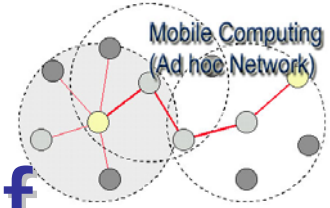
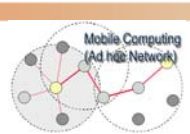
Out of IP Box: Effective Bootstrapping of Peer-to-Peer Networks over Mobile Ad-Hoc Networks



Wei Ding

Declaration

- IP box is not a network device
  - like Microsoft set-top box
  - that relay LAN/WAN cables
- Out of IP Box
  - means thinking out-of-box such that we could abandon stubborn and restrictive thought inherited (probably unconsciously) from TCP/IP protocol suite.



An Example of Out-of-Box Thinking

- Imagine a guy is driving alone in his car on a wild, stormy night. It is raining heavily. He passes by a bus stop and sees three people waiting for a bus.
  - An old lady who looks as if she is about to die.
  - An old friend who once saved his life.
  - An extremely charming girl he has been dreaming about whole his life.
- There could only be one passenger in his car.
- Who would he choose to offer a ride to so he can meet his super high standards in both ethics and utilitarianism?

Outline

1. Background Overview
2. Jump Out of IP Box: Key of Breakthrough
3. Ring Construction (RAN Protocol Suite)
4. Conclusion

1. Background Overview

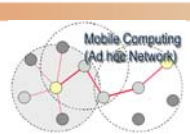
- Mobile Ad-hoc Networks (MANETs)
- Peer-to-Peer (P2P) Networks (or Systems)
- P2P Networks over MANETs
- Bootstrapping P2P Networks over MANETs

1.1 MANETs

- Wireless Distributed systems that consists of multiple mobile nodes.
- Non-neighbor nodes communicate by multi-hop relay via neighbors
- Nodes form arbitrary and transitory (so called “ad-hoc”) networks by self-organization.
- Nodes cooperate to provide network connections and thereafter functionalities.
- No infrastructure and central controller
- Mobility causes frequent topology and route change

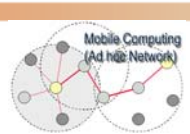
1.2 P2P Networks

- P2P networks are overlay networks
- Traditionally built on wired networks, esp. Internet
  - use IP layer as the communication medium
- Efficient resources (esp. file) sharing
  - locating and transferring
- Excellent fault tolerance
  - No single point of failure; Replicas across network
- Load balancing
- Super scalability
- Easy administration (Nodes self organizing)
- Consumers easily become producers
  - Tremendously speed up resource sharing, eg. BitTorrent



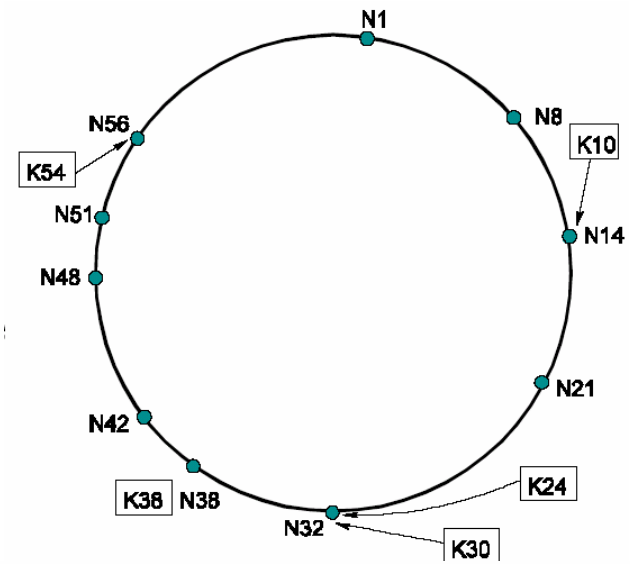
Categories of P2P Networks

- Unstructured P2P networks
  - No fixed overlay topology for routing
  - Include:
    - Centralized — Napster
    - Decentralized — Gnutella
    - Semi-centralized — KaZaA
- Structured P2P networks
  - Use simple topology like ring, grid for routing
  - Use Distributed Hash Table (DHT)
  - Guaranteed scalability, usually log(*N*) searching time
  - Fault-tolerant, one failed node only affects a small fraction of nodes
  - Excellent load balancing

