Optimisation in the design of mobile ad-hoc networks with steerable directional antennae

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Introduction

We study mobile ad hoc networks in which

- Each node has a fixed number of high-gain (narrow beam) steerable directional antennae
  - a node can support at most this number of communication links at any instant
- Servers for the network must be located at a subset of the nodes
  - we seek an optimal subset with respect to minimising server traffic overheads

Advantages of HGSDAs

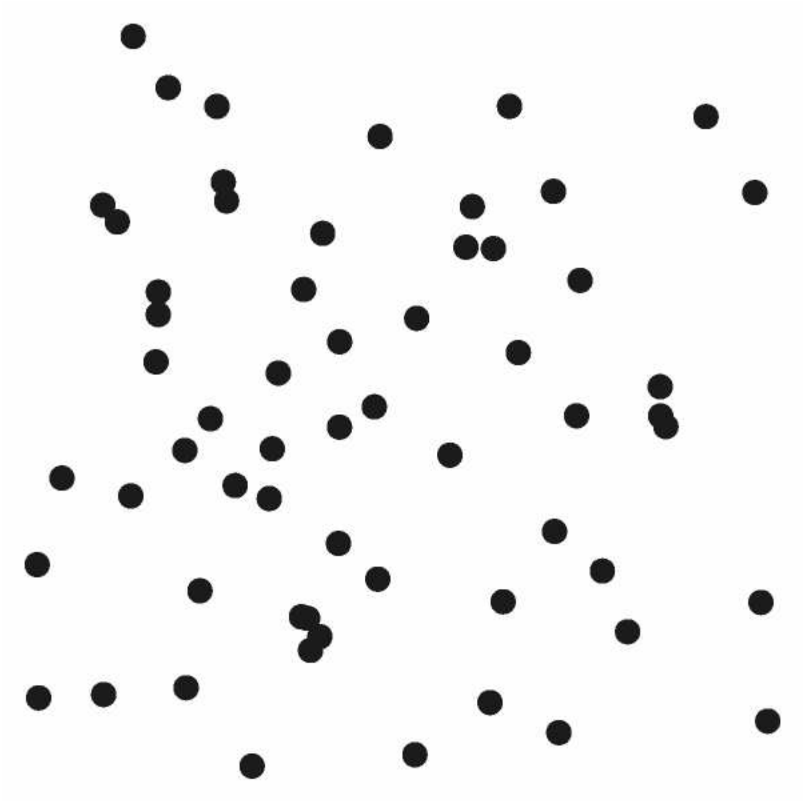
- Reduced radio interference
  - Improved use of the wireless medium
  - Increased network capacity
- Higher SNR ratio
  - Extended transmission ranges
  - Lower power requirements
- Effective in hostile environments
  - Lower probability of detection
  - Greater robustness to jamming

Outline

1) Construct a graph-theoretic model of the problem
2) Identify design objectives in terms of our model
3) Describe an optimisation strategy based on tabu search
4) Evaluate our methodology using a simple mobility simulator

