Dynamic Selection of Network Protocols for Group Communications in Mobile Ad-hoc Networks

Aaron M. Rosenfeld
Advisor: Prof. William C. Regli

College of Computing & Informatics, Drexel University

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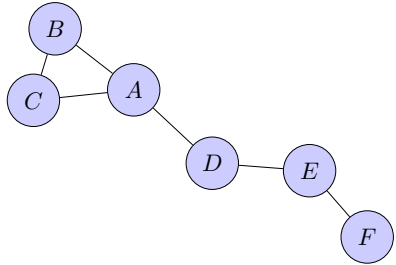
Problem

It is difficult to select protocols for group-communication applications deployed in Mobile Ad-hoc Networks (MANETs).

- No centralized control
- Unknown global state
- Frequent topology and traffic changes
- Disparate conditions across network

Motivating Example



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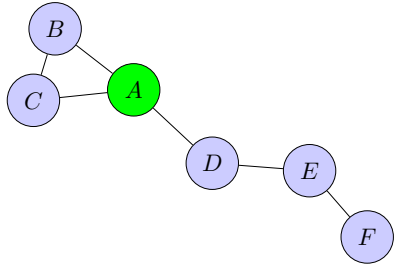

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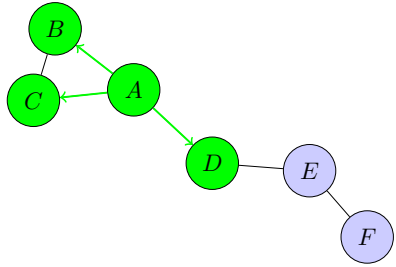

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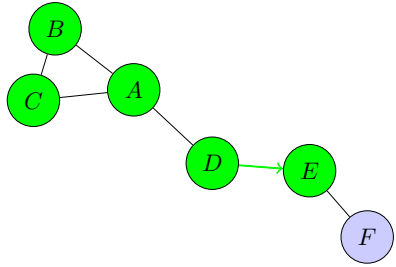

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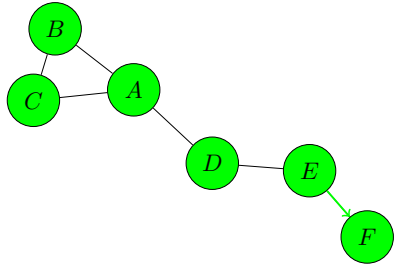

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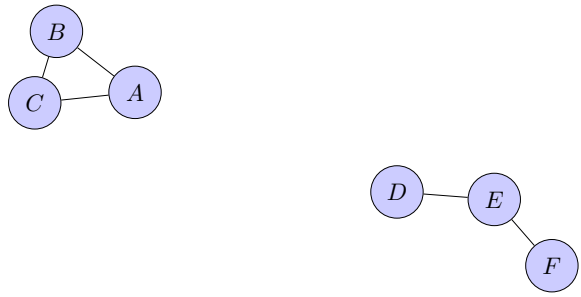

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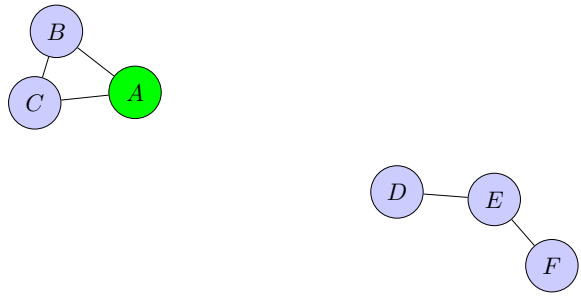

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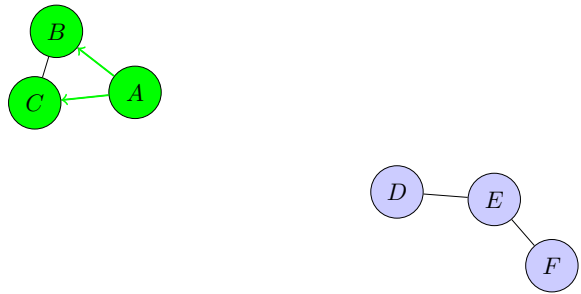

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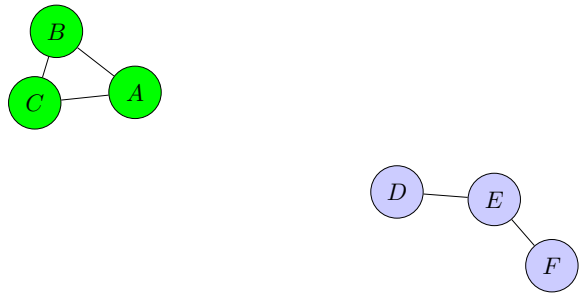