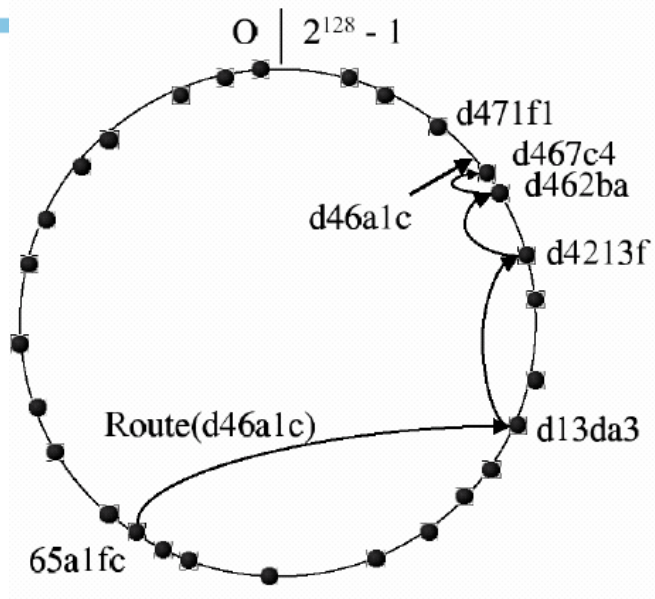


Typical Structured P2P Networks

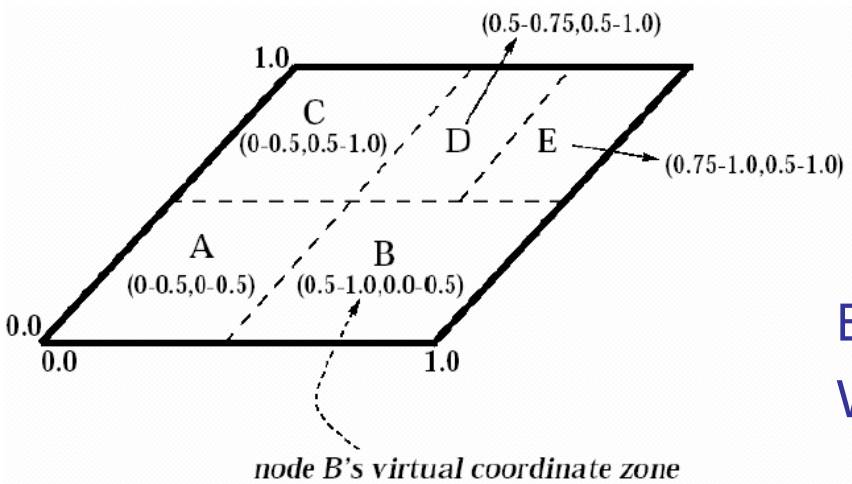
Chord Ring



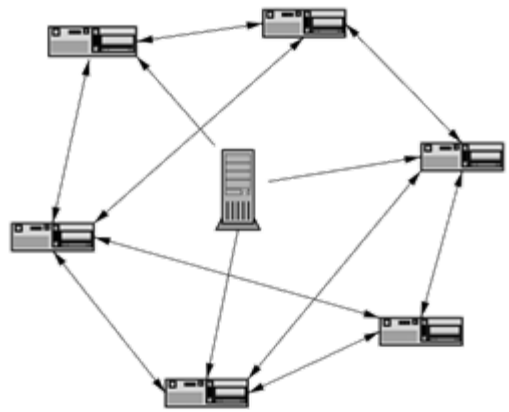
Pastry Ring



CAN Grid



BitTorrent Wheel



1.3 P2P Networks over MANETs

- MANETs and P2P networks are leading technologies of decentralization.
- They are very similar.
  - Both are distributed and dynamic.
  - Both abandoned
    - pre-existing infrastructure
    - client/server model and central controller
    - embodying “networking without networks”.
  - Both use multi-hop as basic communication pattern.
  - Both set up connection by self-organizing
- They are divergent in level of Maturity and Application

Foundation in Layer Model

- P2P networks over MANETs
  - Used to transplant achievements in P2P to MANETs
  - Naturally based on their complementary protocol stacks

ISO OSI Model	MANETs	P2P Networks
Application		Application
Presentation		Presentation
Session		Session
Transport (Routing)	Transport (Routing)	Transport (Routing)
Network	Network	
Data-link	Data-link	
Physical	Physical	

1.4 Bootstrapping: Importance

- Bootstrapping is the self-organizing procedure to initialize all nodes and set up essential connections.
- Foundation for all other procedures.
- Two steps:
  1. Automatic (Node) Address configuration
  2. Topology construction
     - set up specific network topology
     - Building (DHT)
- Our research focuses on topology construction

1.4 Bootstrapping: Status Quo

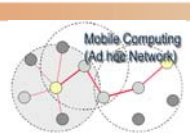
- Unsatisfactory Status Quo
  - Little effort made
  - Common circumvention: unrealistic assumptions
  - Make implementation impossible
- Prominent successes in topology construction in wired P2P networks community
  - T-Man, T-Chord, Ring Network etc.
  - IP box blocks their introduction into MANETs
- No previous success in of P2P networks over MANETs
  - Recent paper by Cramer and Fuhrmann Bootstrapping Chord in Ad Hoc Networks - Not Going Anywhere for a While gives a gloomy prediction.
  - Neither ground nor reasoning is tenable

2 Out of IP Box: Key of Breakthrough

- Problem from IP Box
- Our Solutions

2.1 Problem from IP Box

- Problems with Automatic Address configuration
  - IP Addressing Schemes Incompatible with MANETs
- Problems with Topology Construction
  - Stubborn train of thoughts from IP
- Historical Reasons
  - IP was extremely successful in wired networks.
  - Most research in MANETs was done when IP is the dominant standard.
  - Most proposals in MANETs inherited context from IP.



