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

Broadcast specifier

Built-in periodic trigger

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

ls2 lsu(@*,S,N,C,Z) :- lsu(@Z,S,N,C,W).

- 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=f_pow(2,K), T=TTL*Tp,
K=range[1,5].

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

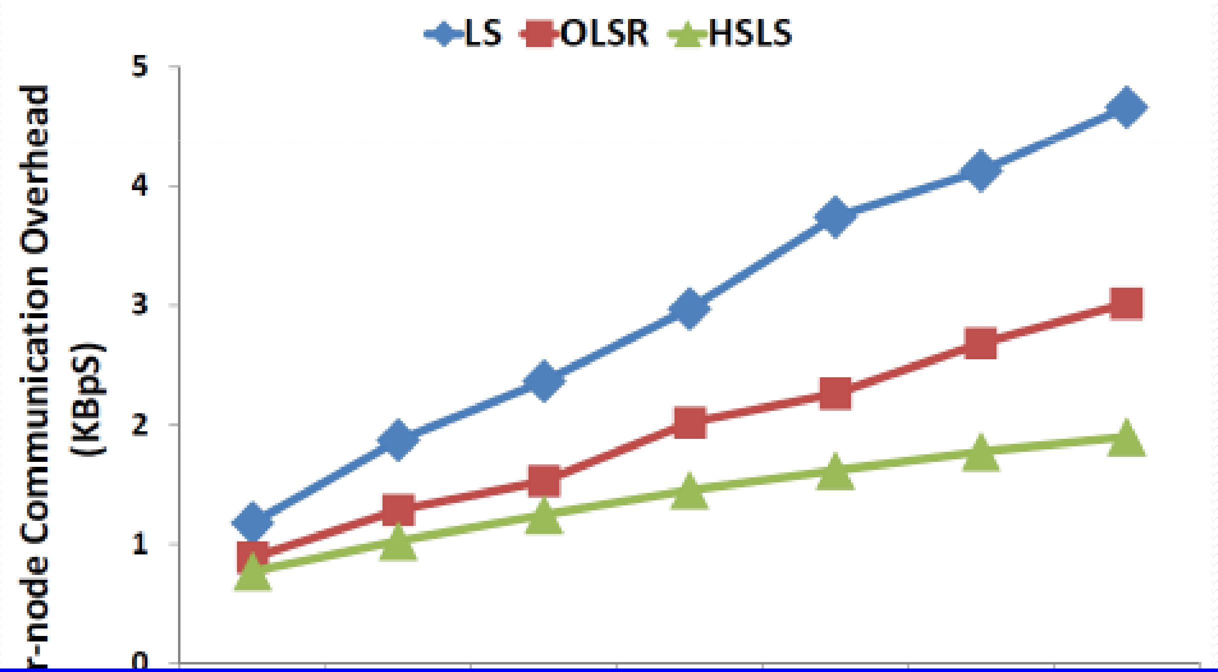
- Input**: link (@src, next, cost)**
- Output: **lsu (@loc, src, next, cost, from)**
- Scoped flooding
  - Link updates to farther nodes sent less frequently
  - TTL field to limit the forwarding range of LSU

