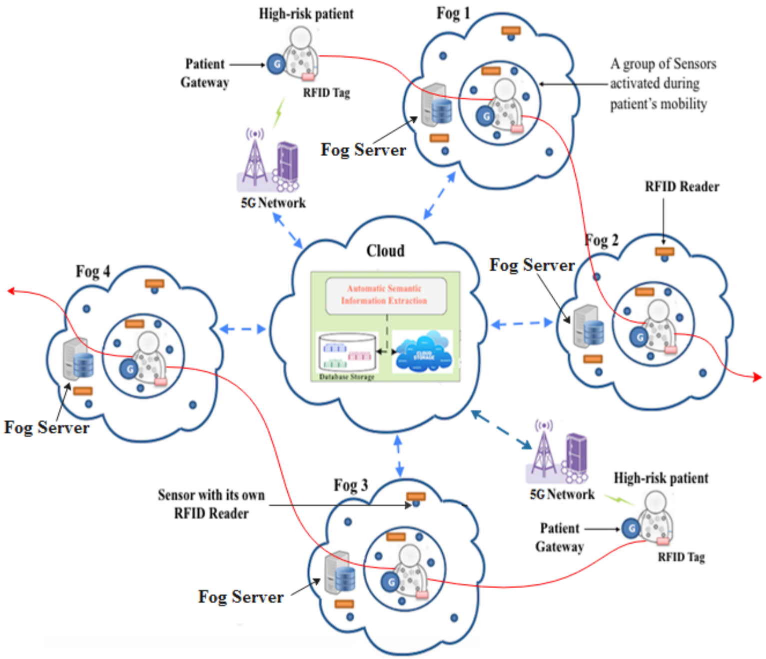
Presentation overview

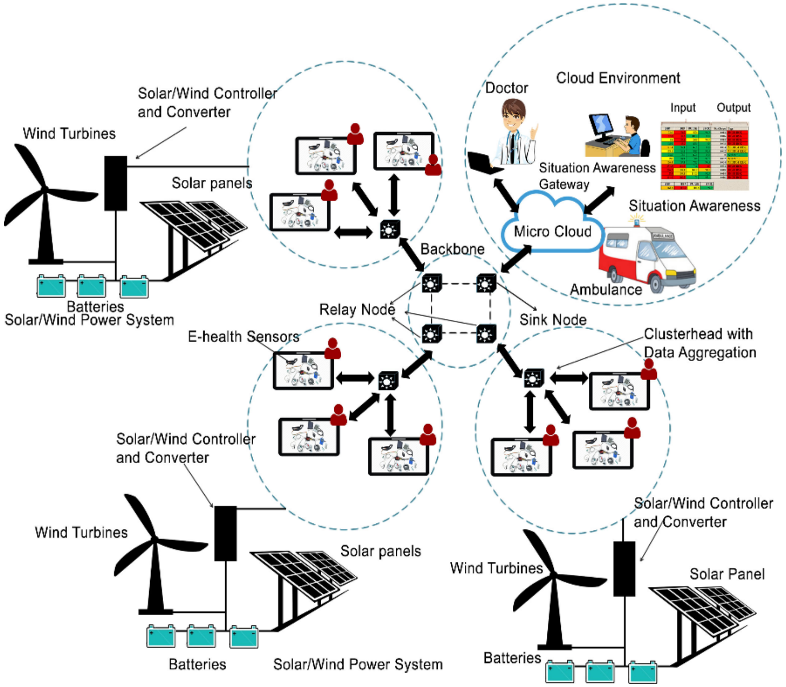
- Motivation
- The Problem
- Contribution
- Network optimization function
- Sparse network topology design algorithm
- Backbone network design algorithm
- Experimental evaluation
- Conclusion

Motivation

Cyber Physical Health Systems (CPHS)