2.1.1 Problems with Automatic Address Configuration

IP Addressing Incompatible with MANETs

- IP address loses its routing functionality
- Hierarchical IP address becomes a pure identifier due to hardware constraints
- Replicable by any other identifier
- Many IP specifications, regulations, and provisions become impediments in terms of performance and efficiency.

2.1.2 Problems with Topology Construction

- Topological structure is essential for structured P2P networks over MANETs.
  - Routing and data transmission are based on it.
  - Successes in wired P2P community (T-Man, T-Chord, Ring Network etc.) can not be transferred to MANETs
  - T-Man etc. basically do not need IP
    - They work on flat dynamic networks without hierarchy
  - IP Box requires “replacing layers below IP in wired P2P networks with networking layer and routing protocols of MANETs”
  - The requirement makes the transferal impossible

2.2 Our Solutions

- FAPSR for Automatic Address Configuration
  - Flat Address P2P Source Routing protocol
  - A novel non-IP addressing scheme
  - No predicaments from IP addressing
  - Use Pastry node ID for P2P layer and Network layer
  - Efficient, light-weighted

2.2 Our Solutions - Continued

- RAN to build a ring topology in node ID space
  - Ring Ad-hoc Network protocol
  - Configuration free, self stabilizing
  - First successful attempt in the field
  - Have root in T-Man, T-Chord, and Ring Network
  - Adapt very well to MANETs
  - Use only neighbors and local information
  - On this ring Chord protocol could run immediately without stabilization
  - Integrates automatic non-IP address configuration into bootstrapping

3 Ring Construction

- Ring Ad-hoc Network (RAN), a ring construction protocol for structured P2P networks over MANETs
  - First successful attempt in the filed of bootstrapping
- Related Works
  - Chord
  - T-man
  - T-Chord
  - RN
- Protocol Details
- Algorithms
- Simulation

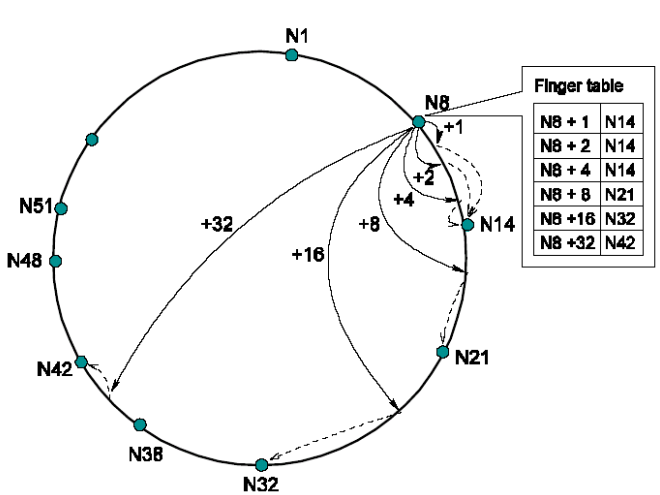
3.1 Related Works - Chord

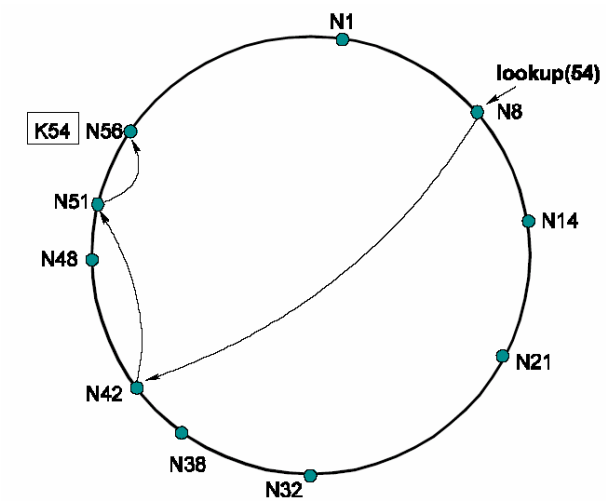
- Consistent Hashing
  - assign ID to nodes and keys and provide DHT
  - Make routing scalable to network size
    - A node track O (log N) other nodes in its finger table
    - lookup for a key only needs O (log N) messages
    - map keys evenly to nodes
    - scalable to base
    - superb load balance
  - Make Chord stable
    - smoothly absorb disturbance from joining and leaving
    - only move $O(1/N)$ keys in network to maintain load balance

3.1.1 Chord – Continued

- Finger table
  - n's ith finger points to first node that succeeds n by 2^{i-1}
  - To look up a key, first locate the furthest node that precedes the key in the finger table.