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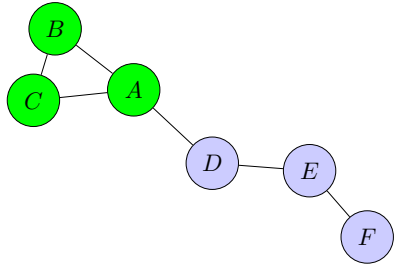

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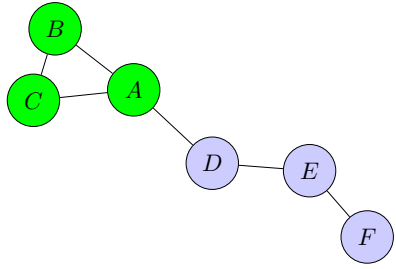

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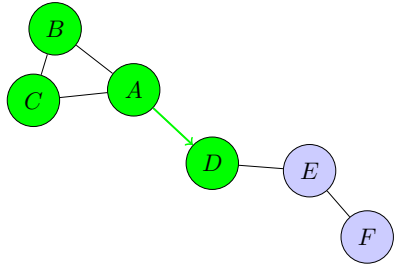

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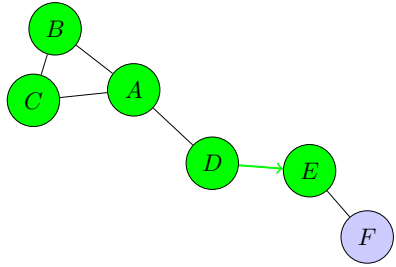

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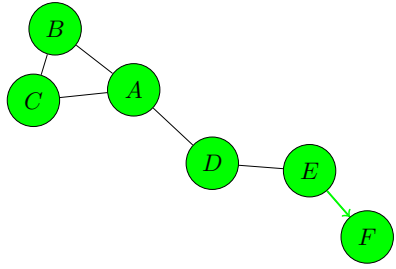

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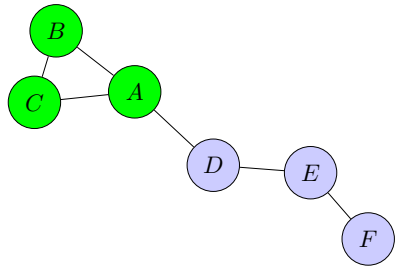

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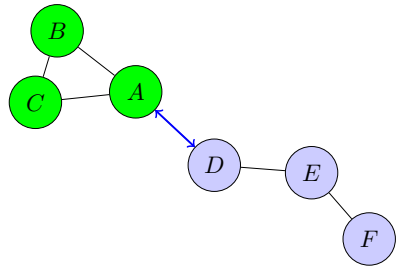

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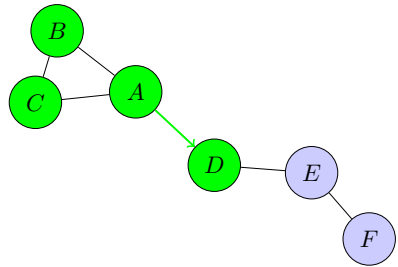

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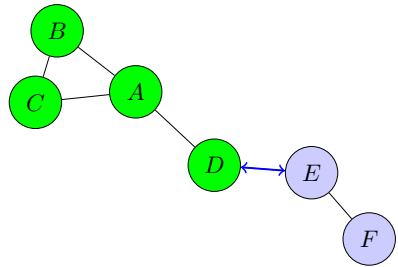

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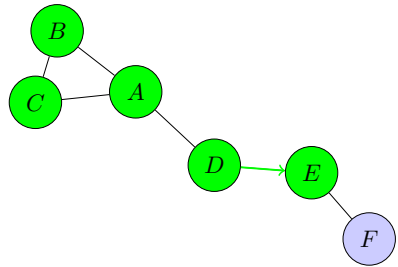

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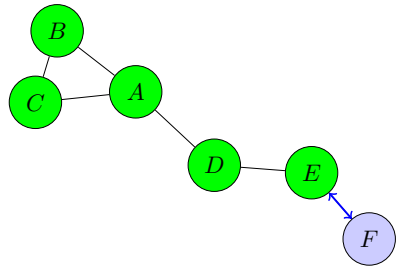

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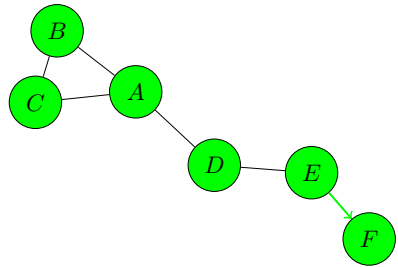

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- Depends on traffic load
- Different parts of the network have varying properties
- Future mobility is unknown
- Is speed or overhead more of a concern?

Empirical Motivation

Published paper in MILCOM 2012 demonstrating the difficulty in statically selecting protocols.