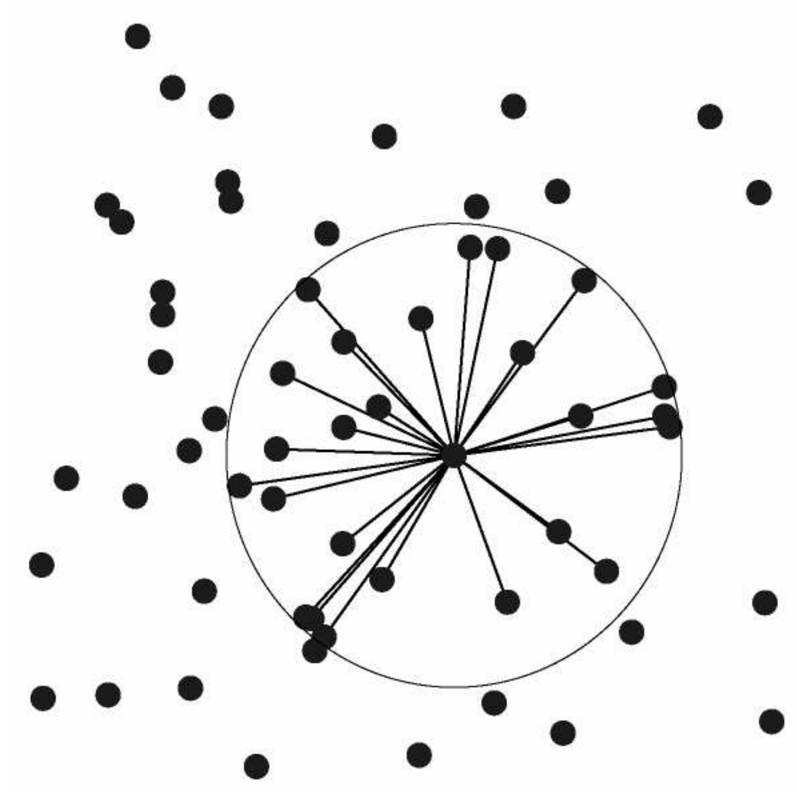
The model

- A set of autonomous communications nodes



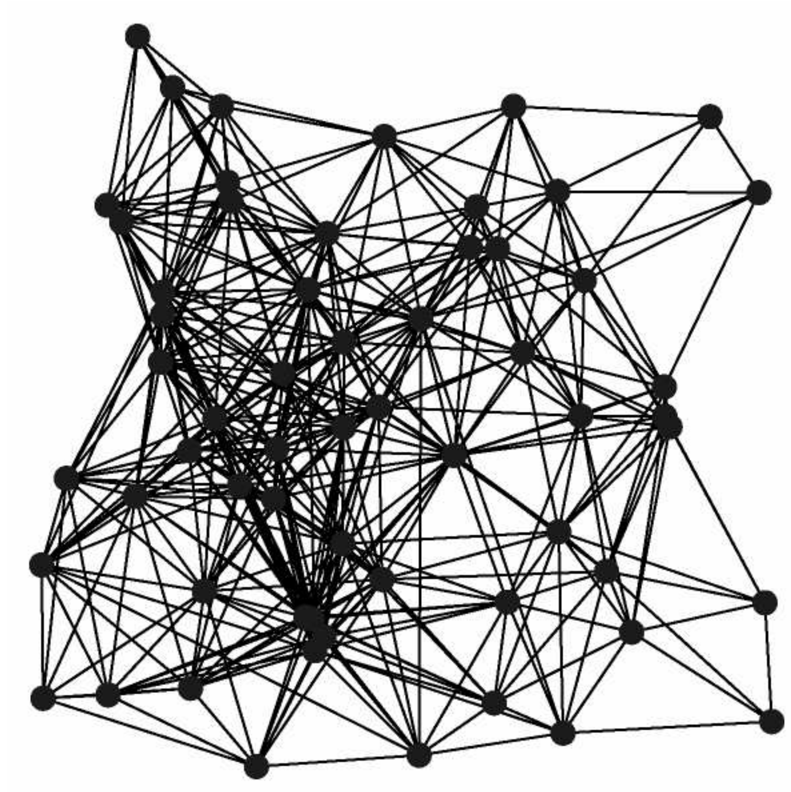
The model

- A set of autonomous communications nodes
- Each node has a broadcast range



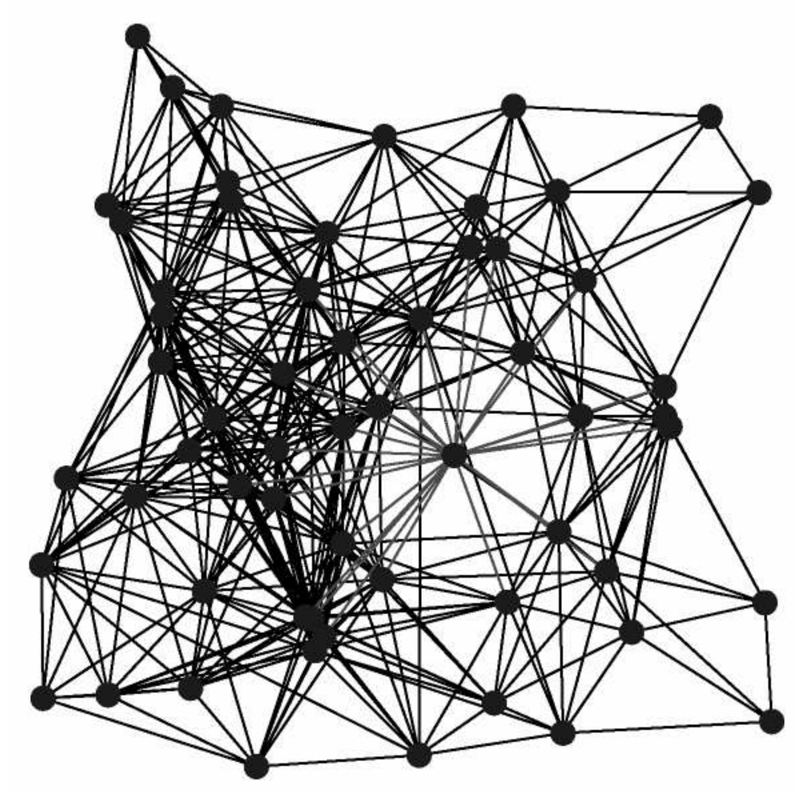
The model

- A set of autonomous communications nodes
- Each node has a broadcast range
- This defines a set of potential links
- The graph G



