Declarative Policy-based Adaptive MANET Routing

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Motivation

• Variety of MANET routing protocols
  • Reactive (DSR, AODV)
  • Proactive (LS, OLSR, HSLS)
  • Epidemic
  • Hybrid (ZRP, SHARP)

• However, a one-size-fits-all MANET protocol DOES NOT exist:
  • Variability in network connectivity, wireless channels, mobility
  • Wide range of traffic patterns
Approach

• Policy-based adaptive protocols
  • Composed from any number of known protocols
  • Generic set of policies for selecting and switching amongst different routing protocols due to network/traffic conditions

• Declarative networking
  • A general platform and framework for specifying and implementing network protocols
Declarative Networking [Loo et. al., SIGCOMM’05]

- Use a database query language to specify network protocols
- Specifying “what” to do instead of “how”
- Distributed query engine executes specifications to implement network protocols
  - Similar to Click modular router
- Efficient performance compared to imperative implementations
Why Declarative for MANETs?

- Compact and high level representation of protocols
  - Orders of magnitude reduction in code size
  - Chord DHT in 47 rules
  - MANET routing protocols in a few rules

- Easy customization for policy-based adaptive MANETs
Example (1): Link State

ls1 lsu(@*,S,N,C,N) :- periodic(@S,T), link(@S,N,C).

- Input: link (@src, next, cost)
- Output: lsu (@loc, src, next, cost, from)
Example(2): Hazy Sighted Link State

hs1 lsu(@*, S, N, C, N, TTL) :- periodic(@S, T), link(@S, N, C),
TTL=fpow(2, K), T=TTL * Tp,
K=range[1, 5].

hs2 lsu(@*, S, N, C, Z, TTL) :- lsu(@Z, S, N, C, W), TTL > 0.

- Input: link (@src, next, cost)
- Output: lsu (@loc, src, next, cost, from)
- Scoped flooding
  - Link updates to farther nodes sent less frequently
  - TTL field to limit the forwarding range of LSU
Declarative MANET protocols

- **Reactive**
  - DSR (Dynamic Source Routing) (10 rules)

- **Proactive**
  - LS (Link State) (8 rules)
  - HSLS (Hazy Sighted Link State routing) (14 rules)
  - OLSR (Optimized Link State Routing) (27 rules)

- **Epidemic**
  - Summary Vector based (16 rules)
Validation of Declarative MANETs

- Declarative MANET protocols executed by the P2 declarative networking system
- Local cluster consisting of 15 nodes interconnected by high-speed Ethernet emulating up to 40 MANET nodes
- Emulate network dynamics by adding/deleting links during rule execution

Declarative MANETs show expected scalability trends
Measurements on ORBIT Wireless Testbed

- **ORBIT** wireless testbed at Rutgers University
- 1 Ghz VIA Nehemiah, 64 KB cache, 512 MB RAM
- Atheros AR5212 chipset 802.11 a/b/g ad hoc mode
- 33 nodes in a 7m x 5m grid
Policy-based Adaptive MANETs

- In declarative networking framework
  - Hybrid protocol composed from any number of known protocols
  - Generic set of policies for selecting and switching among different routing protocols due to network/traffic conditions
  - Policies also specified in declarative language

- Examples
  - Hybrid link state
  - Hybrid proactive-epidemic
Example(1): Hybrid Link State

- **LS**: quick convergence, may perform better in stable network
- **HSLS**: incurs low bandwidth overhead, scales better
- **Switch between LS and HSLS**
  - Low mobility: LS
  - High mobility: HSLS
  - Mobility measurement: link average availability (AA), i.e. percentage of time when link is up

```c
#define THRES 0.5
s1 linkAvail(@M, AVG<AA>) :- lsu(@M, S, N, AA, Z, K).
s2 useHSLS(@M) :- linkAvail(@M, AA), AA<THRES.  // unstable
s3 useLS(@M) :- linkAvail(@M, AA), AA>=THRES.  // stable
```
Evaluation of Hybrid Link State

- 33 wireless nodes on 7m x 5m grid on ORBIT testbed that communicate over 802.11a
- Linux *iptables* to filter packets from non-neighbors
- Emulate 2-dimensional random waypoint model
- Random jitter and desynchronized broadcasting to alleviate packet collision
- Alternate at 60 seconds interval of:
  - Moderate stage: nodes move at 0.06 m/s
  - Fast stage: nodes move at 0.15m/s
Evaluation of Hybrid Link State

- Link dynamics
- Average link AA
- Protocol switching
- Bandwidth overhead
- Route