- Tested combinations of persistence protocols (Session layer) and transport protocols.
  - **Persistence**: Rumor Mongering (fast, high-bandwidth), Trickle (slower, low-bandwidth)
  - **Transport**: UDP link-local broadcast, UDP classical flooding multicast
- Showed that without full knowledge of both connectivity and traffic load, one cannot select a single protocol that delivers the most messages

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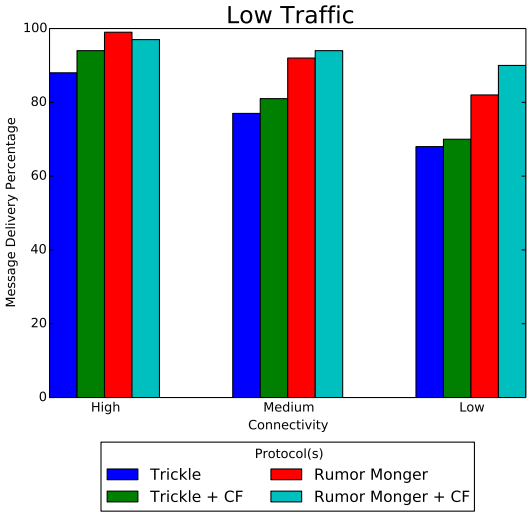
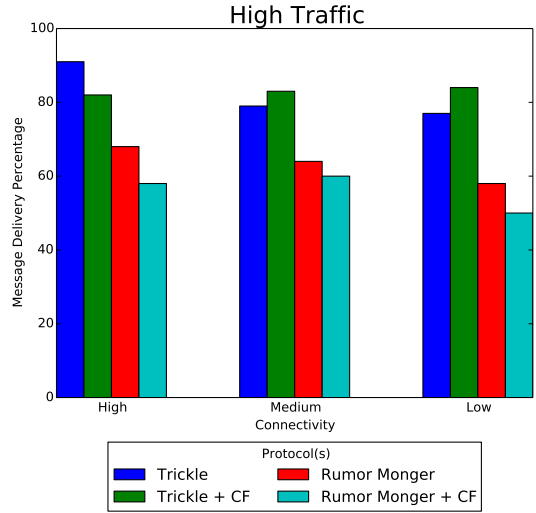
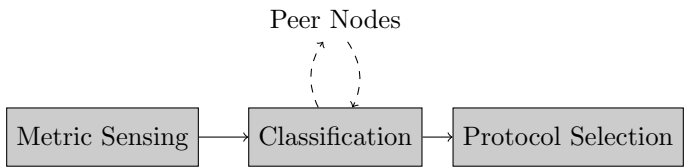




Proposed Solution

Dynamic Protocol Selection

Using locally sensed network state and information from peers, dynamically select and utilize the best protocol(s) for that current moment.



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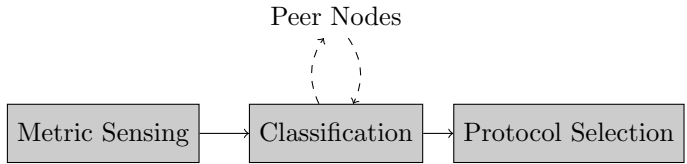

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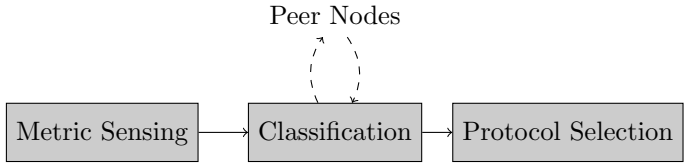

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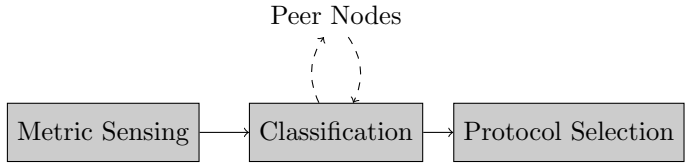

Related Work — AMQP

AMQP is an standardized protocol for message-oriented applications.

- Allows applications to stipulate delivery requirements (e.g. order, guarantee)
- Alleviates the need for developers to specify a specific protocol
- Most implementations utilize TCP and UDP
- Do not generally utilize or exchange network state

Related Work — MASs

Protocols at the application-layer for Multi-agent Systems are necessary for coherent interaction patterns.

- Quenum, et al. introduced a novel way of negotiating protocols during runtime to optimize certain metrics (e.g. time to complete tasks)
- Requires some degree of agreement between agents
- Does not utilize any network state measurements, only agent metrics
- Protocol agreement is computationally very expensive

Related Work — Markov Random Fields

Doyle, et al.'s work in Markov Random Fields inspired portions of this thesis, including methods to merge local and remote information.