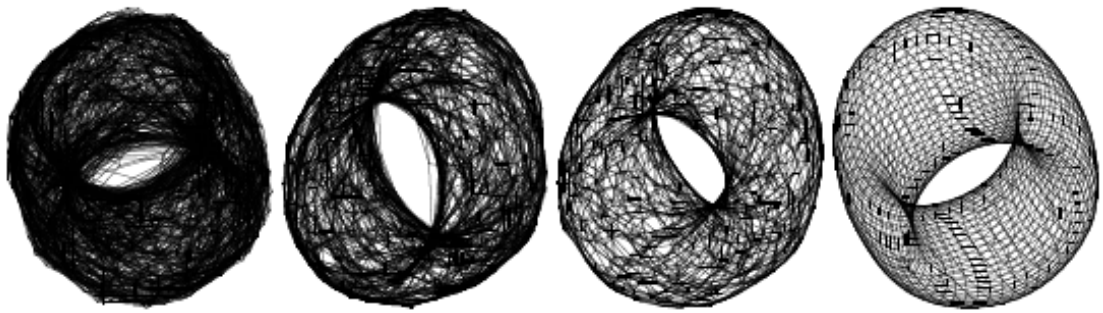
```
n.find_successor(id)
if (id ∈ (n, successor])
    return successor;
else
    p = closest_preceding_node(id);
return p.find_successor(id);

n.closest_preceding_node(id)
for i = m downto 1
    if (finger[i] ∈ (n, id))
        return finger[i];
return n;
```





3.1.2 T-Man

- T-Man breaks away from old style of bootstrapping
  - No a prior configured initial network or jumpstart nodes.
  - All starts simultaneously
  - Topology is defined by a ranking function, which is very versatile.
  - Constructing is realized via connecting nodes to right neighbors.
  - nodes executes the same protocol concurrently.
- Old stereotype of bootstrapping.
  - Use jumpstart nodes and joining procedure.
  - Nodes are booted one by one in a sequence.

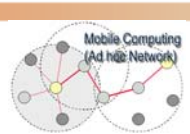


3.1.3 T-Chord

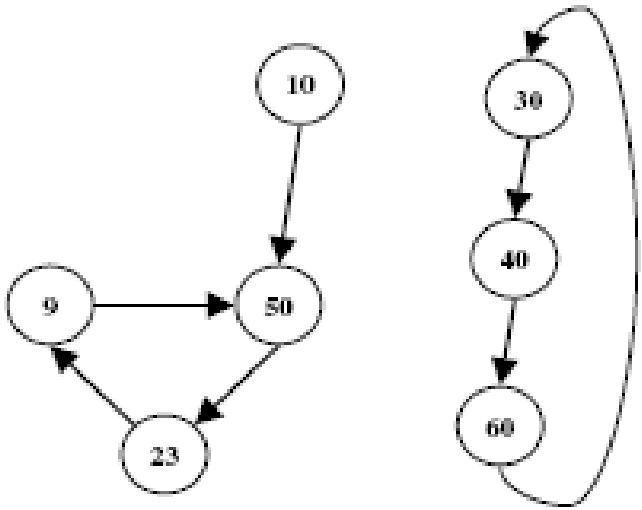
- Based upon T-Man
- Starts from an unstructured random topology.
- Not include node ID automatic configuration.
- IDs from a circular ID space are a prior configured
- Then T-Man is called to build the ring.
- Outcome is successor and predecessor of ring.
- However, it does not work on MANETs.

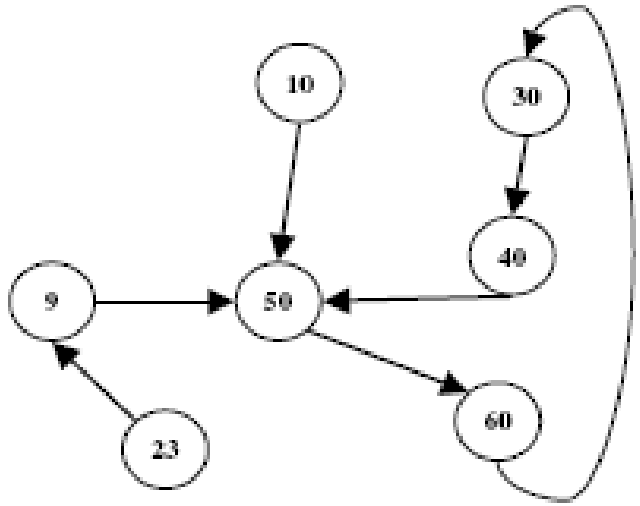
3.1.4 RN (Ring Network)

- An asynchronous message-passing protocol
- Require a weakly connected initial network called minimum bootstrapping system.
  - not specify the scale of the bootstrapping system and how the system is configured.
- Peers asynchronously run same protocol and exchange messages.
- A peer periodically calls *CloserPeerSearch* procedure to find a closer successor.
- Peers record information from any message received.
- each peer selects a currently closest successor.
- This process repeats till a complete ring is formed.