Hybrid Link State protocol achieves the best of both LS and HSLS
Example(2): Hybrid Proactive-Epidemic

- LS: good performance for well connected network
- Epidemic: for DTN, reliable message delivery in the sacrifice of high bandwidth
- Switch between LS and Epidemic
  - Well connected network: LS
  - Disrupted network: Epidemic
  - Network connectivity measurement: path length
- Refer to our paper for more details about evaluation

Declarative framework makes it easier to express policies for runtime adaptation of routing protocols
Summary

- MANET protocols in declarative framework
  - Reactive, Proactive, Epidemic
  - Compact specification
  - Exhibit expected behaviors

- Policy-based adaptive MANETs
  - Easy to build using existing declarative MANET protocols
  - Protocol switching due to policies and network/traffic conditions
  - Experiment results demonstrate that hybrid protocol can achieve the best of different protocols
Ongoing work

- Enhance declarative policy-based framework for adaptive protocols
  - Adapt in a unified manner amongst proactive, reactive and epidemic
  - Integrate with a channel selection policy engine
- Formally verifiable networking
  - Verification of network protocols [HotNets ‘09]
- RapidNet
  - A development toolkit that unifies rapid prototyping, simulation and experimentation [SIGCOMM ’09 Demo]
  - Integrates a declarative networking engine with the ns-3 network simulator and emulator
  - Successful evaluation on the ORBIT testbed [WinTECH ’09]
Backup
Network Datalog (NDlog) Example

R1: reachable(@S,D) ← link(@S,D)
R2: reachable(@S,D) ← link(@S,Z), reachable(@Z,D)

"For all nodes S, D, "
If there is a link from S to D, then S can reach D”.

reachable(@a,b) – “node a can reach node b”

Input: link(@source, destination)
Output: reachable(@source, destination)
Network Datalog (NDlog) Example

R1: reachable(@S,D) ← link(@S,D)

R2: reachable(@S,D) ← link(@S,Z), reachable(@Z,D)

“For all nodes S, D and Z,
If there is a link from S to Z, AND Z can reach D, then S can reach D”.

Input: link(@source, destination)
Output: reachable(@source, destination)
Epidemic (Summary vector based)

\[ e1 \] \ eBitVecReq(\@Y,X,V) :- summaryVec(\@X,V),
\quad eDetectNewLink(\@X,Y).

\[ e2 \] \ eBitVecReply(\@X,Y,V) :- eBitVecReq(\@Y,X,V1),
\quad summaryVec(\@Y,V2),
\quad V = f\_vec\_AND(V1,f\_vec\_NOT(V2)).

\[ e3 \] \ eNewMsg(\@Y,I,S,D) :- eBitVecReply(\@X,Y,V),
\quad msgs(\@X,I,S,D),
\quad f\_vec\_in(V,I)==true.

\[ e4 \] \ msgs(\@Y,I,S,D) :- eNewMsg(\@Y,I,S,D).
Evaluation of Hybrid Proactive Epidemic

- Emulate 35 wireless nodes on 7m x 5m grid on local cluster
- Application level filtering to accept packets only from neighbors
- Emulate 2-dimensional random waypoint model
- Vary neighbor distance to construct connected/disconnected network
- Alternate at 60 seconds interval:
  - Low connectivity with high mobility: nodes move at 0.03 m/s
  - High connectivity with low mobility: nodes move at 0.001 m/s
Evaluation of Hybrid Proactive Epidemic

- Performance Metrics:
  - Per-node communication bandwidth overhead
  - Packet delivery ratio: messages are forwarded from random sources to random destination

<table>
<thead>
<tr>
<th>Connectivity</th>
<th>Performance</th>
<th>LS</th>
<th>Epidemic</th>
<th>Hybrid-Epi</th>
</tr>
</thead>
<tbody>
<tr>
<td>Low</td>
<td>BW (KBps)</td>
<td>3.2</td>
<td>14.8</td>
<td>14.9</td>
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<tr>
<td></td>
<td>Delivery Ratio</td>
<td>80.1%</td>
<td>100%</td>
<td>100%</td>
</tr>
<tr>
<td>High</td>
<td>BW (KBps)</td>
<td>0.25</td>
<td>8.3</td>
<td>0.24</td>
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<tr>
<td></td>
<td>Delivery Ratio</td>
<td>99.4%</td>
<td>100%</td>
<td>97.5%</td>
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</tbody>
</table>

Hybrid Proactive Epidemic achieves the best of both LS and Epidemic