

Declarative Policy-based Adaptive MANET Routing

Changbin Liu*, Ricardo Correa*, Xiaozhou Li*
Prithwish Basu†, Boon Thau Loo*, Yun Mao‡

*University of Pennsylvania



†BBN Technologies



‡ AT&T Labs - Research



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 $\text{lsu}(@^*, S, N, C, N) :- \text{periodic}(@S, T), \text{link}(@S, N, C).$

ls2 $\text{lsu}(@^*, S, N, C, Z) :- \text{lsu}(@Z, S, N, C, W).$

- Input: **link (@src, next, cost)**
- Output: **lsu (@loc, src, next, cost, from)**

Example(2): Hazy Sighted Link State

hs1 $\text{Isu}(@^*, S, N, C, N, \text{TTL})$:- $\text{periodic}(@S, T)$, $\text{link}(@S, N, C)$,
 $\text{TTL} = f_pow(2, K)$, $T = \text{TTL} * T_p$,
 $K = \text{range}[1, 5]$.

hs2 $\text{Isu}(@^*, S, N, C, Z, \text{TTL})$:- $\text{Isu}(@Z, S, N, C, W)$, $\text{TTL} > 0$.

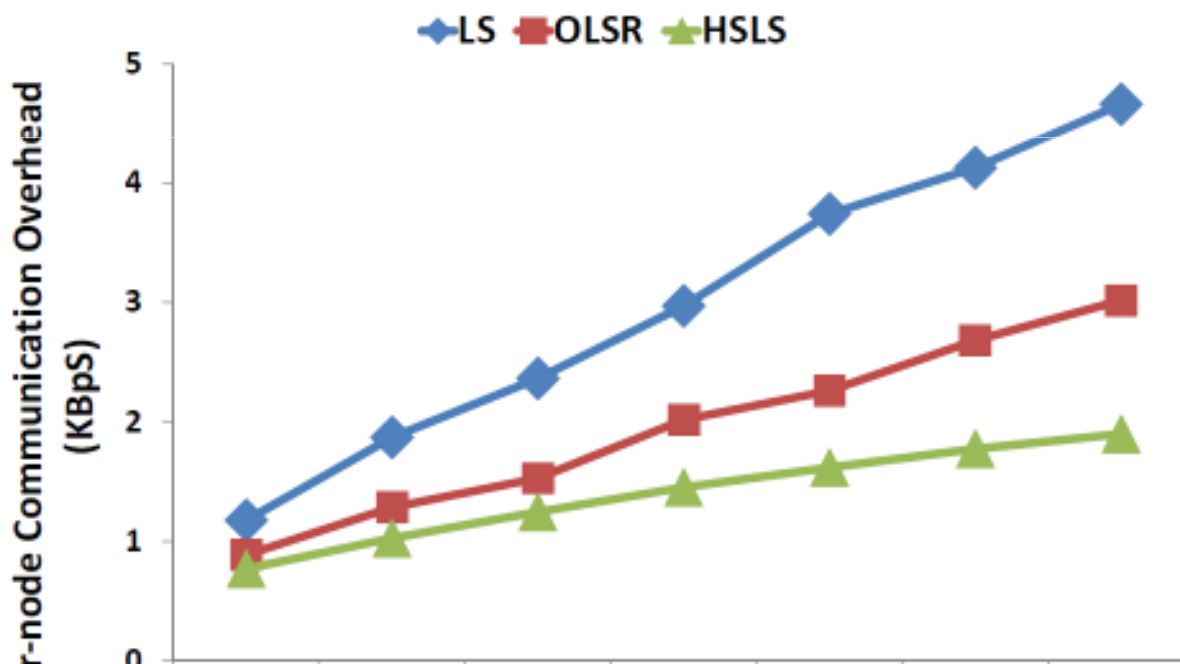
- Input: $\text{link}(@src, next, cost)$
- Output: $\text{Isu}(@loc, src, next, cost, from)$
- Scoped flooding
 - Link updates to farther nodes sent less frequently
 - TTL field to limit the forwarding range of LSU