- Uses Markov Random Fields to assign the network labels based on sensed network state
- State is exchanged with peers and merged to find the label most probable
- Using this information, the routing protocol is changed
- Not actually implemented, only simulated at a high level

Related Work — Appia

Appia is a policy driven toolkit for dynamically changing and parameterizing protocols.

- Rosa, et al. added the ability for policies to react to network events:

```
WHEN BandwidthEvent: BandwidthEvent.value < BW_THRESHOLD DO
    setValue(timeoutvalue, UPDATED_TIMEOUT)
FOR TransportProtocol
```

- Does not implement data fusion with peer nodes
- Does not implement a formal method of using remote data to select protocols, only provides a framework

Related Work — Summary

- Most existing work is at only a single layer
- Do not fully address the challenges of exchanging local and remote state in real/emulated networks
- Provide a framework for dynamically selecting protocols, not a usable middleware implementation.

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- **Protocol Sets**: $\mathcal{P}_1, \ldots, \mathcal{P}_c$.

Example

- **Network Factors**: $\mathcal{F} = \{F_{conn}, F_{traff}\}$
  - $F_{conn} = \{\text{low}, \text{medium}, \text{high}\}$
  - $F_{traff} = \{\text{low}, \text{medium}, \text{high}\}$
- **Measured Network Conditions**: $\mathcal{M} = \{(\text{neighbors}, 3), (\text{bytes/sec}, 120)\}$
- **Dynamic Stack Size**: $c = 2$
- **Protocol Sets**:
  - **Session**: $\mathcal{P}_1 = \{\text{Trickle}, \text{Rumor}\}$
  - **Transport**: $\mathcal{P}_2 = \{\text{UDP}, \text{NORM}\}$

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- A function for each factor that maps the *local* network state (given by $\mathcal{M}$) to an associated label
- A method of merging these local labels with remote ones, to create a final label to be applied locally
- A function mapping all combinations of possible labels, one per factor, to a protocol for each layer

Labelling Approach

For this thesis, chose:

- Network factors of **connectivity** and **traffic load** as $\mathcal{F}$.
- Labels for each of "high," "medium," and "low."
- Local Conditions of **number of neighbors** and **bytes/sec**.
  - Gathered from the network interface via the OS

Labelling Process

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3. Integrate local and remote beliefs to assign a final label for each network factor

Labelling Process — Local Labelling

Label each factor F as high, medium, or low by breaking ranges into thirds. Select a $(d, v) \in \mathcal{M}$ for F and assign a label by:

$$T(d,v) = \begin{cases} low, & 0 < \frac{v}{mv(d)} \leq \frac{1}{3} \\ medium, & \frac{1}{3} < \frac{v}{mv(d)} \leq \frac{2}{3} \\ high, & \frac{2}{3} < \frac{v}{mv(d)} \end{cases}$$

Where $mv(d)$ is the maximum value for the network condition d, currently measured as v.

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Occasionally[1] broadcast a set:

$$b = \langle (F_1, l_1), \ldots, (F_{|\mathcal{F}|}, l_{|\mathcal{F}|}) \rangle$$

where each l_i is most probable for F_i.

[1] 2 seconds for this implementation

Labelling Process — Belief Fusion

For each label, l_i received in b for F_i, update the associated $P_{F_i}(l_i)$ to:

$$P_{F_i}(l_i) = \tfrac{1}{2}\left(\underbrace{(1-\lambda)\mathcal{N}_{F_i}^{l_i}(M_{F_i})}_{\text{Local measurement}} + \underbrace{\lambda\frac{C_{F_i}(l_i)}{\mathcal{B}_{F_i}}}_{\text{New broadcasts}}\right)$$

The label assigned for factor F_i is then given by

$$L_{F_i} = \arg\max_{l \in F_i} P_{F_i}(l)$$

Labelling Effectiveness — Experimental Setup

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CORE Configuration	
Parameter	**Value**
Scenario Dimensions	1000 × 1000 meters
Range	20 meters
Bandwidth	5 Mbps
Delay	20 ± 5 milliseconds
Jitter	0 milliseconds

Traffic Configuration		
Load	**Frequency**	**Size**
High	1 seconds	1024 ± 50 bytes
Medium	5 seconds	512 ± 20 bytes
Low	10 seconds	256 ± 10 bytes