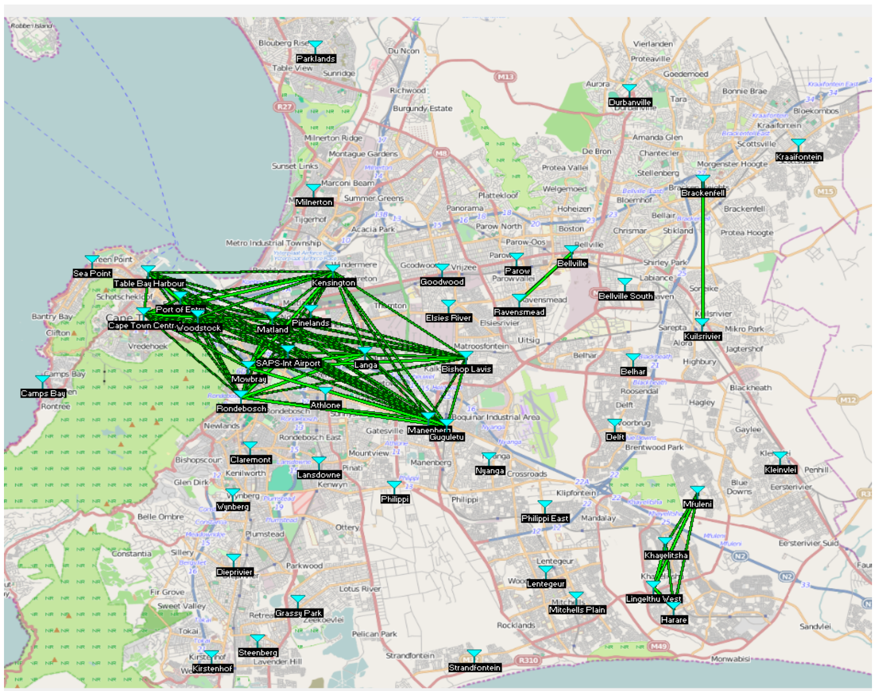
Smart City Deployment



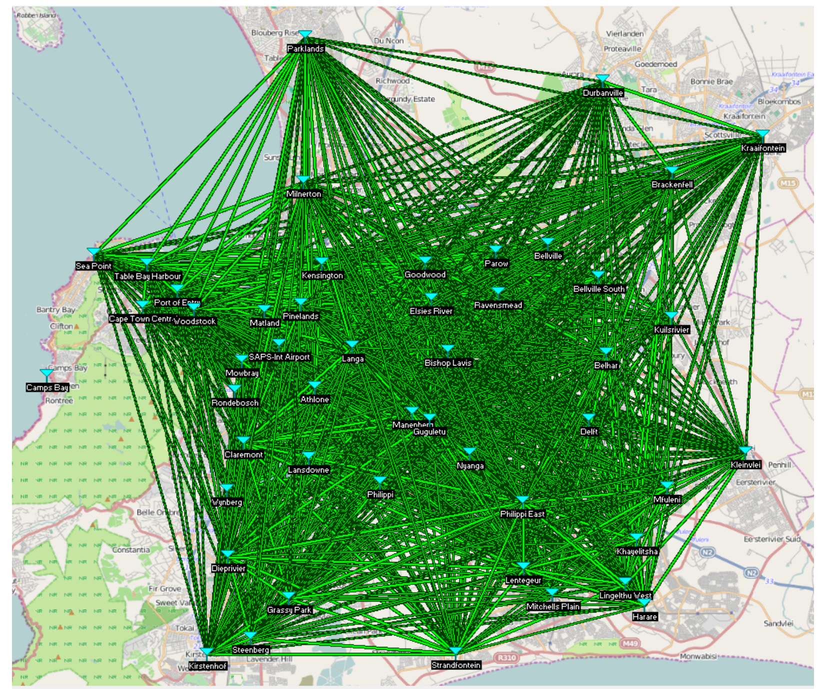
Smart Villages Deployment

The Problem

The Spectrum Selection Challenge



A 2.4 Ghz Fragmented Network



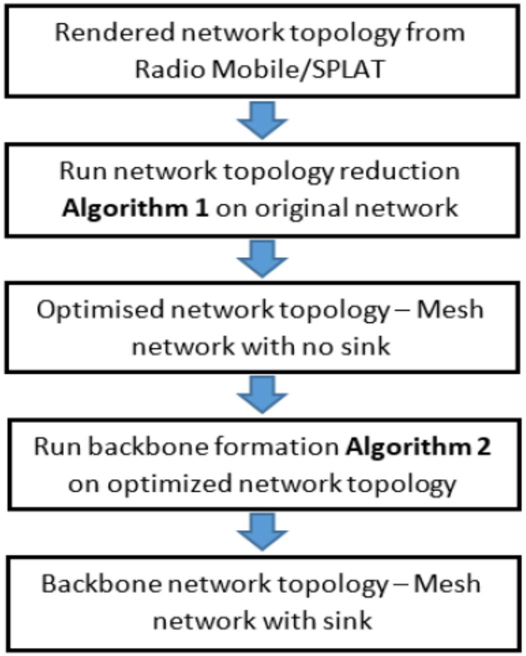
A White Space Dense Network

Contribution

- While algorithms designed for application in physical networks exist, i.e., power control technique, power mode mechanism, hierarchical formation technique [2][3][4], the proposed designs are for predesigning a network topology offline before it is replicated in reality.
  1. A link-based topology reduction algorithm is proposed to reduce a dense mesh network topology designed in white space frequencies into a sparse mesh network topology.
  2. A network optimization function is also proposed to introduce a hierarchical backbone-based network topology from the sparse network topology for better scalability.

Contribution

- The network engineering process in the figure below was followed to evaluate our designs.



Network optimization function

- The network engineering profit function $P(\mathcal{G})$ is considered, which combines reliability and quality of service (QoS) features, based on metric measures;
  1. node degree,
  2. link margin and
  3. Euclidean distance.
- The network engineering profit function $P(\mathcal{G})$ is expressed as follows:

$$P(\mathcal{G}) = \sum_{i \in N} P(i) \quad (1)$$

$$P(i) = \alpha * nd_i + \beta * lm_i + \gamma * sp_i \quad (2)$$

where, α, β and γ are coefficients of proportionality used to express the preference for a given metric measure.

Network optimization function cont’

- The node degree *nd(i)* of node *i* in a network graph with *N* number of nodes is calculated as:

$$nd(i) = \sum_{j=1}^{N} x_{ij} \qquad (3)$$

where $x_{ij}=1$ if there is a link between node *i* and node *j* and $x_{ij}=0$ otherwise.

- Link margin – links and nodes that are better for communication
  1. Links with higher link margins.
  2. Nodes whose corresponding links have smaller differences in link margins.
- Therefore, to know which nodes are well connected, the link margin of each node is considered as the coefficient of variation corresponding to the link margins of all the links connected to that node.

Network optimization function cont'

- For a node *i*, the coefficient *lm(i)* of variation is calculated as follows:

$$lm(i) = \frac{Avg_{lm}(i,x)}{Std_{lm}(i,x)} \; \forall \; x : (i,x) \in \mathcal{L} \qquad (4)$$

where $Avg_{lm}(i)$ and $Std_{lm}(i)$ is the mean and the standard deviation of the link margins of the links connected to the underlying node respectively.

- Average shortest path – it is the average distance from a node *i* to all other nodes using the Dijkstra's shortest path algorithm [5].

$$sp(i) = Avg_{sp}(i,x) \; \forall \; x : (i,x) \in \mathcal{L} \qquad (5)$$

- The link lengths are considered to be the Euclidean distances separating the connected nodes.
- Nodes with lower average shortest paths are the more likely ones to be part of the backbone than nodes with higher average shortest paths.

Sparse network topology design algorithm

- In order to design fault-tolerant networks, the algorithm uses the K-Shortest Path (K-SP) algorithm [6] to compute K-shortest paths between source-destination pairs, where K > 1.

Algorithm 1: LTR algorithm

```
mark all links in dense mesh network as non-visited;
for each non-visited link of the network do
    select worst non-visited link of the network; // i.e.,
        link with lowest link margin.
    artificially delete the link;
    run the K-shortest path to detect if the network is still
        k-connected; // it is k-connected if you
        can find k-disjoint shortest paths for
        each source-destination pair of the
        reduced network.
    if it is k-connected then
        remove the link permanently;
    else
        leave the link and mark it as visited;
end
```

Backbone network design algorithm

- The algorithm uses a graph coloring approach, where nodes of the network are initially assigned a white color and thereafter, they are colored black or gray, depending on whether they have qualified for backbone or edge status.

Algorithm 2: Backbone formation

1. Initialisation.
   Assign a white colour and zero height to all nodes of the network,
   Select a node n from $White$ whose profit/reward is highest,
   $Backbone \leftarrow \{n\}$,
   $Grey \leftarrow$ all neighbours of n,
   $White \leftarrow N \setminus (\{n\} \cup Grey)$.
2. Select a node k from $Grey$ whose profit/reward is highest and height is lower.
   Include k into the $Backbone$,
   Assign a black colour to k and update its height,
   Remove k and its neighbours from $White$,
   Include the neighbours of k in $Grey$.
3. Repeat Step 2 whenever $White \neq \emptyset$.