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

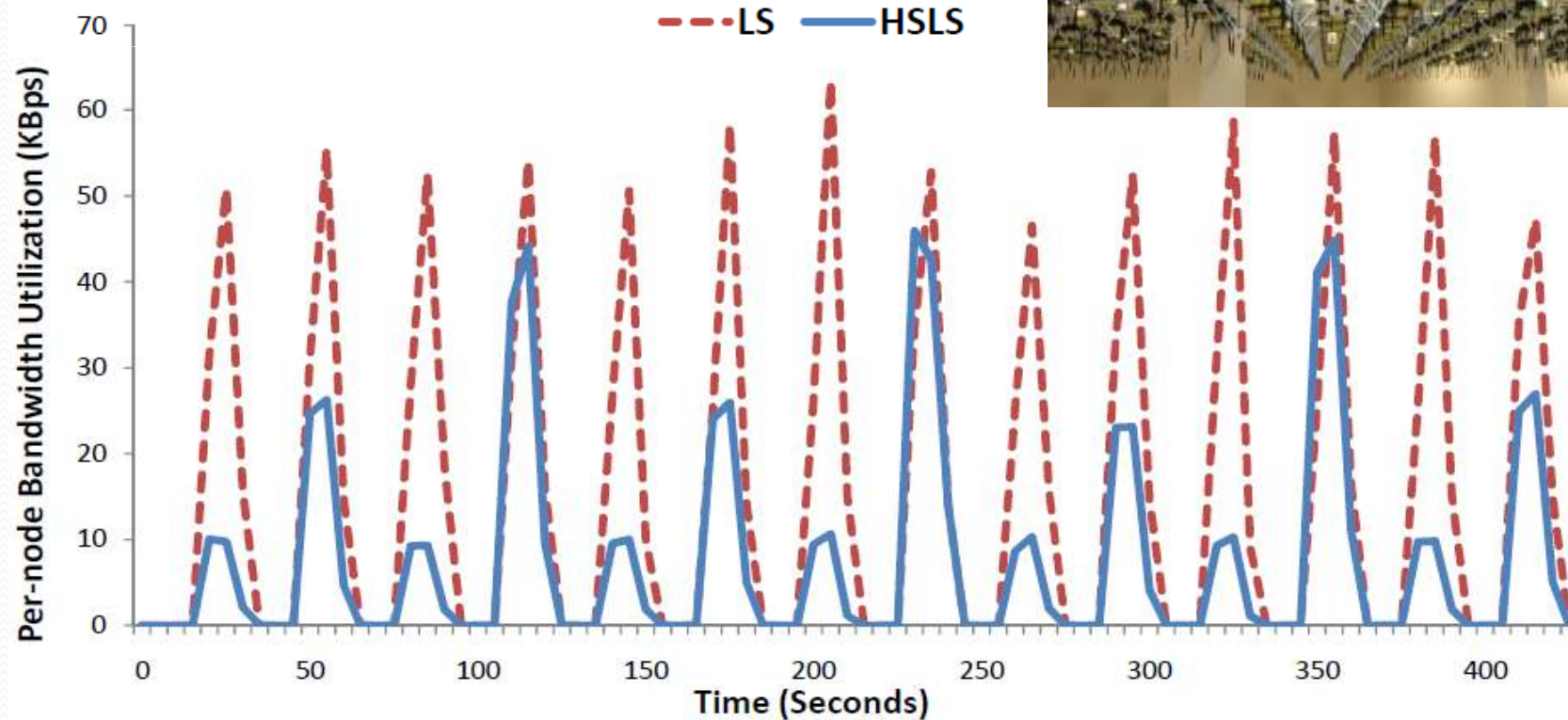
- Declarative MANET protocols executed by the P2 declarative networking system
- Local cluster consisting of 15 nodes interconnected by high-speed Ethernet emulating up to 40 MANET nodes
- Emulate network dynamics by adding/deleting links during rule execution