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

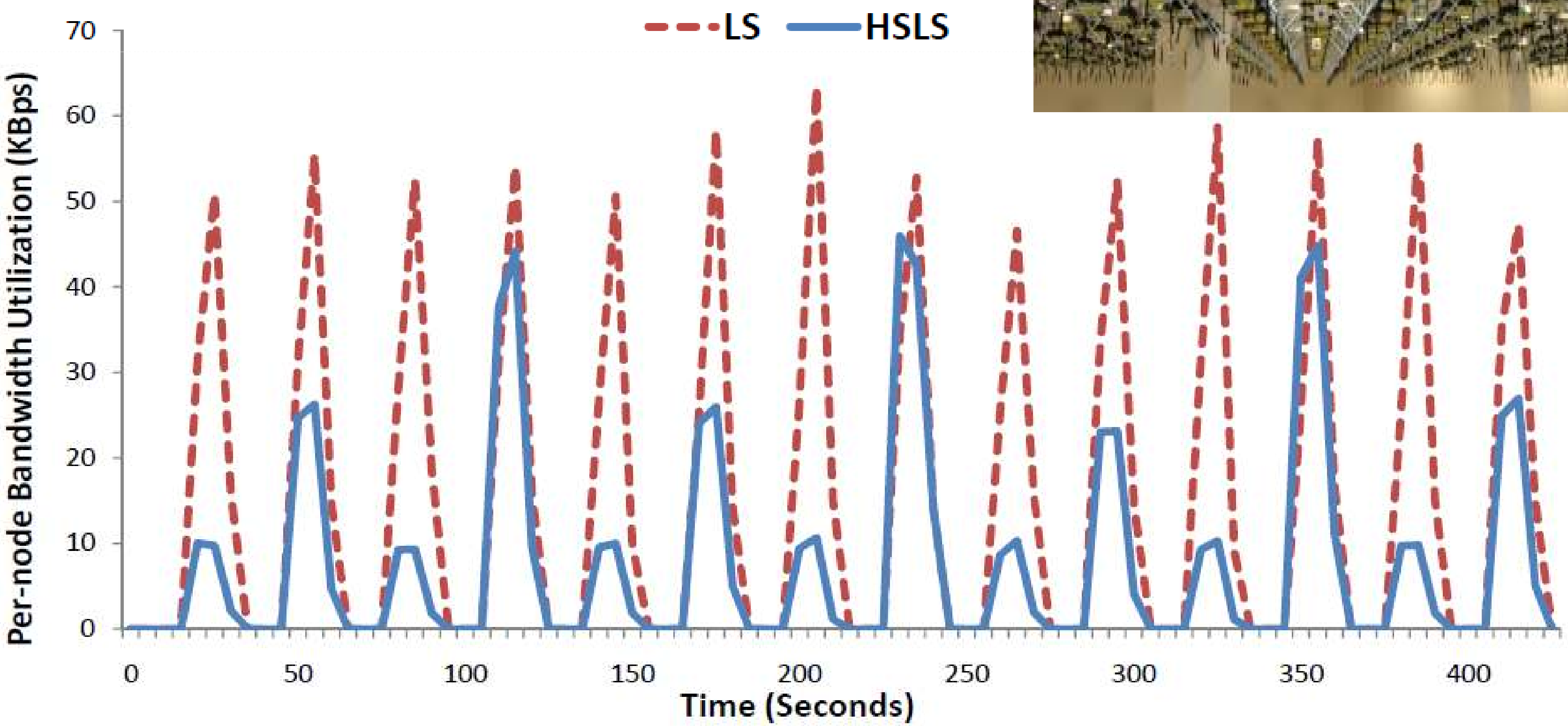
- Declarative MANET protocols executed by the P2 declarative networking system
- Local cluster consisting of 15 nodes interconnected by high-speed Ethernet emulating up to 40 MANET nodes
- Emulate network dynamics by adding/deleting links during rule execution