Performance evaluation

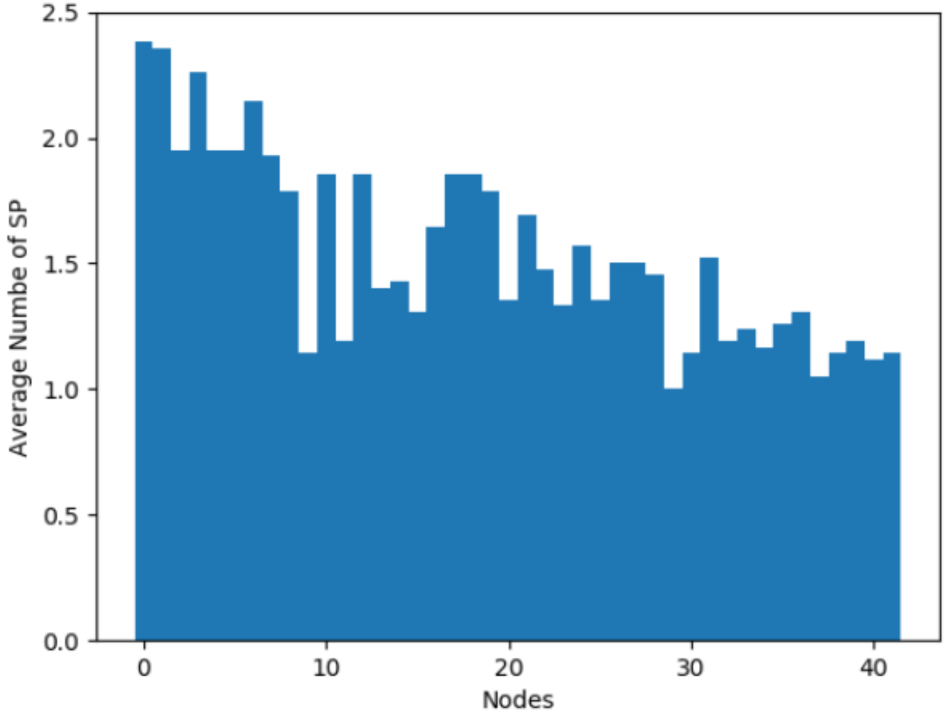
- The public safety mesh network design connecting police stations in the city of Cape Town in South Africa was used, and the network was simulated in TV white space frequency using Radio Mobile network planning tool [7] .
- Sparse network topology:
  - During the reduction process, links that provided two disjoint shortest paths from each node to the network sink were considered and included in the sparse network topology.
- Hierarchical backbone network topology:
  - A Python code implementation of Algorithm 2 was run on the network reports for the sparse network topology to introduce hierarchical backbone network topology.

Sparse network topology reliability using the link length

- We evaluated the reliability of the computation by looking at the number of disjoint shortest paths computed with link length as routing metric.
- Number of disjoint paths from a node to all other nodes of sparse network is called disjoint path multiplicity (DPM) for that node.
- The following performance metrics were considered:

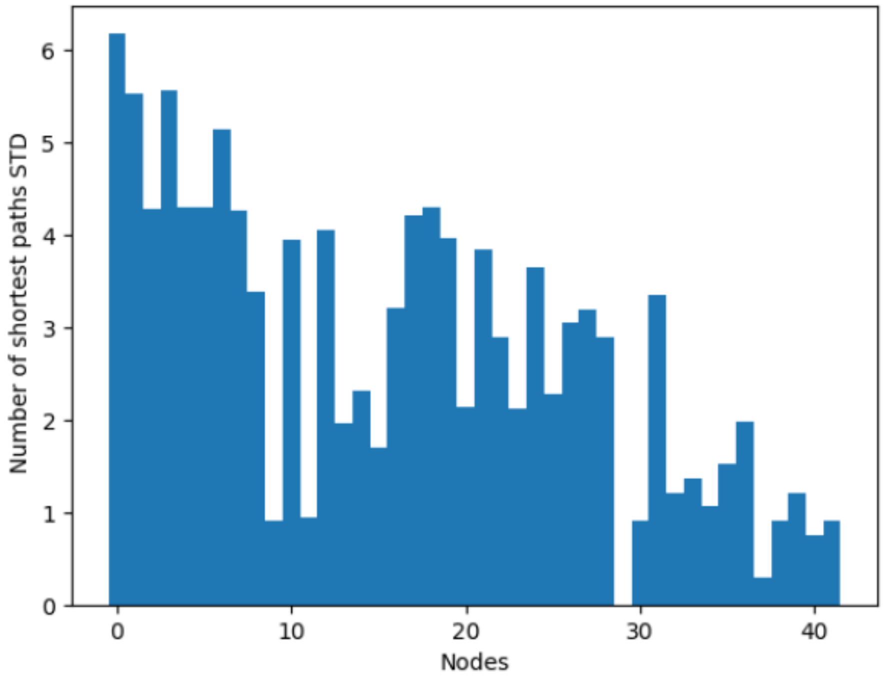
1. Average number of disjoint shortest paths per node – We set each not to be the sink and evaluate the average number of disjoint shortest paths from all nodes to the sink.
2. Variation of number of shortest paths per node – We let each node to be a sink and evaluated the standard deviation in the number of shortest to the sink from each node of the network.
3. Maximum number of shortest paths – To determine the liability of nodes (to be sinks), we computed this metric, which shows the node to which other nodes can reach using more alternatives paths.