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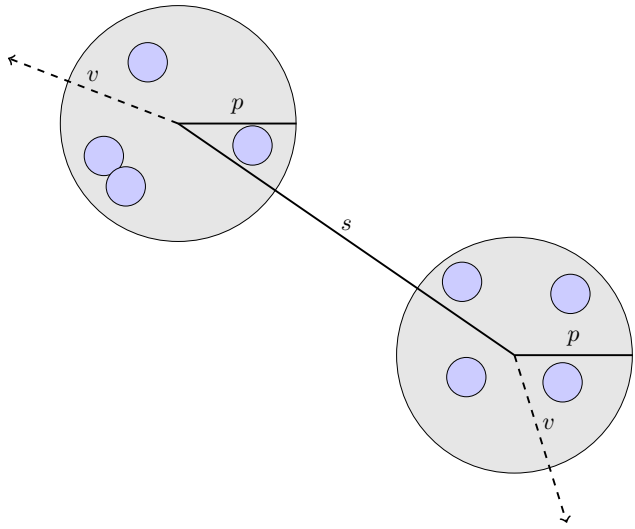
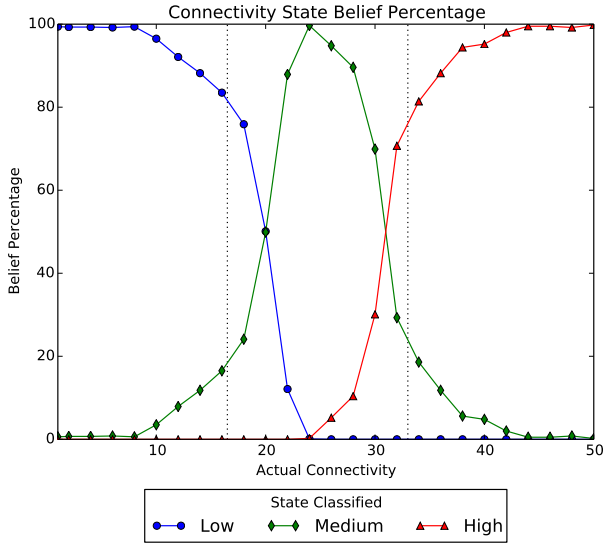


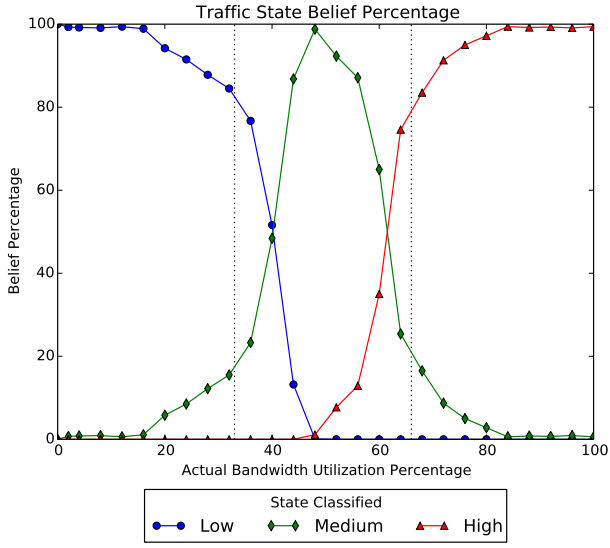
Labelling Effectiveness — Experimental Setup

Parameter	**Value**
Number of Nodes	50
Number of Groups	2, 4, 5, 10, 25
Reference Point Separation	150, 250, 800 meters
Node Separation	25 meters
Speed	2 ± 5 meters per second
Pause Time	2 ± 2 seconds

Labelling Effectiveness — Connectivity



Labelling Effectiveness — Traffic



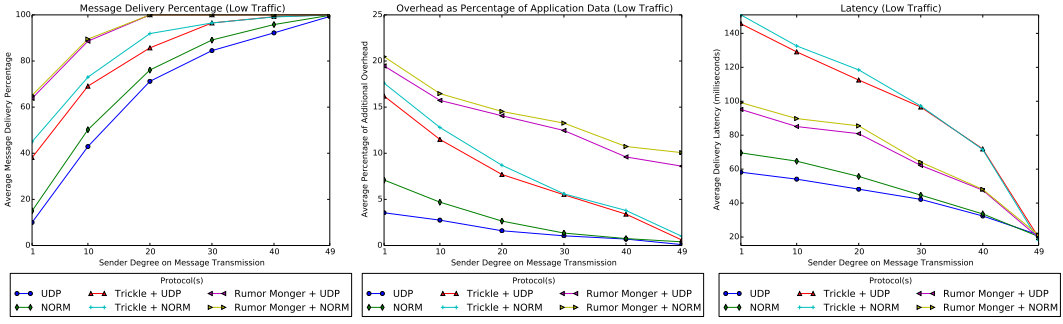
Protocol Performance

- The network can now be labelled
- Based on the labels, determined which protocol performs best
- Individually tested protocols at the Session and Transport layers with various connectivity levels and traffic loads

