A Flock-Based Model for Ad-Hoc Communication Networks

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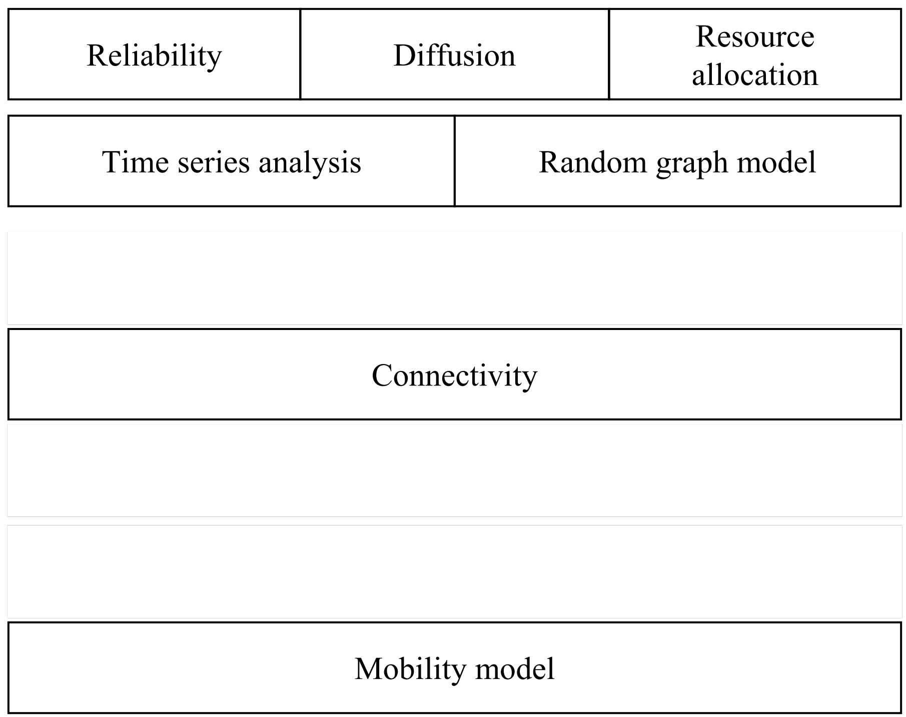
Vulnerability of Command and Control Networks

- In network-centric forces, the network itself will presumably be a prime target of enemy attacks.
- Need to assess vulnerabilities of different designs.
- Standard methods of Network Reliability unsuited for highly dynamic, mobile networks.
- Connectivity measures, Performability measures
- Probability of finding functional chains, small subgraphs more relevant for Network-centric operations.

Mobile Ad-Hoc Communication Networks

- Distributed communication system
- Messages routed through intermediate nodes
- Complexity caused by
  - Constant movement of units
  - Units enter and leave area of operations