3.1.4 RN (Ring Network)

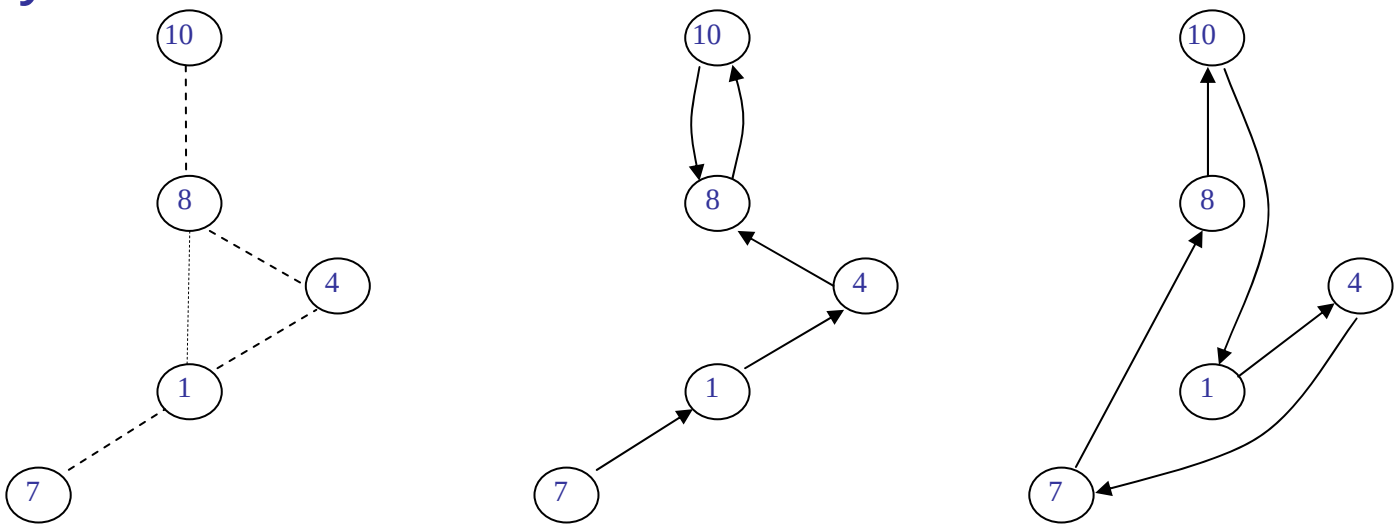




Closer Peer Search

3.2 RAN Protocol Details

- Integrate merits of T-Chord and RN
- RAN builds an ideal ring for each connected component.
- Chord run immediately on the generated ring without lengthy stabilization.

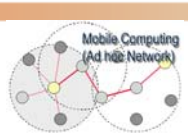


Left is a network with only neighborhood relation
Middle shows original successor relation.
Right is successor relation after running RAN

3.2.1 Component Tree

Spanning tree of the connected graph which is derived from a connected component.

- Set the searching node as the root.
- Add all neighbors of root to the first level of the tree
- At all following levels, construct the next level according to the direct neighborhood relation.
- Delete all edges which connect a lower level node to an upper level node.



3.2.2 Three Patterns to Find Optimal

- Balance between effectiveness and efficiency.
- Two exhaustive patterns (Distributed, Virtual Centralized)
  - use unicast in message exchange
  - exhaustive search at each level of component tree
  - Output is guaranteed to be ideal
  - all node IDs are compared
  - Exhaustion may suffer from high cost
  - Distributed exhaustive pattern has better performance
- Random pattern has its root in RN.
  - use BFS in lieu of minimum bootstrapping system.
  - Search traverses the entire component to make up the poor effectiveness of RN.

3.2.3 Two Options to Improve Efficiency

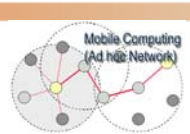
- Approximation Option
  - applies to all patterns
  - not change underlying algorithm
  - loosen the end condition of all patterns.
  - Originally patterns set the ideal ring as objective.
  - approximation option allow a small fraction of nodes left out of the final rings.
- Multicast option
  - A node sends a message to all direct downward neighbor nodes by one multicasting instead of multiple unicasting messages.
  - Considerably improves time, message, and storage complexity.
  - Multicast option can not be applied to random pattern.

