

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

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Problem

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Proposed Solution

Related Work

Problem Formalization

Approach

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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

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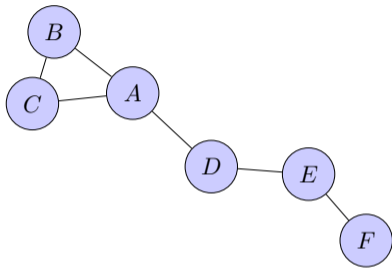
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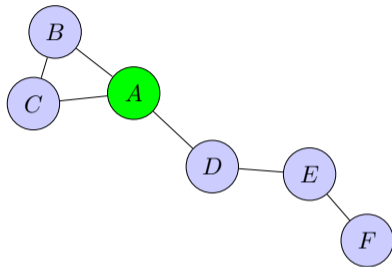
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Motivating Example



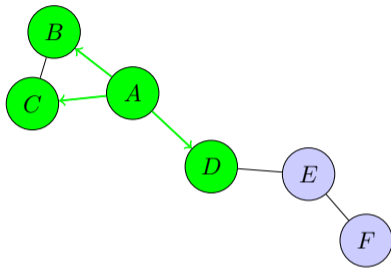
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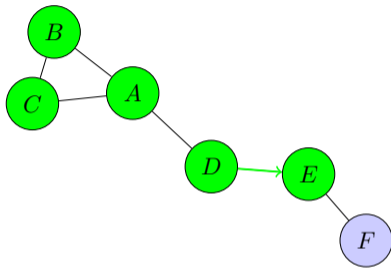
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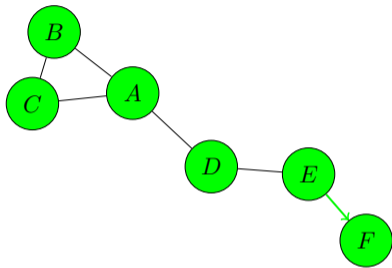
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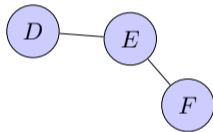
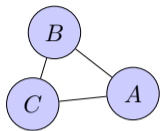
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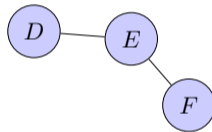
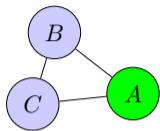
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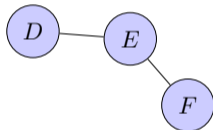
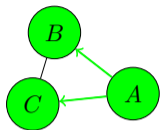
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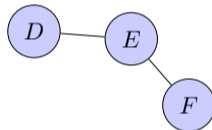
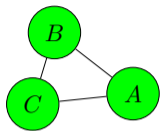
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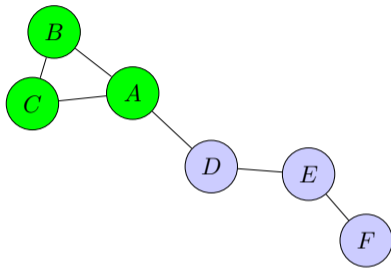
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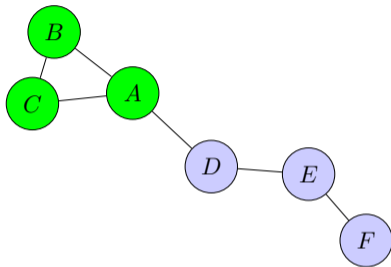
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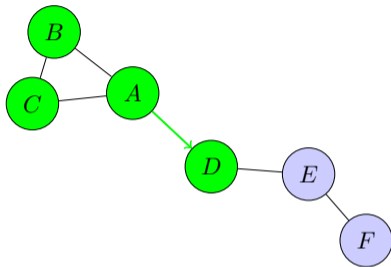
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1. Frequently retransmit all prior messages (fast, high bandwidth)