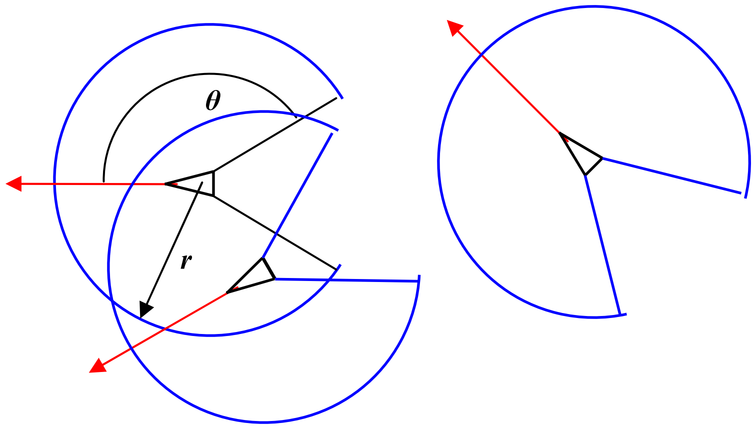
Model structure



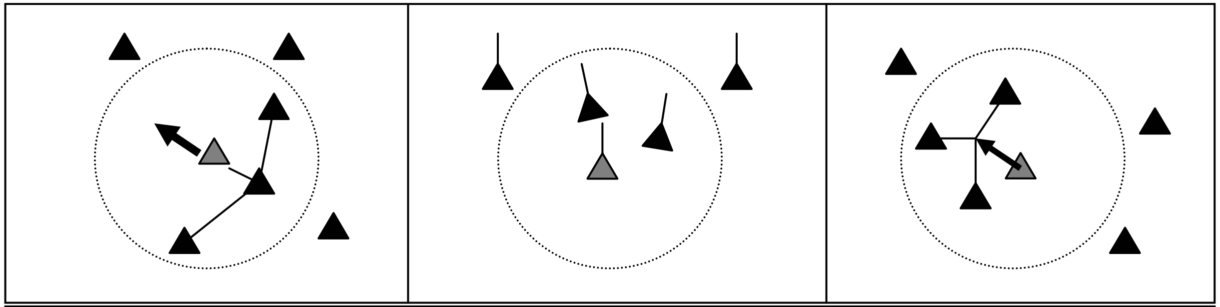
Classes of mobility models

- Random models
  - random walk,
  - random waypoints
- Deterministic models
  - Rule-based,
  - predefined movement path
  - real mobility trace
- Hybrid models

