On Constructing Stable Virtual Backbones in Mobile Ad Hoc Networks

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Outline
- Introduction
- Related work
- Connected Maximal Independent Set with Multiple Initiators (MCMIS)
- Conclusion

Mobile Ad-hoc Network
- A collection of wireless mobile hosts forming a temporary network without the aid of any established infrastructure or centralized administration. [Johnson and Maltz]

Mobile Ad-hoc network
- Dynamic topology
- Self-organizing
- Bandwidth and energy constraints
- Multi-hop network
- Shared media

Broadcast storm problem
Capacity tends to be zero as nodes increase

Virtual Backbone
- A subset of all mobile hosts
- Connected
- Dominate the whole network

Applications of Virtual Backbone
- Multi-casting and broadcasting
- Ad hoc routing
- Topology management
- Power management

How to construct a small-scale and stable virtual backbone in mobile environment?
Problem Formulation

- Unit Disk Graph (UDG)
- Dominating Set (DS)
  - A subset $V' \subset V$ such that each node in $V-V'$ is adjacent to some node in $V$
- Connected Dominating Set (CDS)

Finding CDS in UDG

Related Work

- Centralized
- Distributed
  - CMIS_Wan [Infocom02]
    - Leader election
    - Construct and connect 2-hops MIS
    - Ranking: Level, ID
    - Constant performance ratio as 8
  - CMIS_Min [Mass04]
    - Construct and connect 2-hops MIS
    - Not require level, more efficient
    - Consider stability

MCMIS

- An efficient algorithm to create stable and small-scale virtual backbone
- Localized
  - Faster
  - Spatial reuse the wireless channel
  - Proactively consider stability
  - Two phases
    - Construct a forest consisting of dominating trees rooted at different initiators
    - Merge the forest into one backbone

Node Ranking

- Stability
  - Spatial locality
  - Temporal locality

$$s_n = \frac{1}{\sum_{i=1}^{m} \sqrt{(x_i-x_0)^2 + (y_i-y_0)^2}}$$

Dominating tree construction
Reduce the backbone size

- Reduce # of dominating (black) nodes
  - Before a white node turns into black, it needs to make sure that it won't have black neighbors
- Reduce # of interconnecting (red) nodes
  - Let black node choose the neighbor gray node which can connect to most of the black nodes as connector

Coloring Process

Coloring Process

Coloring Process

Coloring Process

Coloring Process
**Coloring Process**

![Diagram](image)

All black nodes and all red nodes compose a dominating tree.

**MCMIS**

- Confliction scenarios
  - No black-black confliction
  - No black-red confliction
  - Black-gray confliction (2-hops)
  - Gray-gray confliction (3-hops)

**Reduce backbone size**

- Introduce the root for a node to check the connectivity

**Reduce Backbone Size**

- Choose the shorter path
- Choose only one path out of multiple paths
Receives a black msg

Has lowest rank among neighbors who sent black msg

Upon receiving gray msg from other tree, unicast connect msg if it has not been connected to that tree;
Upon receiving gray2 msg from other tree, unicast connect2 msg to the sender if it has not been connected to that tree;

Broadcast red msg which includes all its black neighbors’ id and root info
If receives a connect2 msg, send connect to its gray neighbor

Broadcast red msg which includes all its black neighbors’ id and root info
If receives a connect2 msg, send connect to its gray neighbor
**Coloring Process**

- \[ 1 \]
- \[ 2 \]
- \[ 3 \]
- \[ 4 \]
- \[ 5 \]
- \[ 6 \]

**Performance Analysis**

- Performance ratio is 192.
- Message complexity \( O(n^1) \)
- Time complexity \( O(n) \)

**Mobility Model**

- Random Way-point model
  - Randomly choose a destination, move towards it at a fixed randomly chosen speed between \((v_{min}, v_{max})\). When reach the destination, pause for a uniformly-distributed pause time.
  - Border effect
    - Destination selection is not uniform, so node distribution is not uniform
    - Speed tends to be zero
- Modified Version
  - Stability parameter
  - A node selects its destination from a bigger region beyond the border
  - Bounce to move toward center when a node reaches boundary

**Simulation Results – Fixed Area**

**Simulation Results – Fixed Node**

**Simulation Results – Life Time**

<table>
<thead>
<tr>
<th>Algorithm</th>
<th>Average CDS size</th>
<th>Life Time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Marking Process</td>
<td>30.06</td>
<td>27.23</td>
</tr>
<tr>
<td>MCMIS-1</td>
<td>23.81</td>
<td>8.98</td>
</tr>
<tr>
<td>MCMIS-2</td>
<td>24.36</td>
<td>43.48</td>
</tr>
</tbody>
</table>
Conclusions

- Introduce stability into ranking
- Propose localized backbone construction algorithms which are efficient and generate small-scale and stable backbone
- Analyze the performance ratio, time and message complexity
- Verify our argument by extensive simulations

Survivability in MANET

Survivability is the capability of a system to fulfill its mission in a timely manner, even in the presence of attacks or failures

- Resistance
- Recognition
- Recovery
- Refinement

Survivability in MANET

- Challenge
  - Asymmetric link
  - Weak connectivity
  - Episodic connectivity
  - Node mobility [CMIS/MCMIS]
  - Link instability
  - Power restricted
  - Localized, adaptive algorithm

Survivability in MANET

- K-node-connectivity/k-edge-connectivity
- Multi-path routing in MANET
  - Split Multi-path Routing (SMR)
  - Ad-hoc On demand Distance Vector Multi-path routing (AODVM)
- Problems
  - Forwarding duplicate route request messages in order to find multiple path
  - Introduce more message overhead
  - Exacerbate the scalability problem
- Our proposed solution
  - Construct a k-connected virtual backbone
Survivable virtual backbone

- How to construct a virtual backbone which is k-connected with a high probability?
- After the backbone is constructed
  - Adjust the transmission range of the backbone nodes to make the backbone k-connected
  - The backbone nodes select more nodes into backbone if the connectivity requirement is not satisfied. The backbone node needs to check whether it is a bottleneck
- During backbone construction, the neighborhood of backbone node satisfies a certain criteria such that the constructed backbone is k-connected

Thank You!