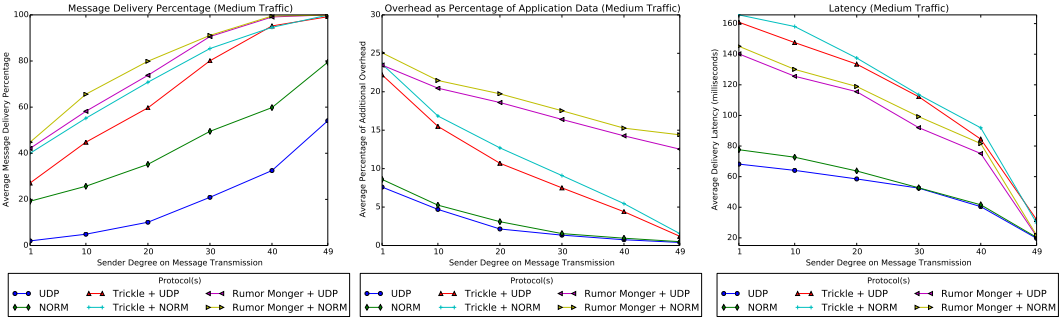
Protocol Performance — Experimental Setup

- Used RPGM model as in prior experiments
- Trickle and Rumor Mongering at the Session layer for data persistence
  - Included no Session protocol for comparison purposes
- UDP and NORM at the Transport layer
  - NORM is a reliable multicast protocol utilizing Negative ACKs
  - Both were set to broadcast only link-locally

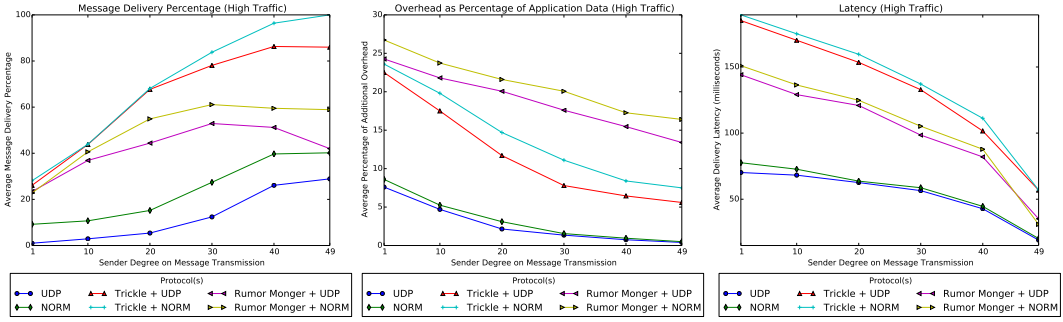
Protocol Performance — Low Traffic Results



Protocol Performance — Medium Traffic Results



Protocol Performance — High Traffic Results



Protocol Performance — Summary

- In low- and medium-traffic, Trickle and Rumor Mongering increase in MDR as connectivity increases at approximately the same rate.
- In high-traffic, Rumor Mongering performs poorly when highly connected
- Using no persistence protocol is not advantageous if MDR is important

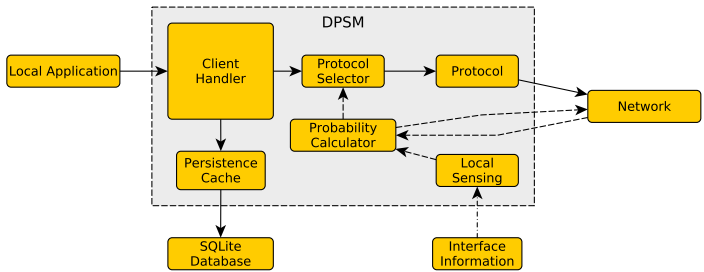
Protocol Performance — Best Protocols

Based on these results, the following appear to offer the best performance tradeoffs:

		Connectivity		
		Low	*Medium*	*High*
Traffic	*Low*	RM + UDP	TR + NORM	TR + UDP
	Medium	RM + NORM	TR + NORM	TR + UDP
	High	TR + UDP	TR + NORM	TR + NORM

Dynamic Protocol Selection Middleware (DPSM)

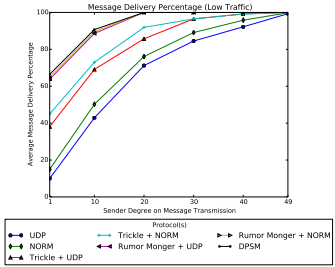
- Created the Dynamic Protocol Selection Middleware (DPSM) to dynamically switch protocols based on these results
- Implemented in Java and acts as an abstraction between applications and lower layer protocols
- Applications subscribe and publish to specific destinations
- For each message, assert the delivery requirements (reliable and/or persistent), destination, and payload

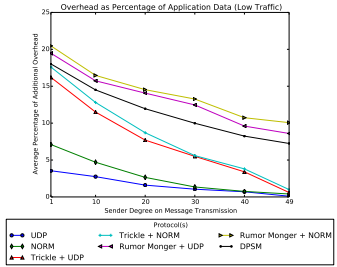


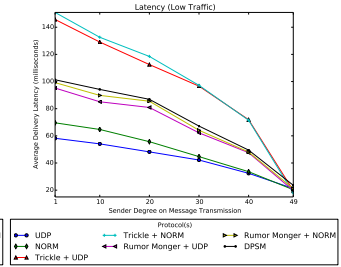
Baseline Results

- Compared the dynamic approach in DPSM to that of the static protocols
- CORE and MGEN were again used with the same parameters
- All messages were marked as both persistent and reliable