Local neighbourhood for flocking behaviour

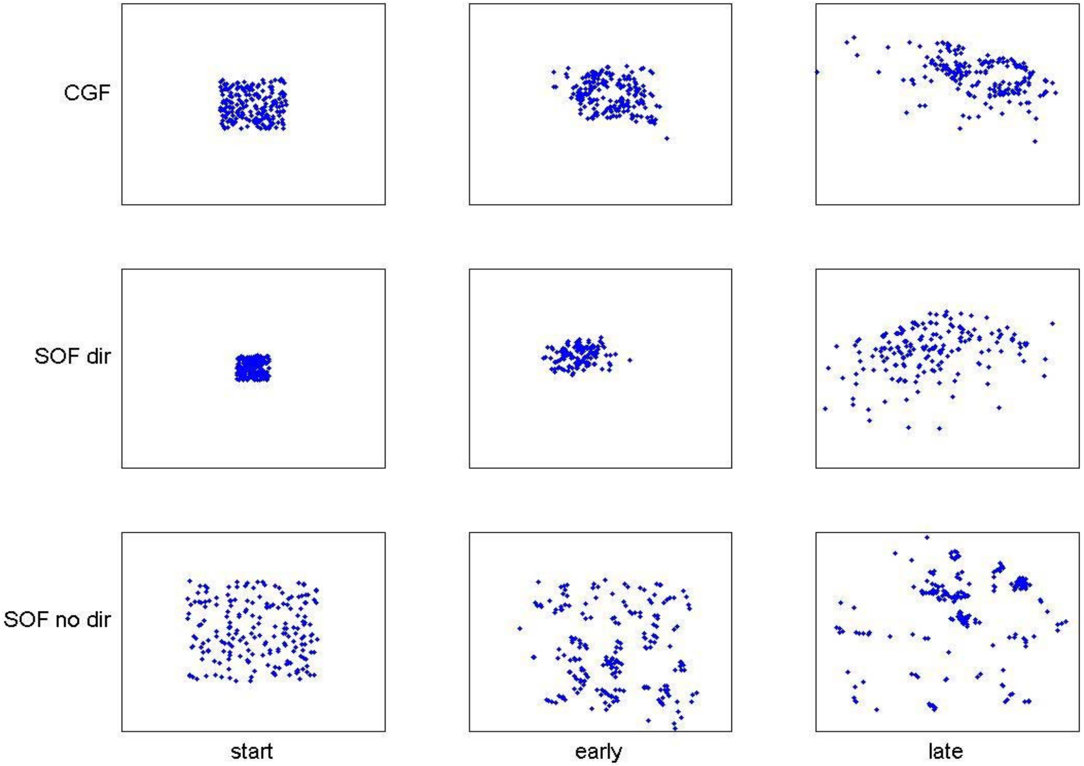


Basic steering rules

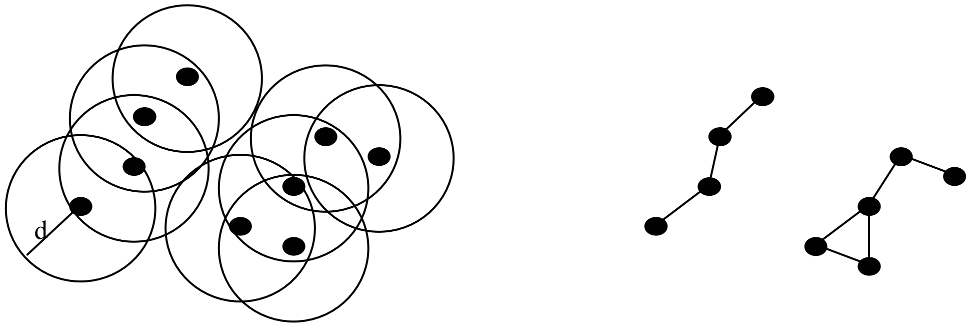


Separation: avoid collision towards average	Alignment: Steer towards the average heading of flock mates.	Cohesion: Steer position of flock mates.

Mobility regimes

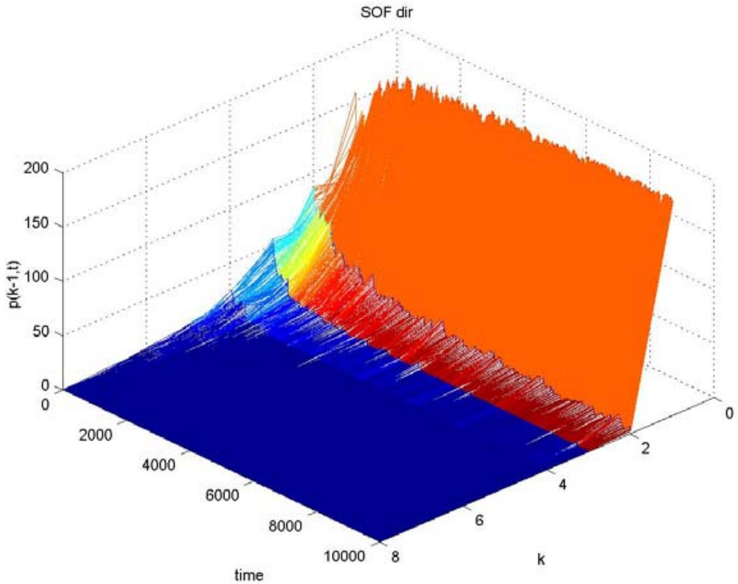


Connectivity graphs



Results

- *p(k,t)* = #nodes with k neighbours
- Quick transient behaviour



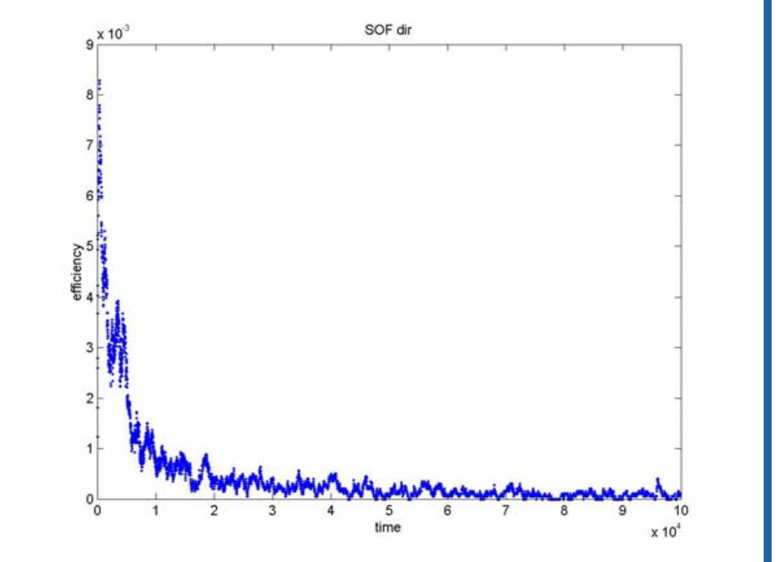
Global efficiency

- Latora and Marchiori:

$$E_{glob} = \frac{1}{n(n-1)} \sum_{i \neq j} \frac{1}{d_{ij}}$$

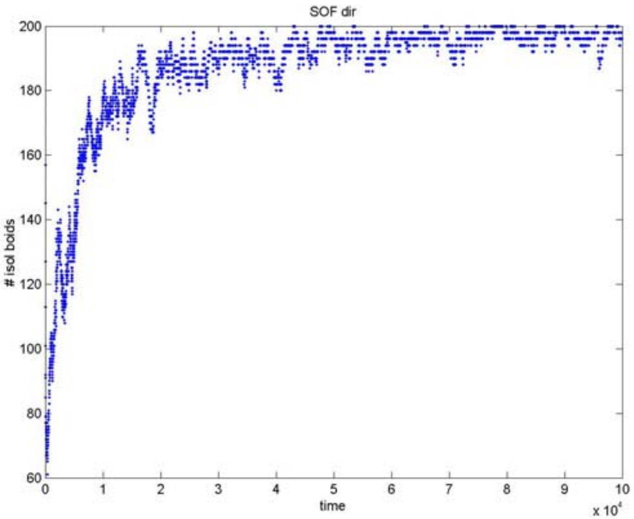
where d_{ij} is the shortest distance

- Works for unconnected graphs
- Quick decay, stabilizes at value characteristic for phase.



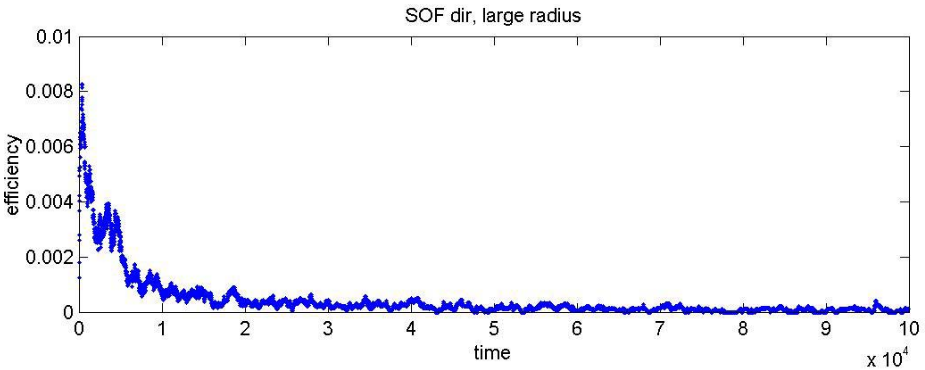
Number of isolated nodes

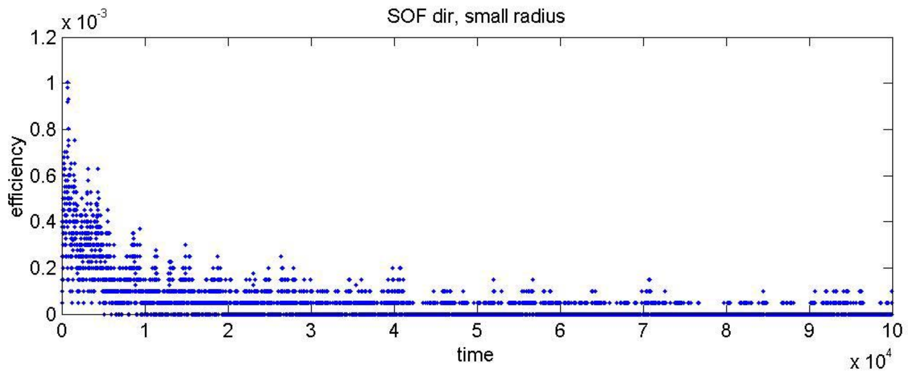
- Fluctuates strongly– many units are periodically out of contact for a short while before they reconnect.
- Reaches stationary behaviour slower