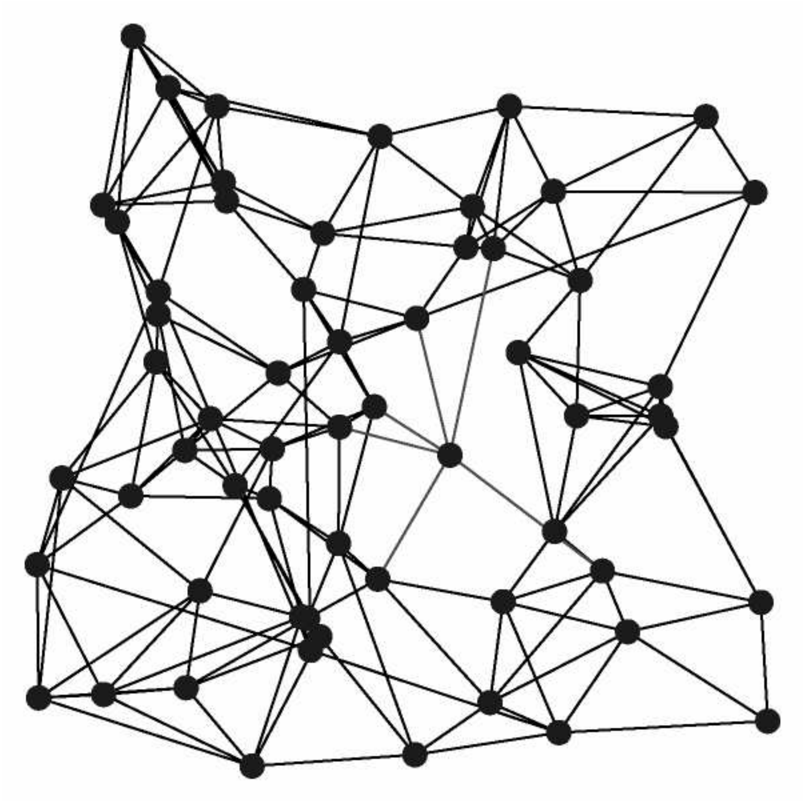
The model

- Each node has a maximum degree constraint



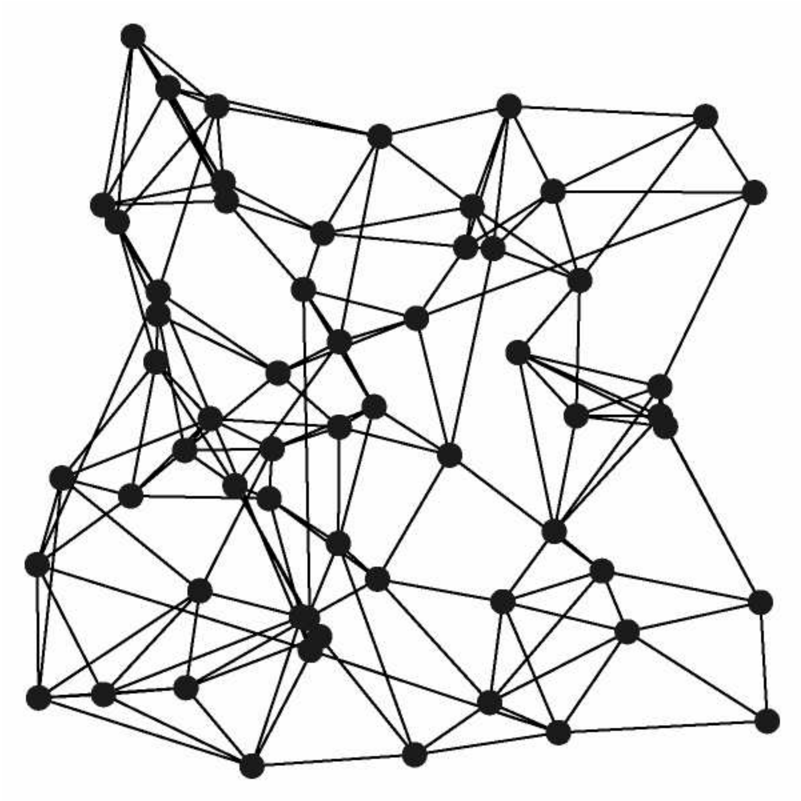
The model

- Each node has a maximum degree constraint
- A feasible network design must respect these constraints