Disjoint path multiplicity



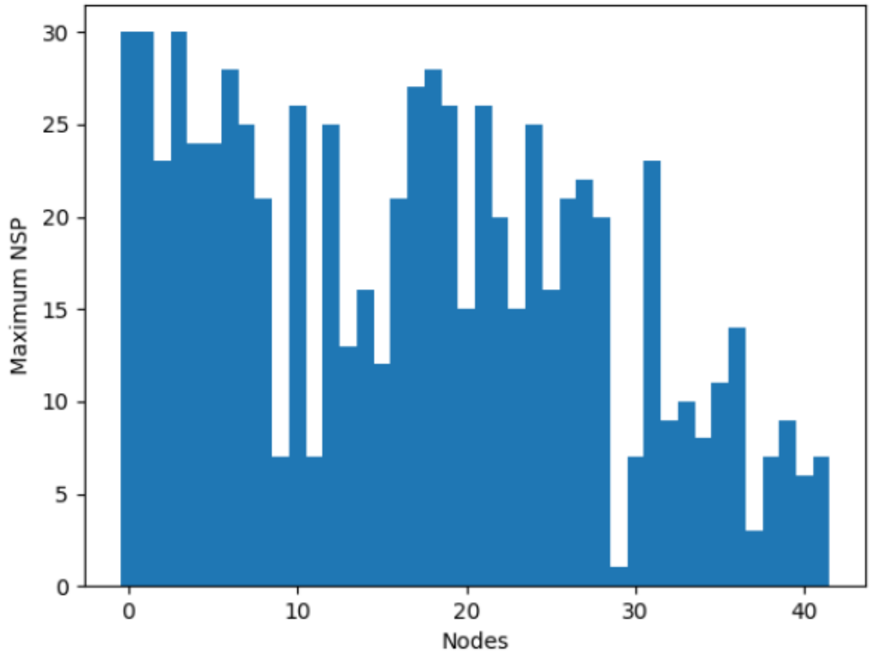
- Node 0 is the most reliable since it has the highest average number of disjoint shortest paths and;
- Node 29 is less reliable.

Disjoint path multiplicity variance



- When node 29 is chosen as the sink, the number of shortest paths from each node to it varies less.
- Choosing node 0 as the sink, the number of shortest paths from each node to it varies most.

Maximum disjoint path multiplicity



- The graph confirms that node 1 is the most reliable.
- The graph also reveals that when node 29 is the sink, the number of shortest paths from each node is minimum.