3.3 Algorithms

- RAN algorithms one-to-one map to RAN patterns
- Random Algorithm
- Distributed Exhaustive Algorithm
- Virtual Centralized Exhaustive Algorithm

3.3.1 Distributed Exhaustive Algorithm

- Searching node sends a Best Candidate Request message to each child.
- Each child concurrently forwards the message to its children
- At following levels nodes forward the message to next level children in same manner until leaf nodes encountered.
- From leaf nodes up, the best candidate in the subtree is calculated at the root of the subtree.
- Best candidate is returned to parent node in a Best Candidate message.
- Distributed Exhaustive Algorithm

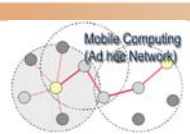


3.3.2 Virtual Centralized Exhaustive Algorithm

- Root sends an All Neighbors Request message to each child and asks them to return their children.
- After receiving all returned neighbor sets from current level, root sets the union of returned neighbor sets as its next level set.
- It sets next level as current level, and does the same thing till leaves are reached.
- Most expensive in in time and message.
- However, it gives the root node tremendous power to control whole process.
  - In real world application, a provider could provide individualized service if virtual centralized exhaustive pattern is used to construct the ring.
- Virtual Centralized Exhaustive Algorithm

3.3.3 Random Algorithm

- Have root in RN
- The basic idea is to seek high efficiency.
- At each level of the component tree, we do not search every node like in exhaustive algorithms.
  - pick up only the closest neighbor of current node.
- random algorithm



3.4 Simulation

- Metrics
  - completeness
  - Time
  - number of sent messages
  - number of received messages
- Analysis of Results

3.4.1.1 Completeness (effectiveness)

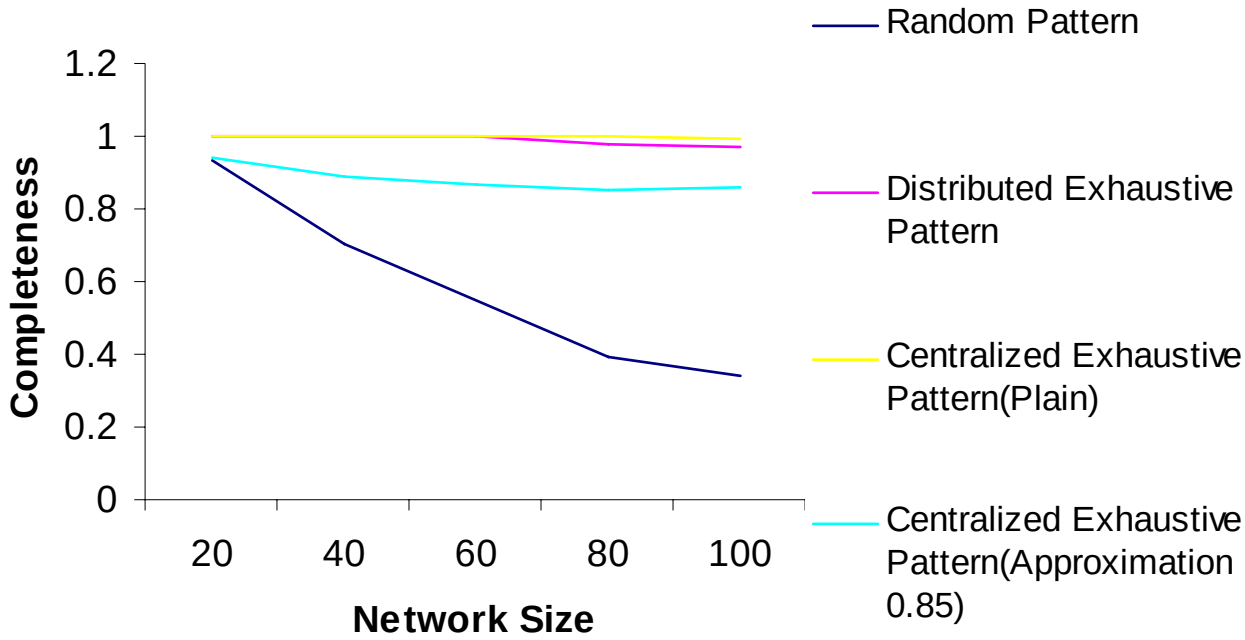


Figure 7.1 Completeness of algorithms

Network Size	20	40	60	80	100
Random Pattern	0.93	0.705	0.547	0.395	0.343
Distributed Exhaustive Pattern	1	1	1	0.98	0.97
Centralized Exhaustive Pattern	1	1	1	1	0.99
Centralized Exhaustive Pattern(Approximation 0.85)	0.94	0.89	0.87	0.855	0.86