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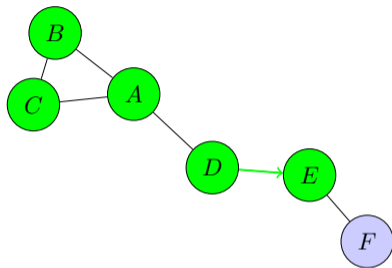
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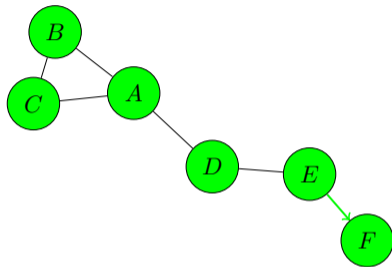
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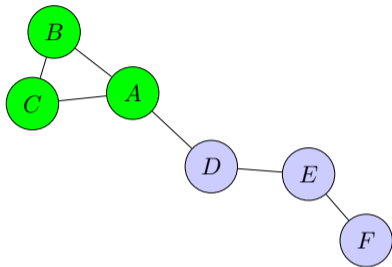
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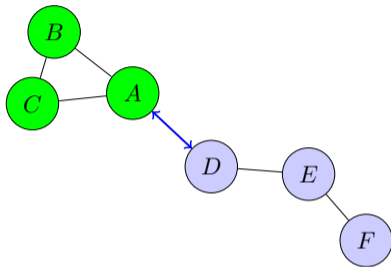
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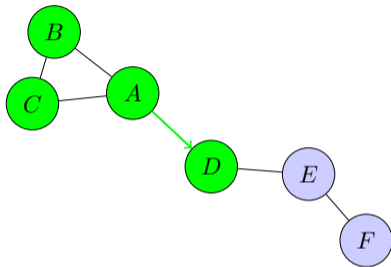
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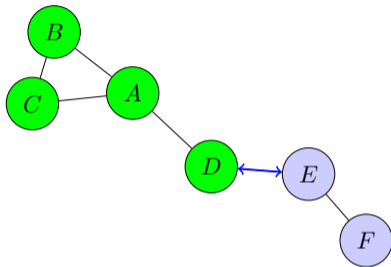
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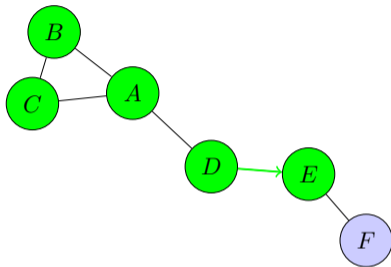
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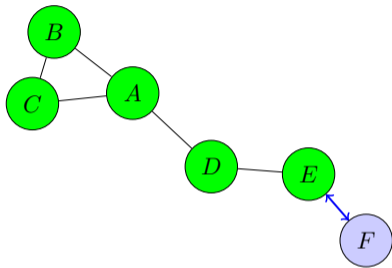
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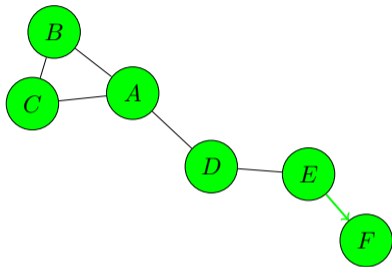
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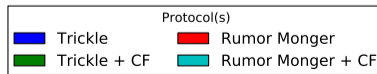
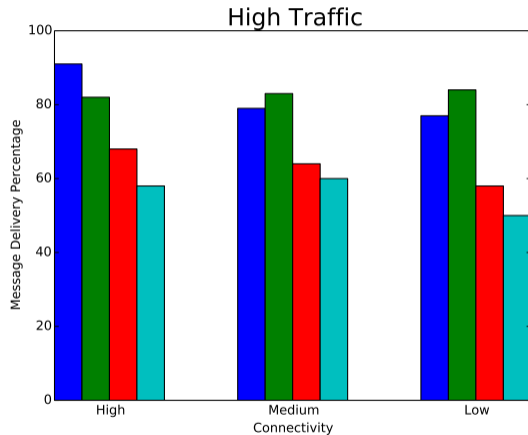
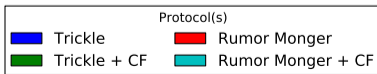
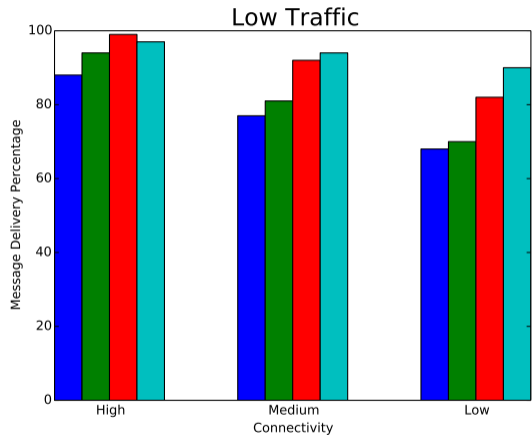
- ▶ Depends on traffic load
- ▶ Different parts of the network have varying properties
- ▶ Future mobility is unknown
- ▶ Is speed or overhead more of a concern?