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

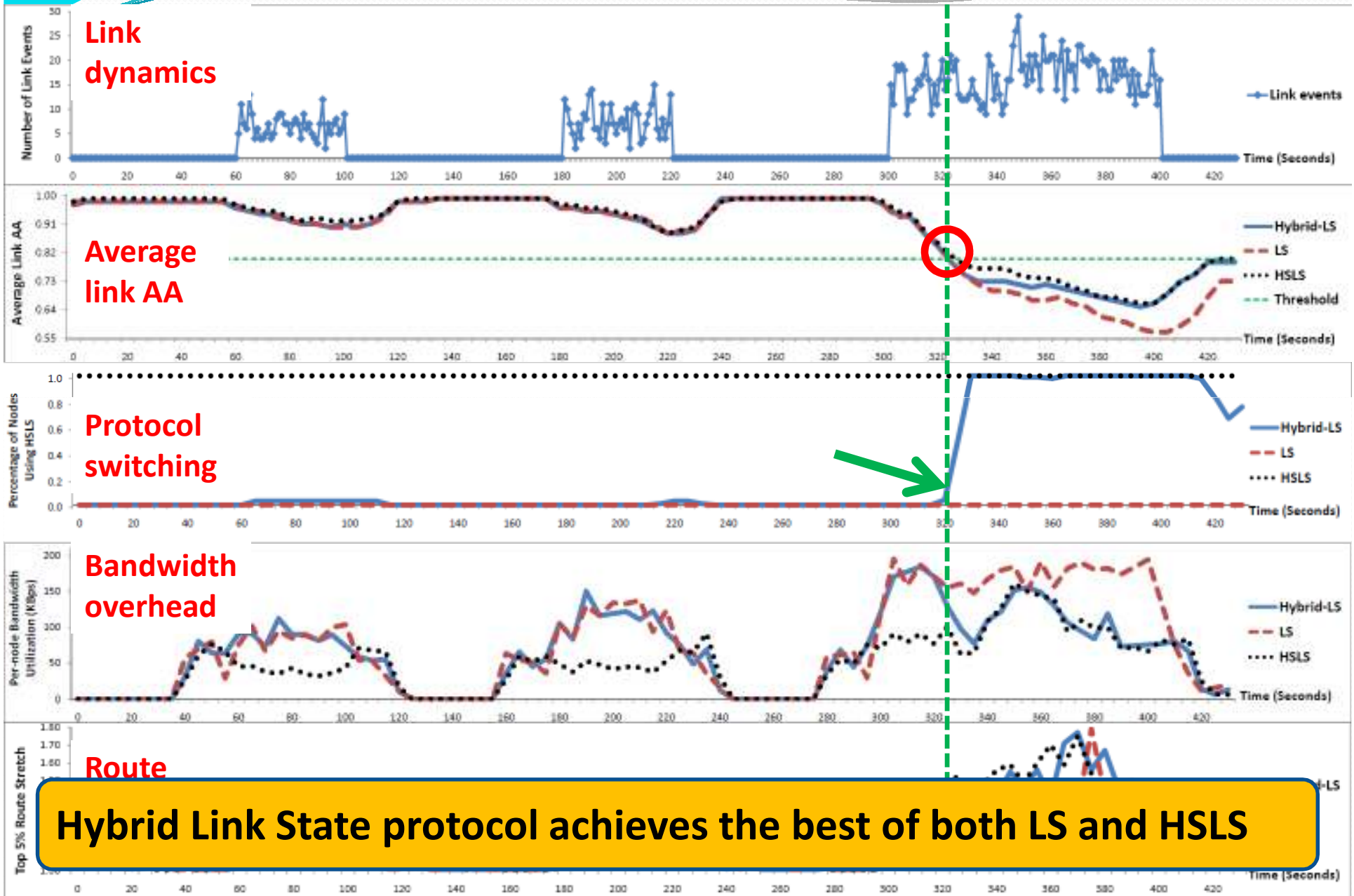
- LS: quick convergence, may perform better in stable network
- HSLS: incurs low bandwidth overhead, scales better
- **Switch between LS and HSLS**
 - Low mobility: LS
 - High mobility: HSLS
 - Mobility measurement: link average availability (AA), i.e. percentage of time when link is up

```
#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

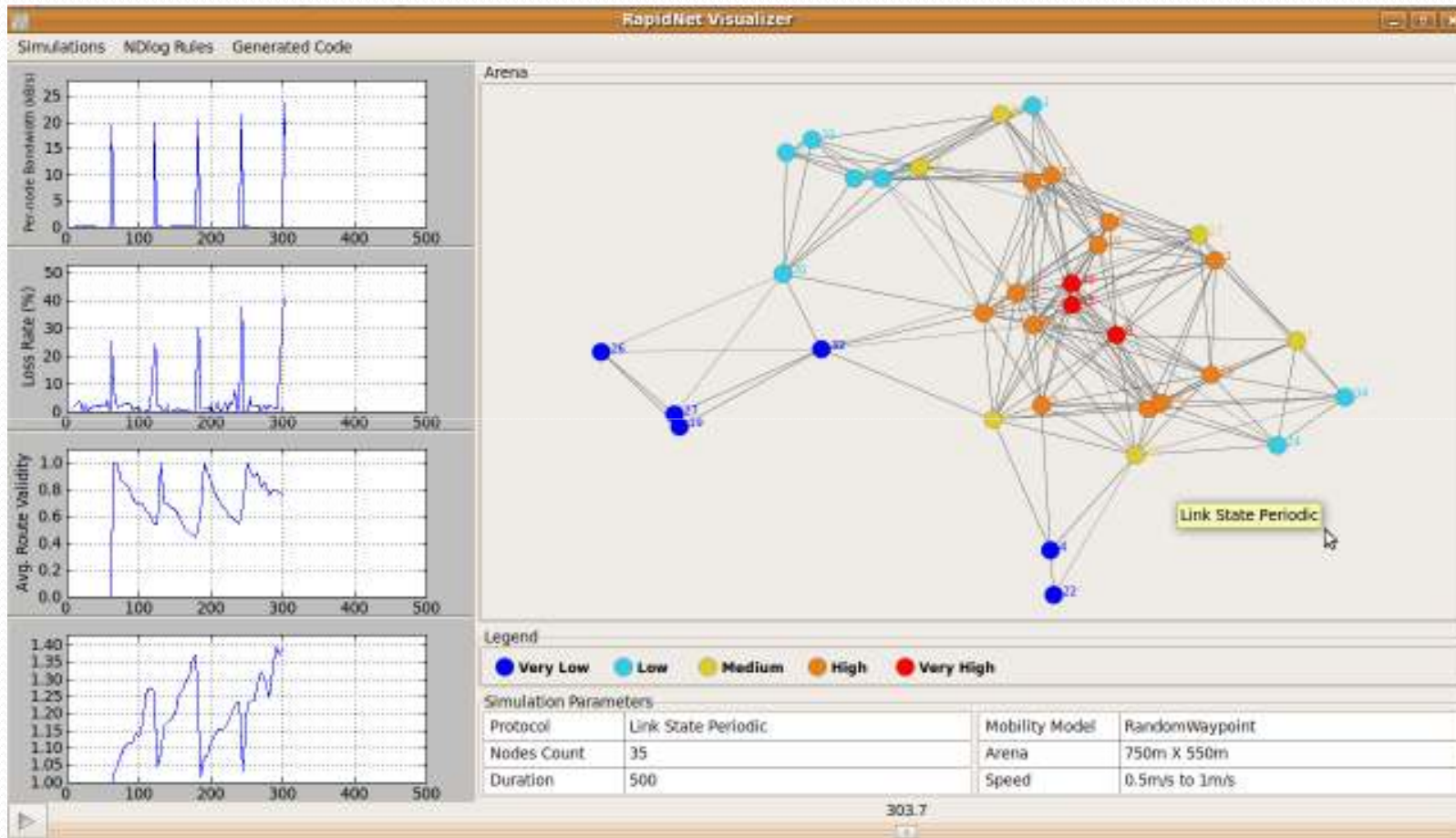
Summary

- 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: $\text{reachable}(@S,D) \leftarrow \text{link}(@S,D)$
R2: $\text{reachable}(@S,D) \leftarrow \text{link}(@S,Z), \text{reachable}(@Z,D)$

link(@a,b) – “S to D is a link from node *a* to node *b*”
If there is a link from S to D, then S can reach D”.
reachable(@a,b) – “node *a* can reach node *b*”

- ◆ Input: $\text{link}(@\text{source}, \text{destination})$
- ◆ Output: $\text{reachable}(@\text{source}, \text{destination})$

Network Datalog (NDlog) Example

R1: $\text{reachable}(@S,D) \leftarrow \text{link}(@S,D)$

➔ R2: $\text{reachable}(@S,D) \leftarrow \text{link}(@S,Z), \text{reachable}(@Z,D)$

“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: $\text{link}(@\text{source}, \text{destination})$
- ◆ Output: $\text{reachable}(@\text{source}, \text{destination})$

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)	3.2	14.8	14.9
	Delivery Ratio	80.1%	100%	100%
High	BW (KBps)	0.25	8.3	0.24
	Delivery Ratio	99.4%	100%	97.5%

Hybrid Proactive Epidemic achieves the best of both LS and Epidemic