The model

- Each node has a maximum degree constraint
- A feasible network design must respect these constraints
- A feasible design is a spanning subgraph H of G



First design objective

To find a spanning subgraph H such that

a) Network connectivity is high

b) Network connectivity is maintained under mobility

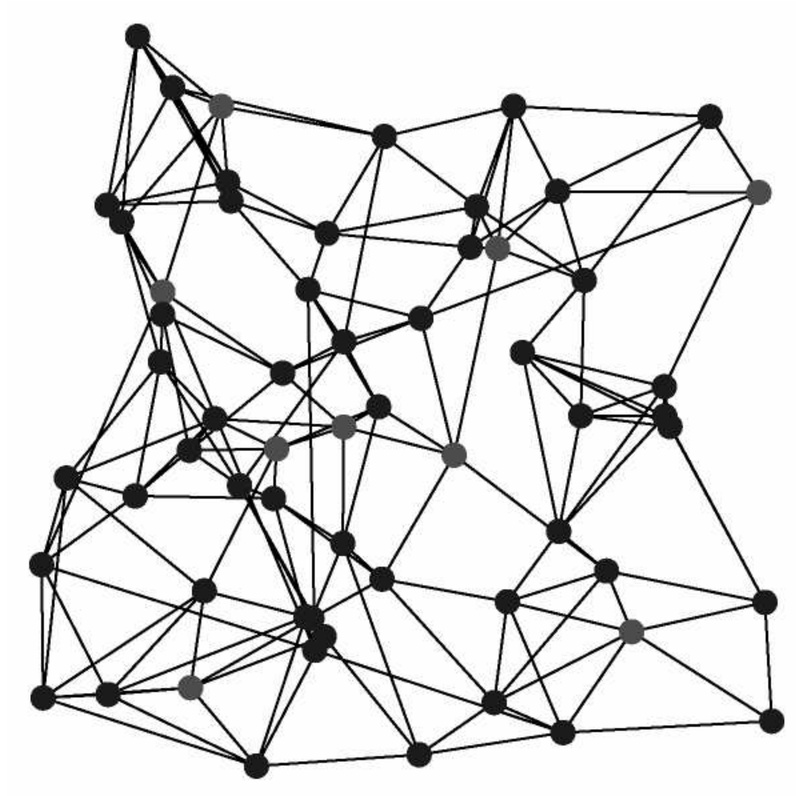
- Objective function

$$\text{conn}(H) = \sum_{u,v \in V} \kappa(u,v)$$

- We aim to maximise conn(H)

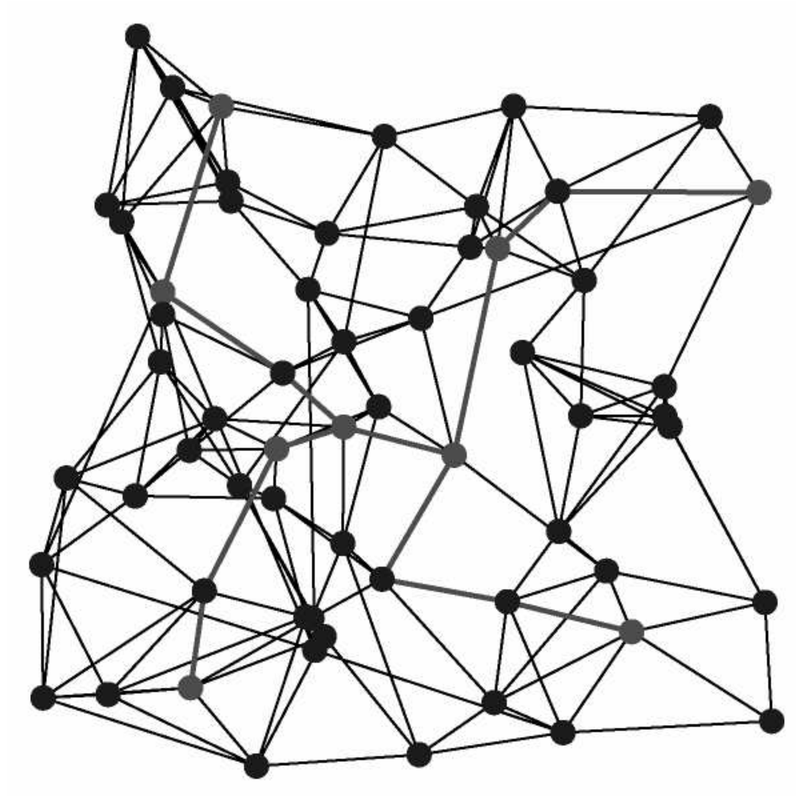
Serving nodes

- A subset S of the nodes must be selected to host servers for the network



Serving nodes

- A subset S of the nodes must be selected to host servers for the network
- The server traffic overhead is estimated by the length of the shortest path between
  - every pair of serving nodes (synchronization traffic)
  - every non-serving node and its nearest serving node (query traffic)