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

Empirical Motivation



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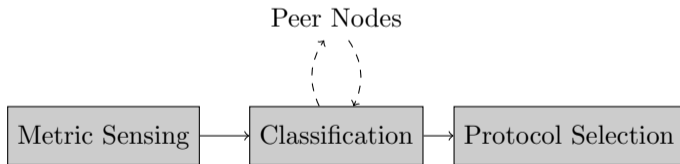
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Dynamic Protocol Selection

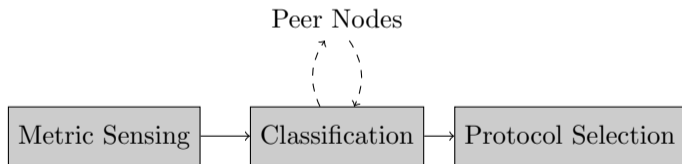
Using locally sensed network state and information from peers, dynamically select and utilize the best protocol(s) for that current moment.



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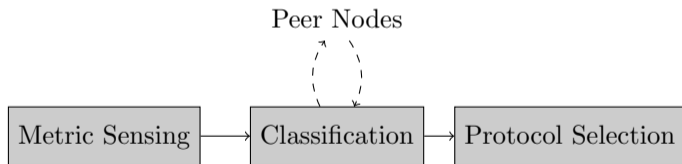
e.g.

Est. Neighbors,
Received Messages

Proposed Solution

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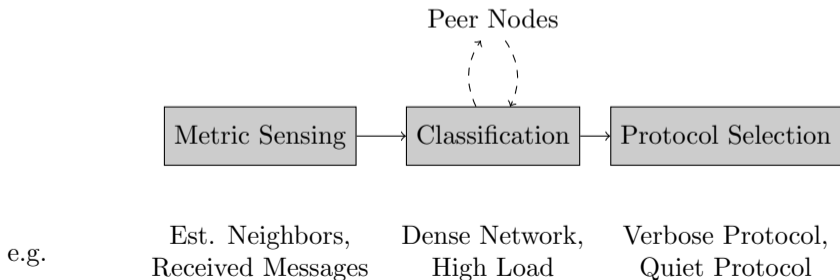
Est. Neighbors,
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Dense Network,
High Load

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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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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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Define the following:

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

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

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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:

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

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

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Each node maintains a timeout value t and for **each** network factor $F \in \mathcal{F}$:

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Occasionally¹ broadcast a set:

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

where each l_i is most probable for F_i .

¹2 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:

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

The label assigned for factor F_i is then given by

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

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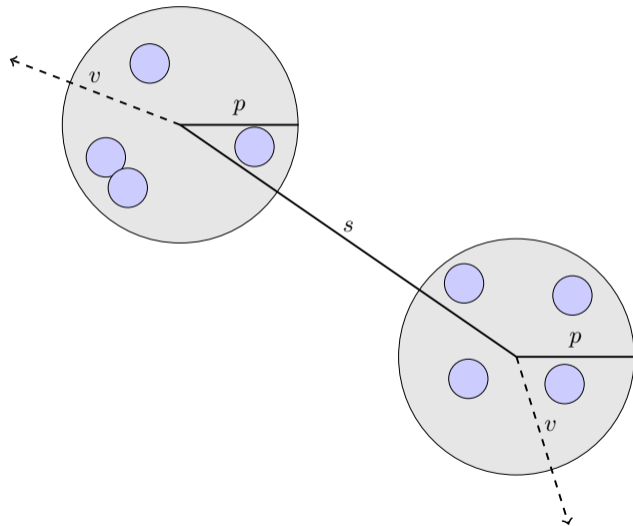
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CORE Configuration	
Parameter	Value
Scenario Dimensions	1000 × 1000 meters
Range	20 meters
Bandwidth	5 Mbps
Delay	20 ± 5 milliseconds
Jitter	0 milliseconds

Traffic Configuration		
Load	Frequency	Size
<i>High</i>	1 seconds	1024 ± 50 bytes
<i>Medium</i>	5 seconds	512 ± 20 bytes
<i>Low</i>	10 seconds	256 ± 10 bytes