Impact of backbone design on network performance

Backbone network topology vs sparse network topology

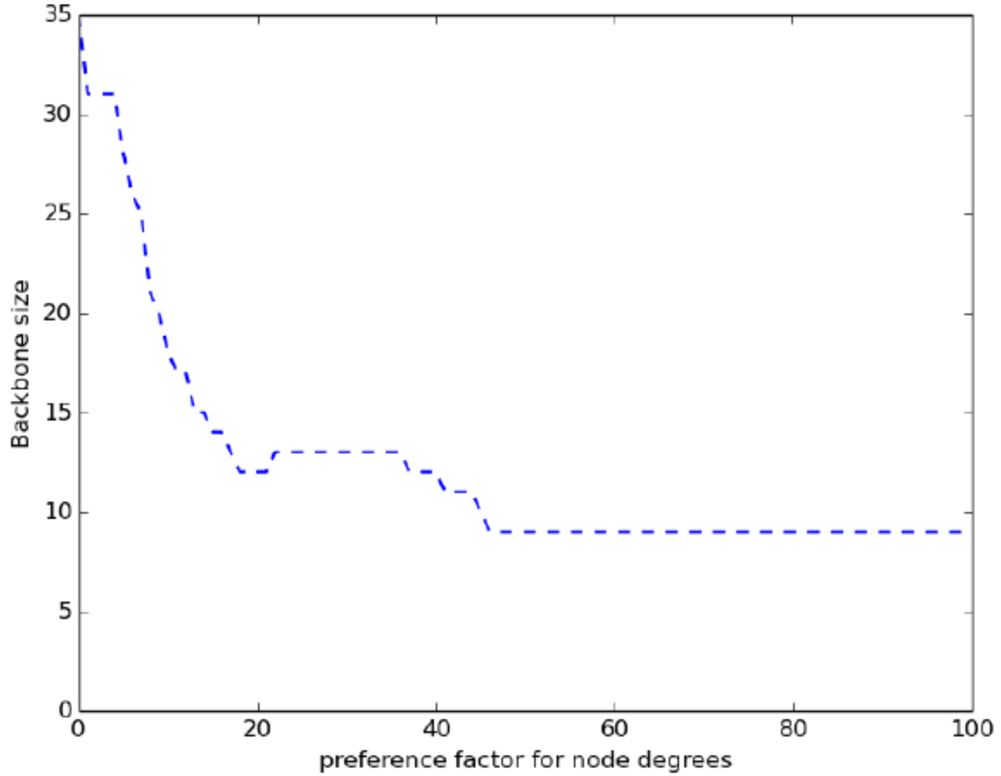
Network performance	Reduced network	Backbone
Node degree	3.81	4.03
Coefficient of variation (link margin-(dBm))	2.83	3.86
Shortest distance (km)	12.88	12.31
Path multiplicity	2	1

- The table confirms the following points:
  1. Nodes with the highest degree or coefficient of variation are likely to be chosen as a backbone node.
  2. Nodes closest to many nodes in the network are also likely to be chosen as backbone nodes.

Impact of the design parameters, (α, β and γ) on the backbone size

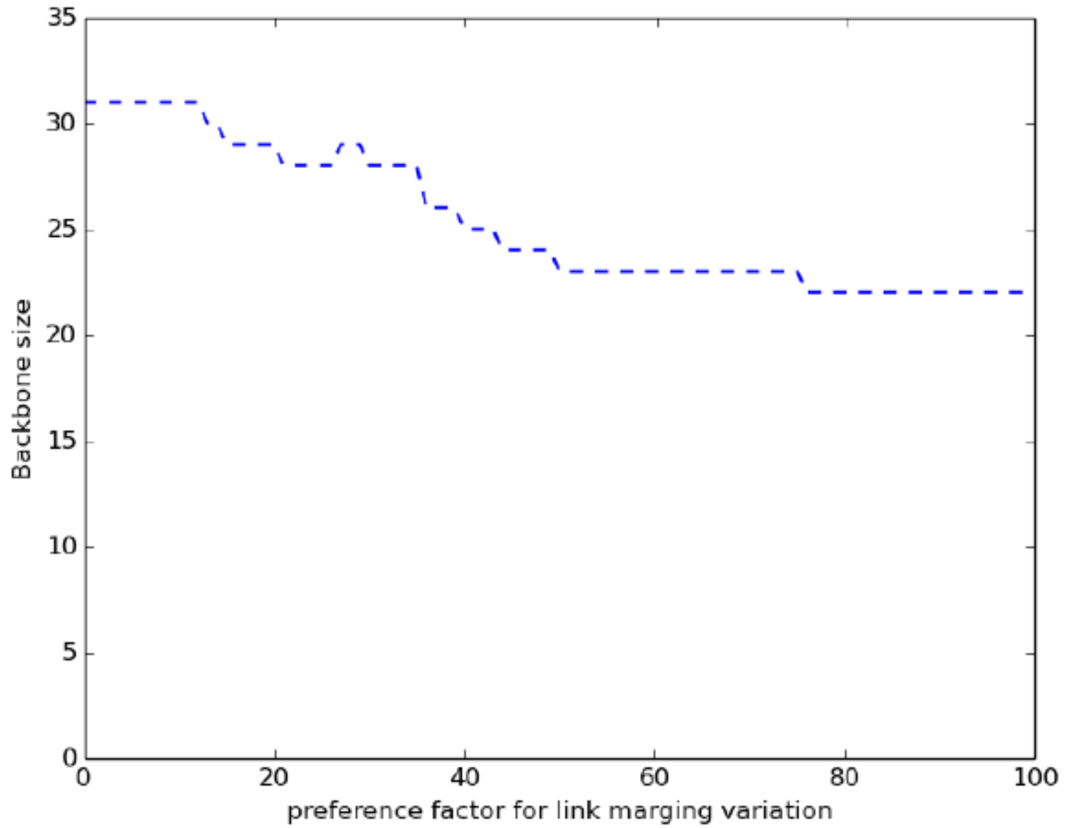
- In each case, two parameters were fixed as the third parameter was being varied from 0 to 100.
- Conclusions drawn from evaluation of the impact of the design parameters on the backbone size are as follows:
  1. The backbone size is affected by change of each of the three parameters.
  2. The results also reveal that the node degree has a much higher positive influence on the backbone size, leading to smaller backbones, which can allow networks to scale while keeping the size of the backbone constant and smaller.