Second design objective

To identify a set of serving nodes S so that

a) Non-application traffic is minimised

b) Non-application traffic remains small under mobility

- Objective function

$$\text{traff}(S,H) = \sum_{u,v \in S} d(u,v) + \sum_{v \in V \setminus S} \min\{d(u,v) : u \in S\}$$

- We aim to minimise traff(S,H)

Third design objective

- We must maintain adequate network reliability and server traffic overheads under the influence of mobility
- For any potential link $e = e(u,v)$ define

$$\begin{aligned} maxLength(e) &= min(range(u), range(v)) \\ \rho(e) &= maxLength(e) - length(e) \end{aligned}$$

- $\rho(e)$ is called the robustness of e, and its endpoints u and v can move at least this distance (relative to each other) before the link fails

Third design objective

- We define the survivability of a network design to be the sum of the robustness of its links

$$\text{surv}(H) = \sum_{e \in E} \rho(e)$$

- We aim to maximise $\text{surv}(H)$

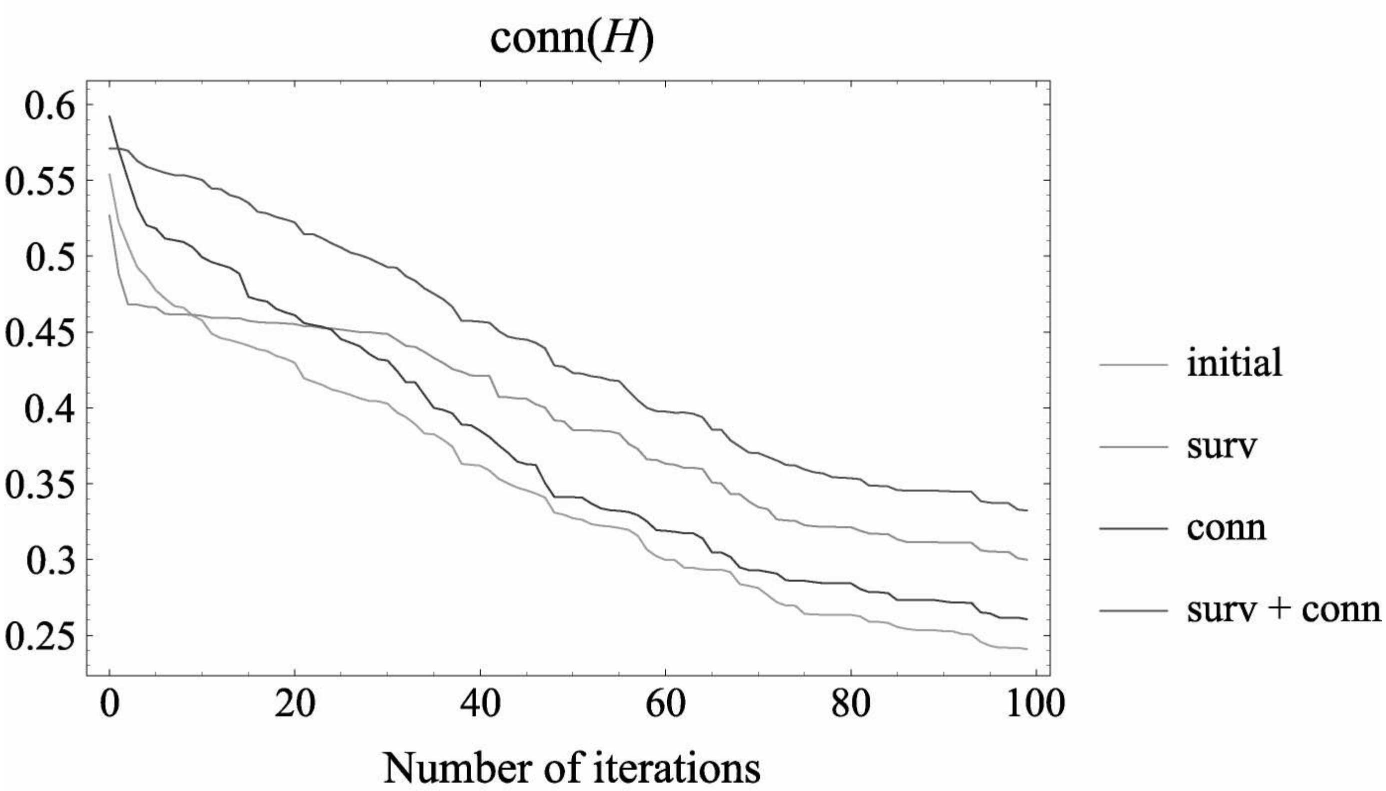
Meta-heuristic search

- The search space of feasible designs consists of
  1) The set of all feasible spanning subgraphs *H* of *G*
  2) The set of all subsets *S* of *V*
- Simple moves are divided into
  1) Node moves (activate or deactivate a node)
  2) Edge moves (insert or remove an edge)
- We use tabu search to look for the best possible network design in terms of reliability (connectivity), server traffic overheads and survivability

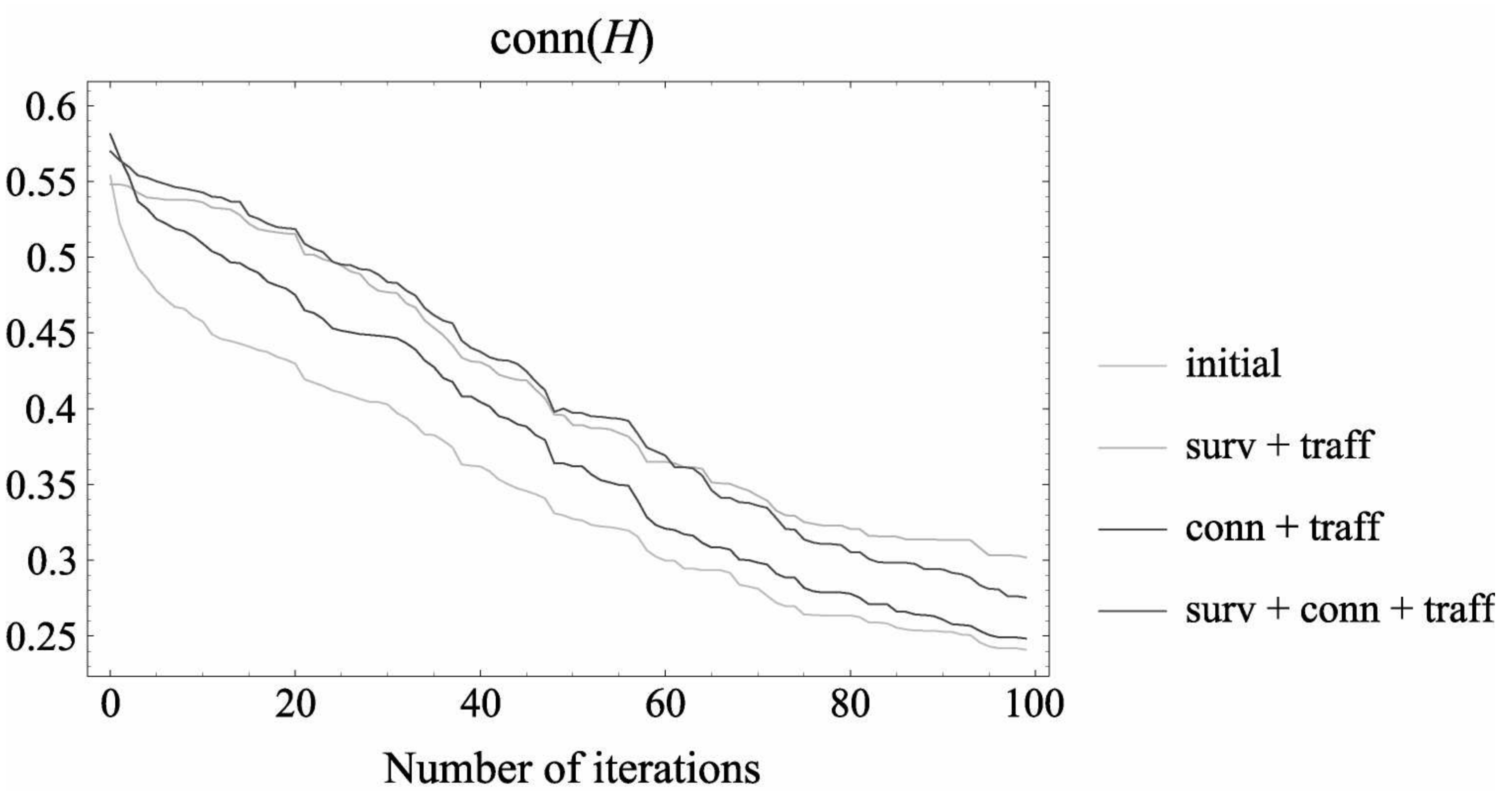
Experimental results

- We optimise separately with respect to the following combinations of objective functions
  - surv(H)
  - conn(H)
  - surv(H) + conn(H)
  - surv(H) + traff(S, H)
  - conn(H) + traff(S, H)
  - surv(H) + conn(H) + traff(S, H)
- We evaluate our optimised network designs using a simple mobility simulator