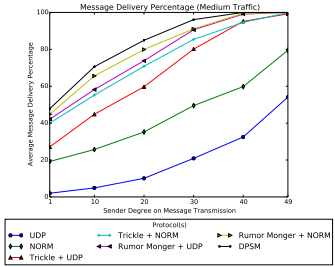
Baseline Results — Low Traffic

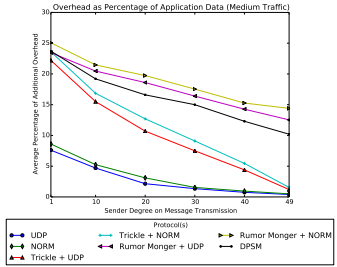


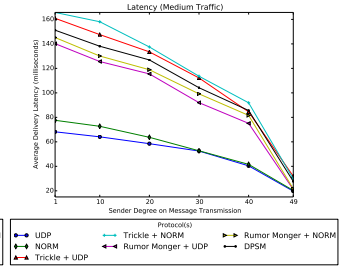




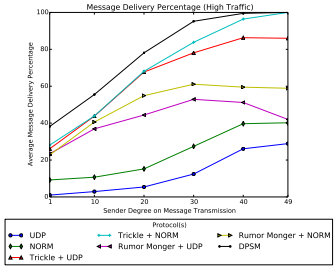
Baseline Results — Medium Traffic

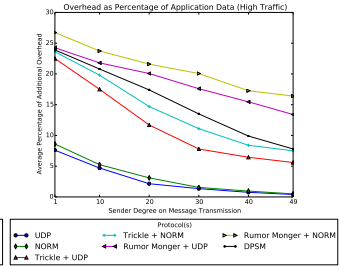


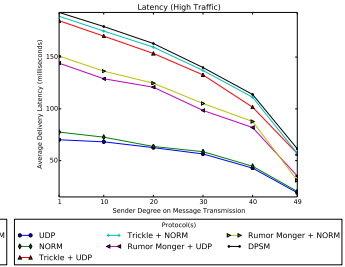




Baseline Results — High Traffic







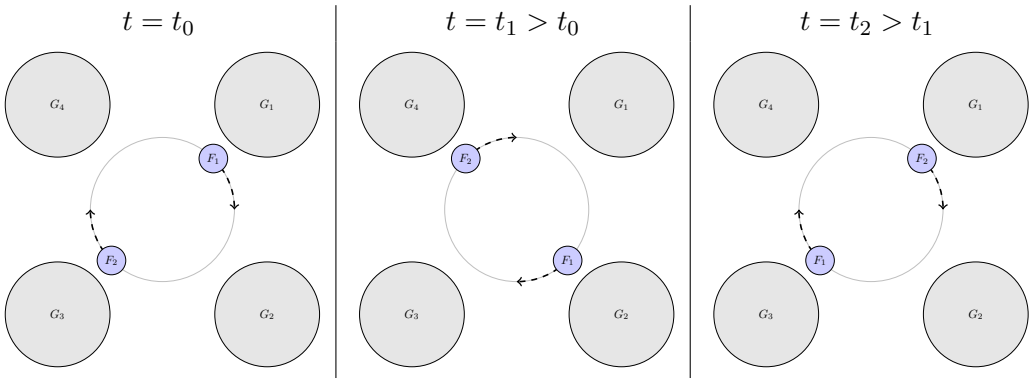
Real-World Scenarios

- Most real-world scenarios do not involve groups moving at random
- Some structure based on a task or objective to accomplish
- Compared DPSM to static approaches in two real-world scenarios
  - Message ferry
  - Group following

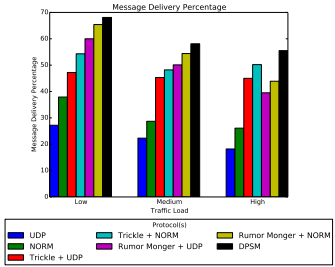
Message Ferrying

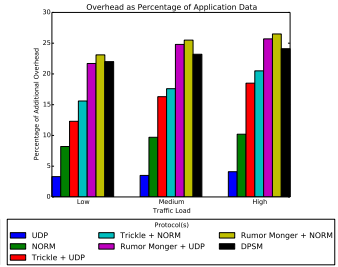
- 48 nodes split into 4 equal groups in a square
- Each group nearly remains connected
- No two groups ever directly come into contact
- Two nodes circle the four groups delivering messages between them

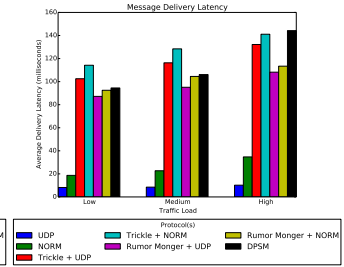
Message Ferrying



Message Ferrying — Results



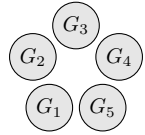




Group Following

- 50 nodes split into five equally sized groups
- First group randomly selects a waypoint and travels there
- Upon reaching it, the second group meets it temporarily
- The first group then moves on
- Repeats for following groups.