3.4.1.2 Time

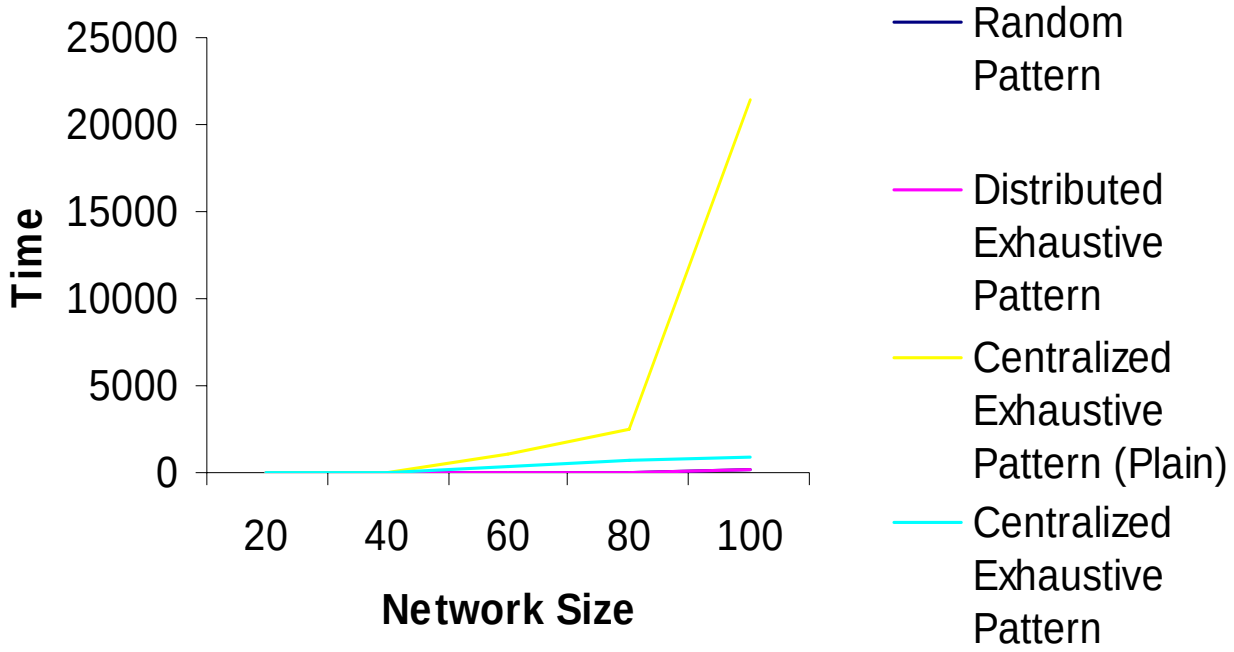


Figure7.2 Time used in ring construction

Network Size	20	40	60	80	100
Random Pattern	11.8	15	32	63.6	91
Distributed Exhaustive Pattern	8.3	21.8	43	87.4	98.5
Centralized Exhaustive Pattern (Plain)	5.8	56.4	1091.4	2552	21409
Centralized Exhaustive Pattern	6	49.6	313.8	632	910

3.4.1.3 Messages Sent

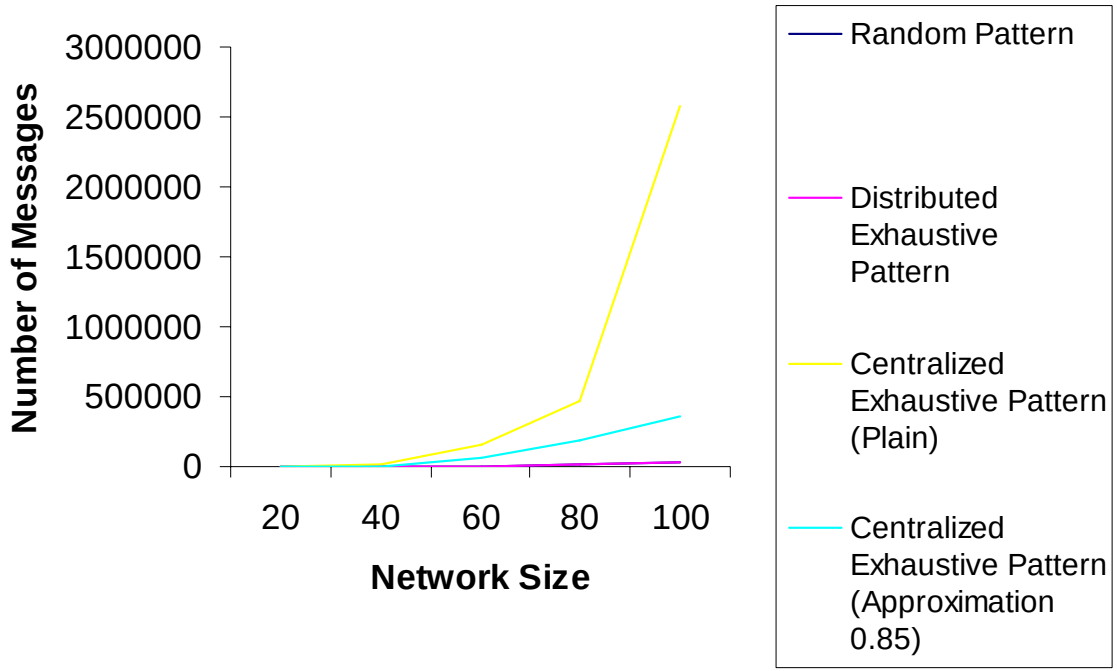


Figure 7.3 Messages sent

Network Size	20	40	60	80	100
Random Pattern	72.8	1117.8	4721	13839	25117.3
Distributed Exhaustive Pattern	103.6	1355.1	5089.8	16077	26853.5
Centralized Exhaustive Pattern (Plain)	412	15863.4	162705.6	465754.6	2581659.6
Centralized Exhaustive Pattern (Approximation 0.85)	226	5556.8	62625.4	186703	364112.2