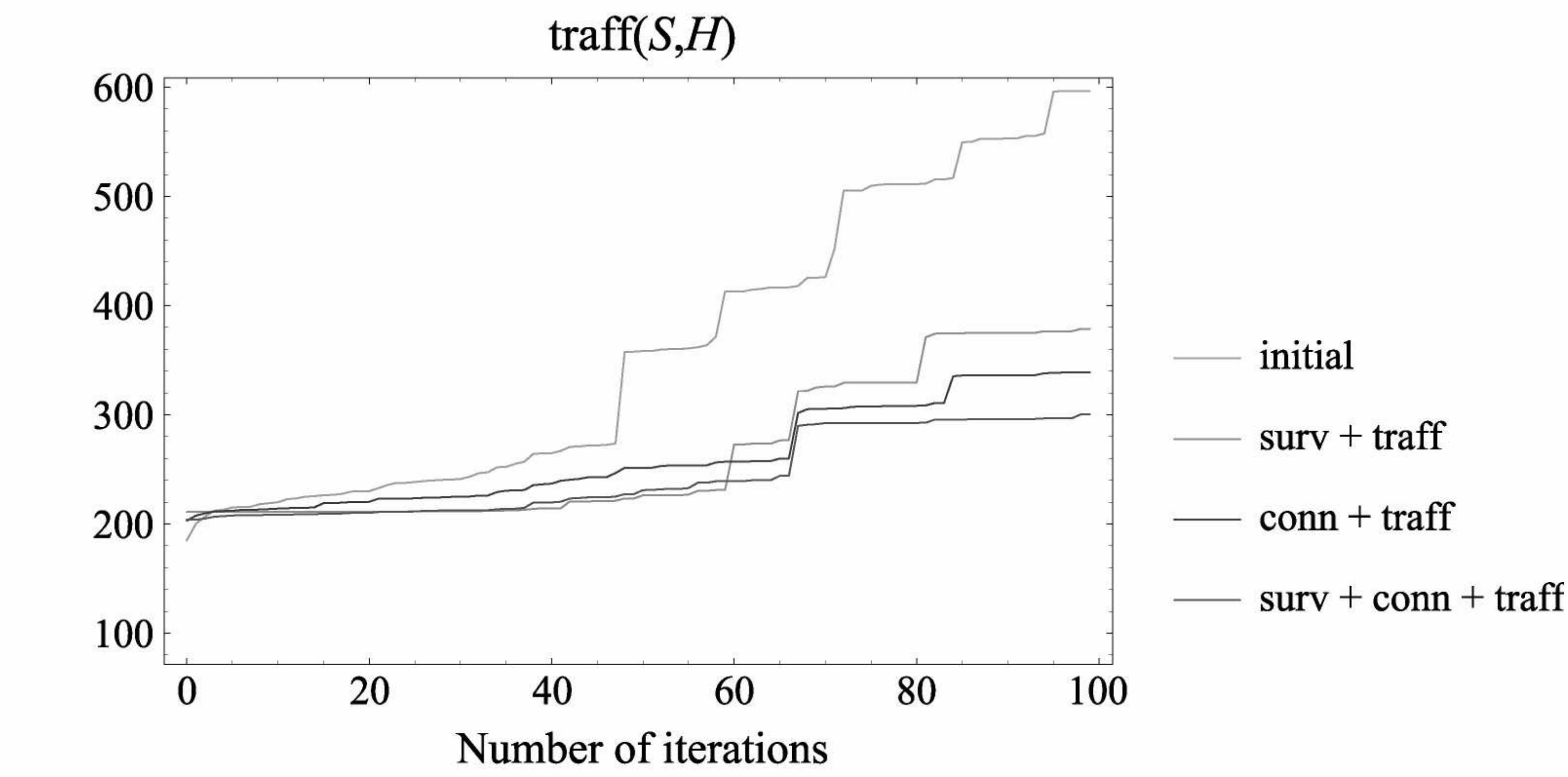
Network reliability I



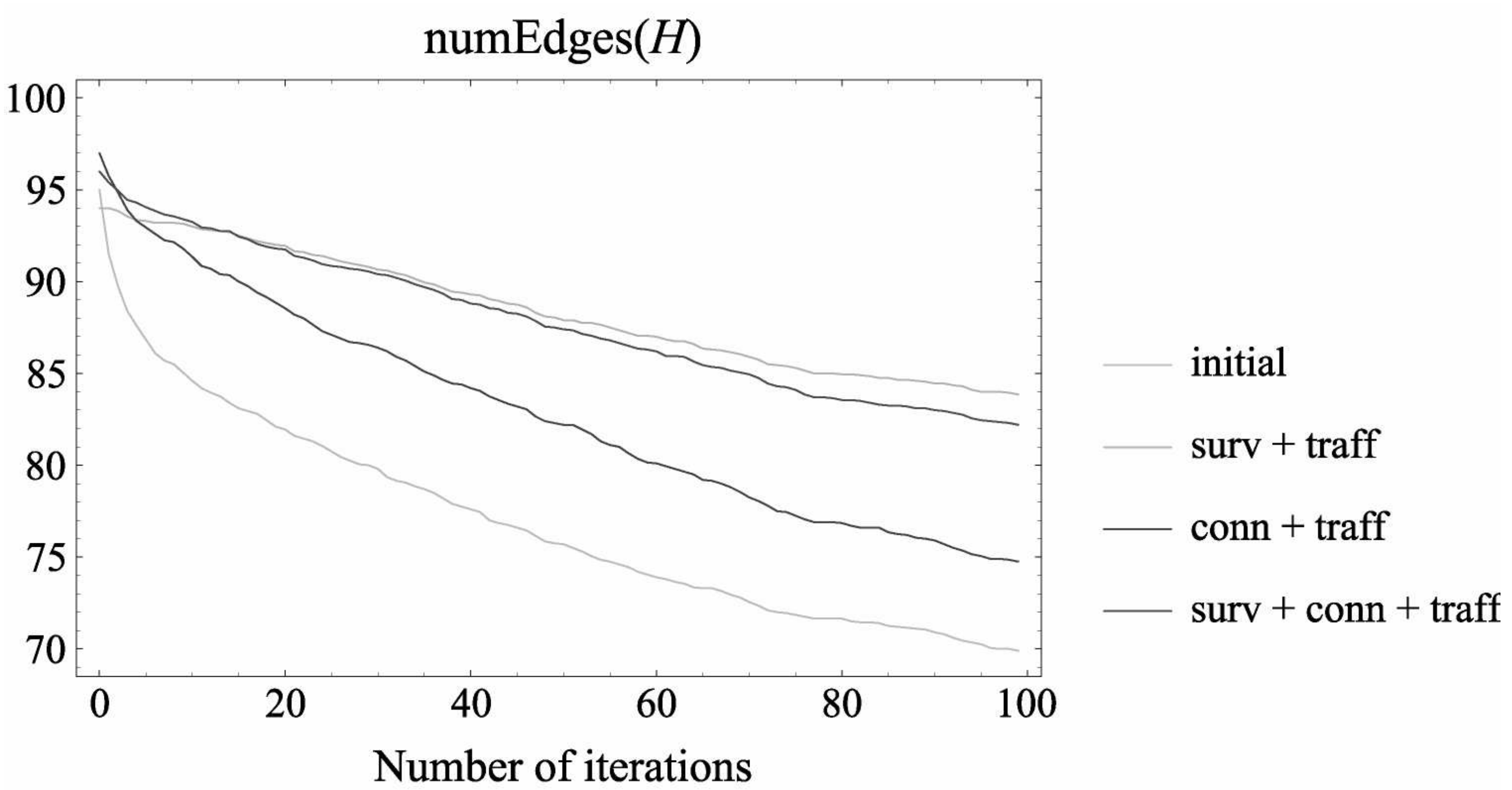
Network reliability II



Server traffic overheads



Number of edges



Network Performance I

	initial	surv	conn	surv+traff	conn+traff
Disconnection Time	226	325	253	419	244
Isolation Time	329	367	344	881	573

Network Performance II

	initial	surv	conn	surv+traff	conn+traff
NAT(0)	61	68	60	59	59
NAT(100)	83	87	81	60	86
NAT(500)	480	356	383	169	374
NAT(1000)	1076	742	843	541	882

Conclusions

We have

- specified design objectives for mobile ad-hoc networks whose nodes employ high-gain (narrow beam) steerable directional antennae
- identified desirable network characteristics in terms of a graph theoretic model
- produced optimised designs with respect to our design objectives using tabu search
- evaluated our designs using a simple mobility simulator