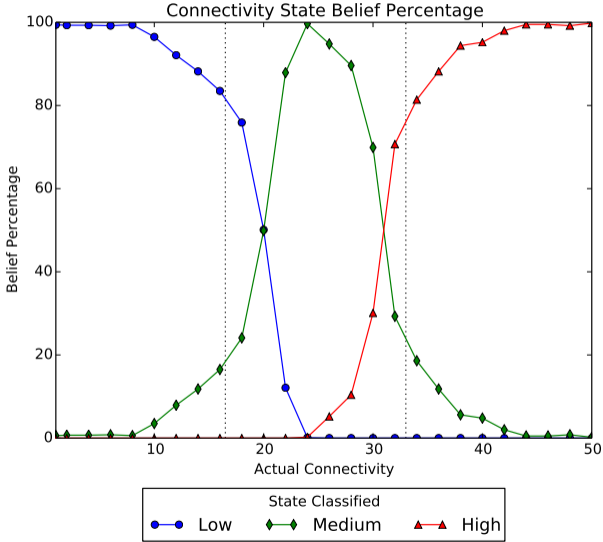
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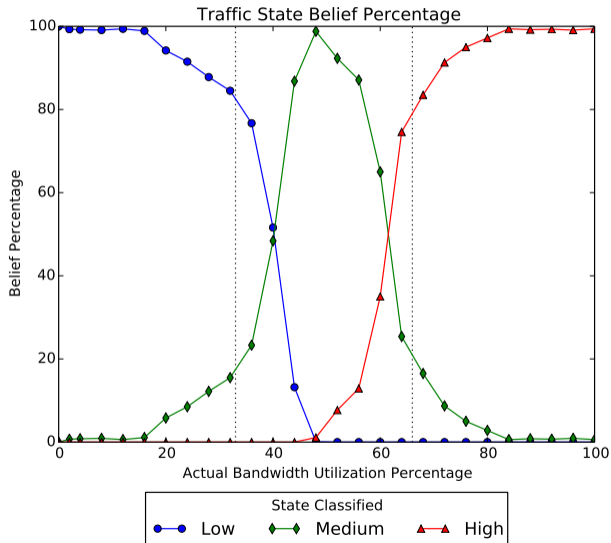
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Parameter	Value
Number of Nodes	50
Number of Groups	2, 4, 5, 10, 25
Reference Point Separation	150, 250, 800 meters
Node Separation	25 meters
Speed	2 ± 5 meters per second
Pause Time	2 ± 2 seconds

Labelling Effectiveness — Connectivity



Labelling Effectiveness — Traffic



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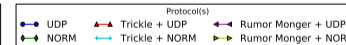
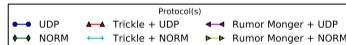
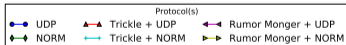
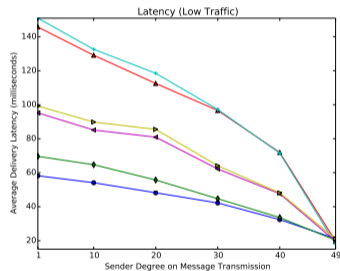
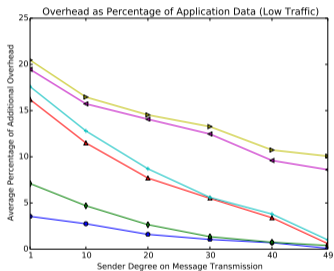
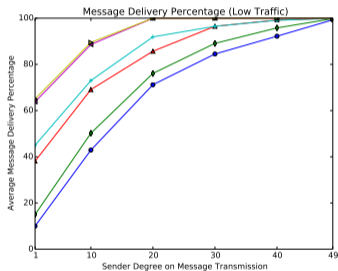
Protocol Performance

- ▶ 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

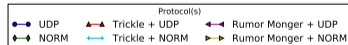
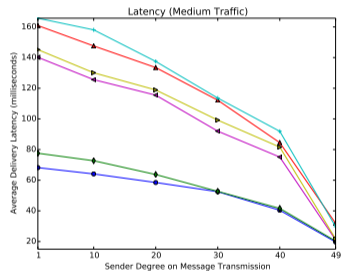
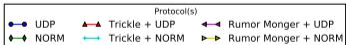
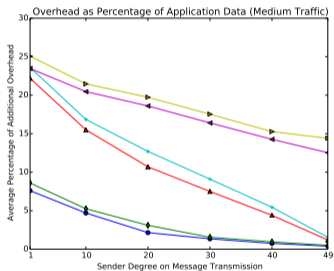
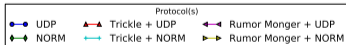
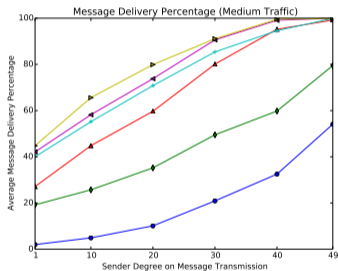
Protocol Performance — Experimental Setup