Impact of node degree parameter on backbone size



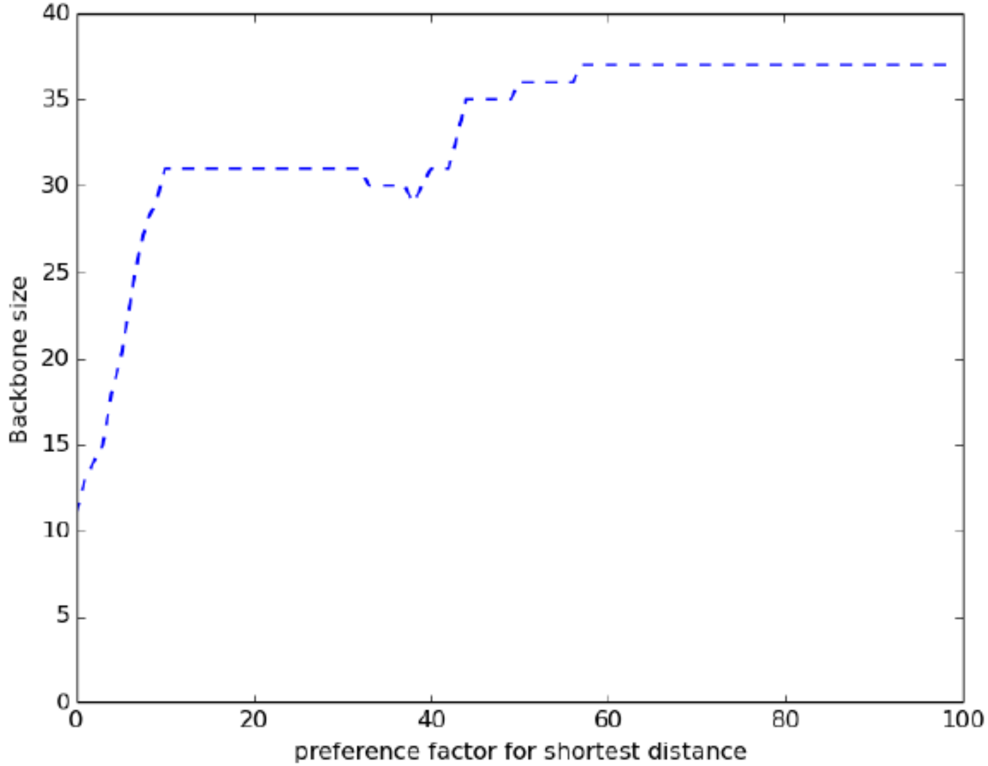
Impact of α on backbone size

Impact of link margin parameter on backbone size



Impact of β on backbone size

Impact of average shortest path parameter on backbone size



Impact of λ on backbone size

Conclusion

- Dense network topology was highlighted as one of the design challenges that network planners and designers in white space frequencies will face.
- A link-based topology reduction algorithm was proposed to reduce a dense mesh network topology into sparse mesh network topology and a network optimization function based on three metrics was developed to introduce hierarchical backbone-based network topology from the sparse network topology.
- Performance evaluation on the proposed designs show that the designs can guide network engineers to select the most relevant performance metrics during a network feasibility study in white space frequencies, aimed at guiding the implementation process.

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Thank you