Group Following — Example



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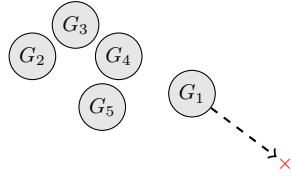

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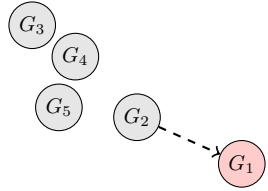

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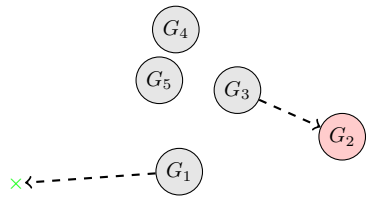

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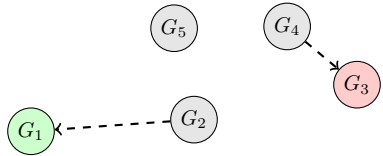

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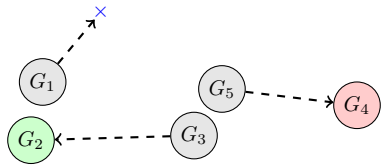

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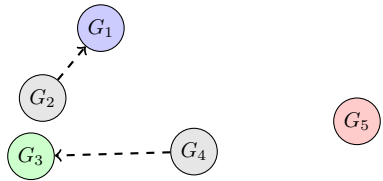
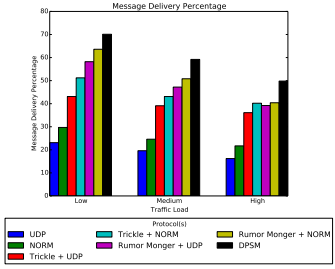
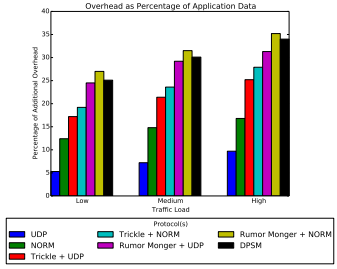
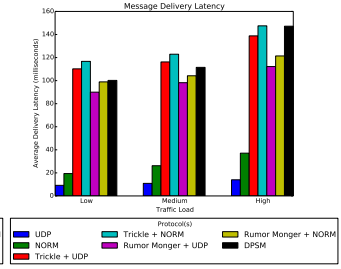


Group Following — Results







Problem

Motivation

Proposed Solution

Related Work

Problem Formalization

Approach

Implementation & Results

Conclusions

Summary

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- Implemented the approach as a generic middleware, DPSM
- Evaluated the performance of static protocol to determine which performed the best with each label combination
- Provided empirical evidence in both generic and real-world scenarios that DPSM can improve message delivery with slight latency or overhead tradeoffs

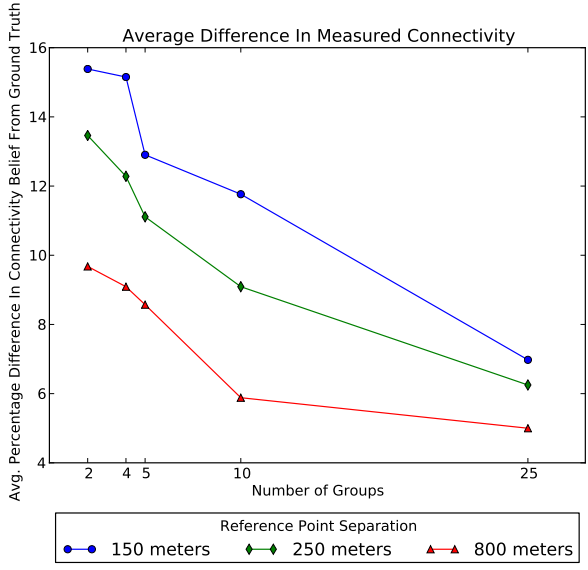
Future Work

- Labelling without knowing bounds on the network
- Alternative labelling approaches using different fusion methods
- Smoothing for fringe nodes
- Dynamic learning of optimal protocol selection rather than pre-programming

Questions?

Contact
Aaron M. Rosenfeld — ar374@drexel.edu
Advisor: Prof. William C. Regli — regli@drexel.edu

Local Labelling Effectiveness



Local Labelling Effectiveness