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

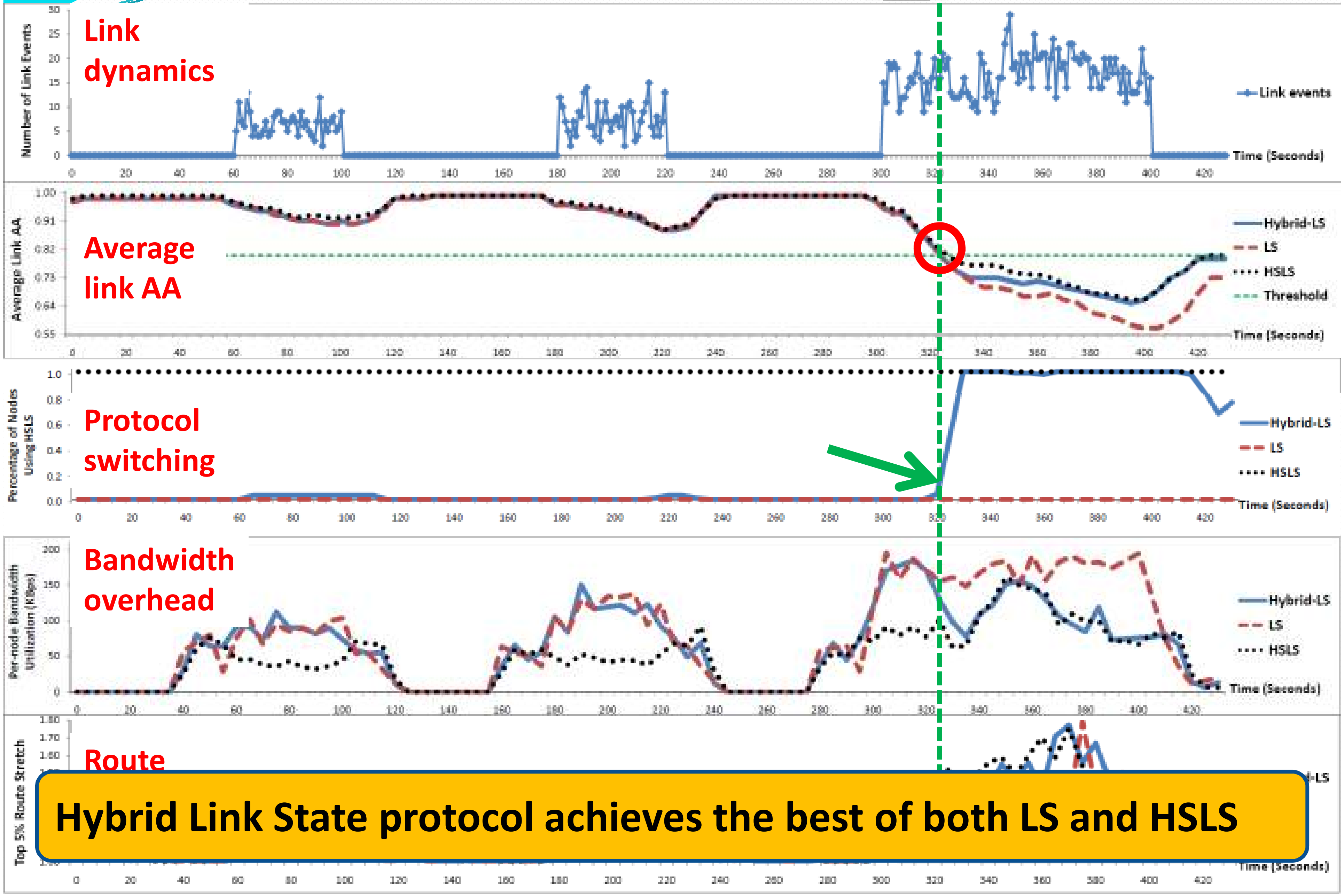
- LS: quick convergence, may perform better in stable network
- HSLS: incurs low bandwidth overhead, scales better
- **Switch between LS and HSLS**
  - Low mobility: LS
  - High mobility: HSLS
  - Mobility measurement: link average availability (AA), i.e. percentage of time when link is up

```
#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



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

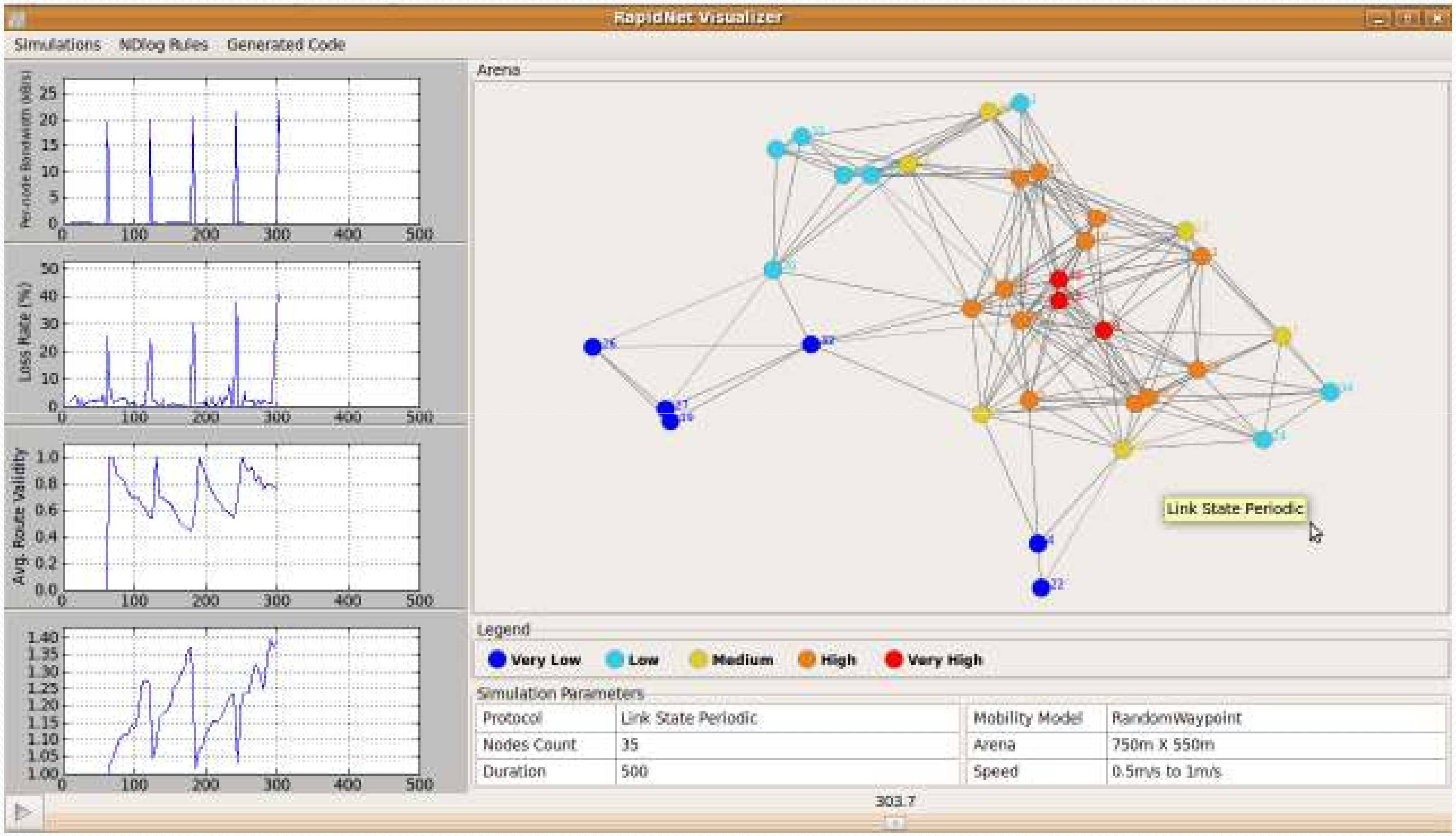
Summary

- 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]**

RapidNet open source code release: **http://netdb.cis.upenn.edu/rapidnet/**



Thank you!

Backup

Network Datalog (NDlog) Example

R1: reachable(@S,D) ← link(@S,D)

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

link(@a,b) – "there is a link from node *a* to node *b*"

"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),
                        eDetectNewLink(@X,Y).
e2 eBitVecReply(@X,Y,V):- eBitVecReq(@Y,X,V1),
                          summaryVec(@Y,V2),
                          V=f_vec_AND(V1,f_vec_NOT(V2)).
e3 eNewMsg(@Y,I,S,D):- eBitVecReply(@X,Y,V),
                       msgs(@X,I,S,D),
                       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 0.001m/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

Connectivity	Performance	LS	Epidemic	Hybrid-Epi
Low	BW (KBps) Delivery Ratio	3.2 80.1%	14.8 100%	14.9 100%
High	BW (KBps) Delivery Ratio	0.25 99.4%	8.3 100%	0.24 97.5%

Hybrid Proactive Epidemic achieves the best of both LS and Epidemic