Different communication ranges d

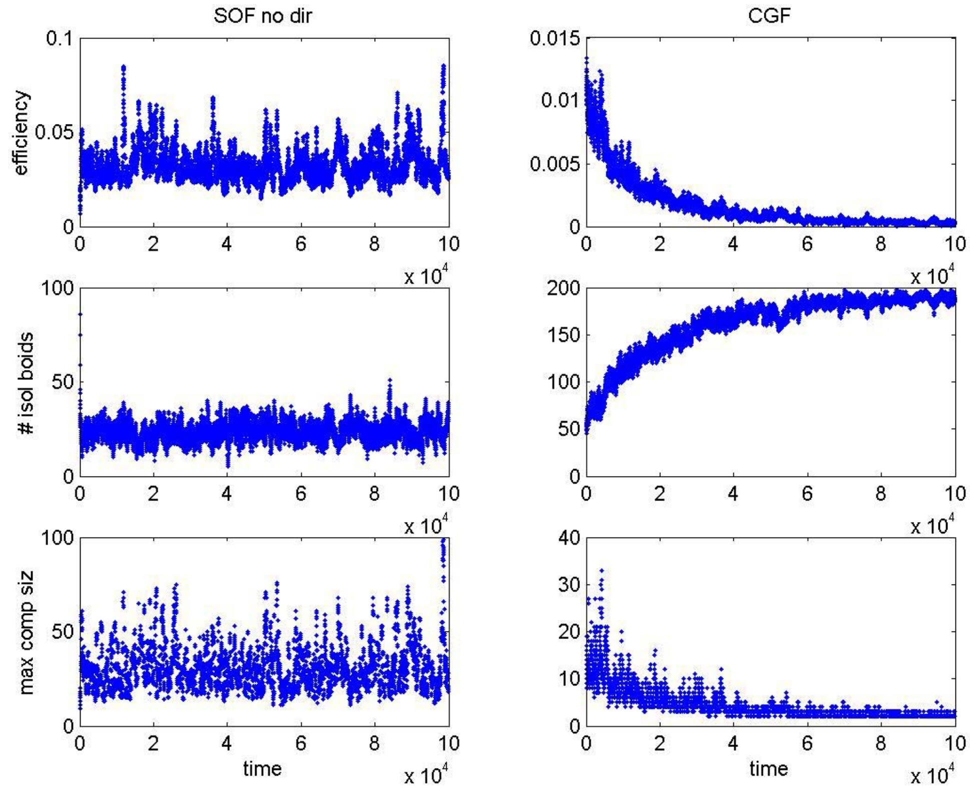
- Large *d* = almost complete graph
- Small *d* = isolated nodes
- Global efficiency for *d=0.5 r* ar *d=2r* using “SOF dir”.
- Order of magnitude difference
- Very important to be able communicate longer!
- But this leads to increased risk of detection





Other types of motion

- Direction important
- CGF and SOF dir similar
- Stable against small perturbations



Summary of work so far

- Flocking model can simulate various behaviours
- Communication range d gives graphs
- Graphs differ for different behaviours
- Graphs are dynamic
- d has large impact on global efficiency

Future work

- **Different types of units, Enemy units**
- **Network reliability**
- **Diffusion of information**
- **Random graph modelling**
  - Define ensemble of communication graphs for different behaviours instead of simulating
- **Resource allocation**
  - functional chains
  - sensor-to-shooter

Vulnerability to attacks

- Physical attack
- Functional attack
- Semantic attack

- Remove nodes or edges
- Nodes change role in time
- Where should we attack enemy's communication nets?
- Hijacking – feeding false data to information fusion node

Diffusion of information

- System is dynamical – nodes change characteristics
- Edges have lifetimes
- Information can spread not only through the connections, but also via physical movement of the nodes
- Give information to node, measure time needed to propagate to all fusion nodes
- Red and blue teams competing for information