3.4.1.4 Messages Received

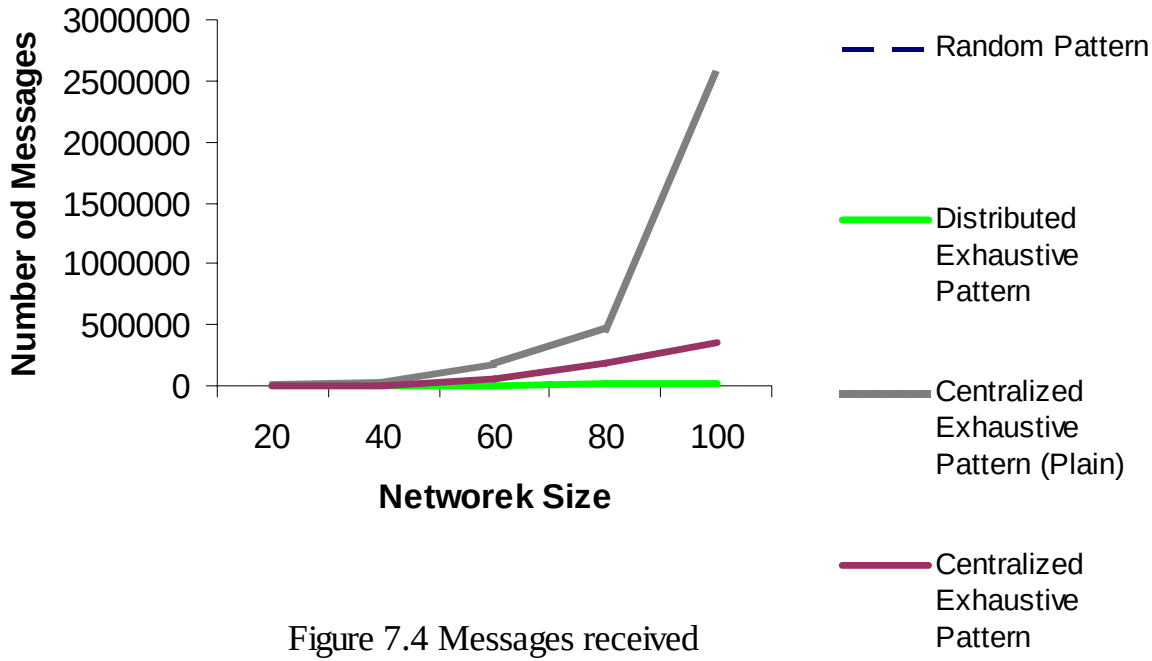


Figure 7.4 Messages received

Network Size	20	40	60	80	100
Random Pattern	72.8	1117.8	4721	13839	25117.3
Distributed Exhaustive Pattern	98	1312.8	5045	15938.3	26783
Centralized Exhaustive Pattern (Plain)	394.6	15639	161335.2	460179.4	2539312.2
Centralized Exhaustive Pattern (Approximation 0.85)	209.8	5452.2	61693.8	183749.6	358354

3.4.2 Analysis of Results

- Distributed exhaustive pattern is the best.
  - It shows perfect effectiveness with no serious side effect
  - Random pattern suffers from its effectiveness.
  - Virtual centralized exhaustive pattern suffers from efficiency.
- Random pattern has best overhead cost in both time and message.
  - also the worst approach in terms of quality of ring
  - closest first criterion does not work in a pure stochastic ID space.
- facing of randomness, exhaustion in search is necessary.

4 Conclusion

- This research targets at the important intersection of two hot research topics
  - peer-to-peer networks
  - mobile ad-hoc networks
- We investigated successful and failed research efforts in synergy of P2P networks and MANETs
- We made two ground-breaking contributions to bootstrapping P2P networks over MANETs.
  - Non-IP automatic address configuration scheme
    - With Well-rounded FAPSR protocol for P2P over MANETs
  - A novel ring construction protocol RAN for building P2P systems over MANETs.

4.1 Non-IP automatic address configuration

- We analyzed advantages of this scheme comparing to other IP-based addressing approaches.
  - IP-based schemes waste the precious bits in MANETs.
  - The requirement for IP address unnecessarily makes the addressing task complicated.
  - The only benefit of IP in MANETs is easier to interface with Internet and existing applications.
- These excuses form no obstacle for our scheme.
  - Our scheme circumvents Internet connection problem by using network gateway.
  - For application compatibility, we can use a virtual mapping layer to convert IP address and our non-IP address into each other.

4.2 Ring Construction Protocol RAN

- RAN protocol suite for ring topology construction
  - RAN builds perfect ring in P2P ID space using only simple unicast and multicast.
  - No underlying MANETs routing protocols are needed.
  - Chord could immediately start without lengthy stabilization.
  - Distributed exhaustive pattern is the best in terms of effectiveness and efficiency.