- ▶ 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

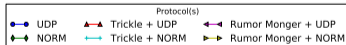
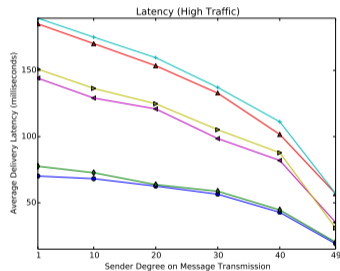
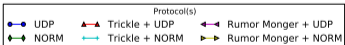
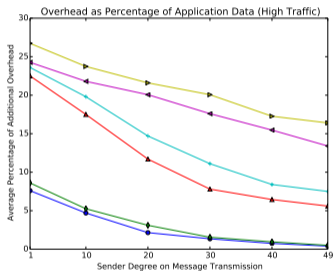
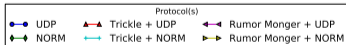
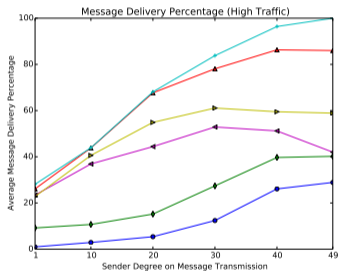
Protocol Performance — Low Traffic Results



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		
		<i>Low</i>	<i>Medium</i>	<i>High</i>
Traffic	<i>Low</i>	RM + UDP	TR + NORM	TR + UDP
	<i>Medium</i>	RM + NORM	TR + NORM	TR + UDP
	<i>High</i>	TR + UDP	TR + NORM	TR + NORM

Problem

Motivation

Proposed Solution

Related Work

Problem Formalization

Approach

Implementation & Results

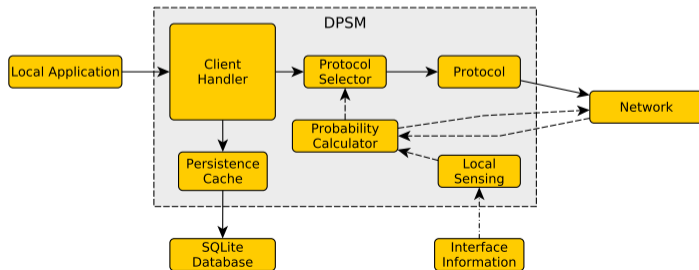
Baseline Results

Real-World Scenario Results

Conclusions

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



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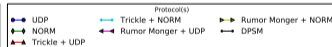
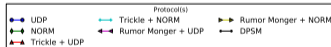
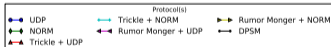
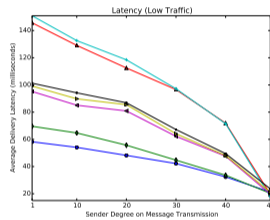
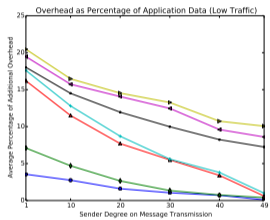
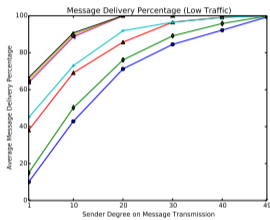
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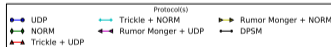
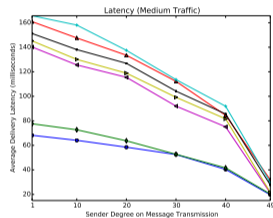
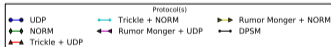
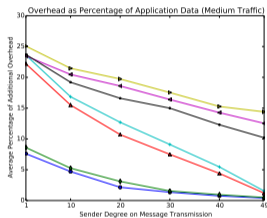
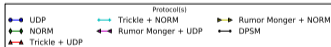
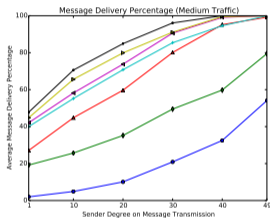
Baseline Results

- ▶ 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

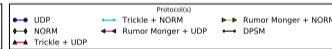
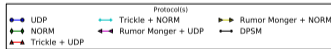
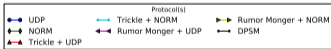
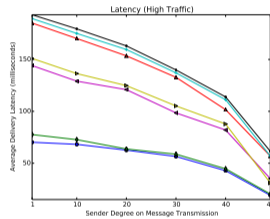
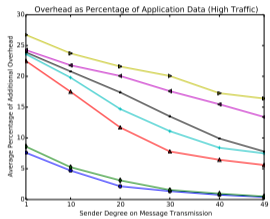
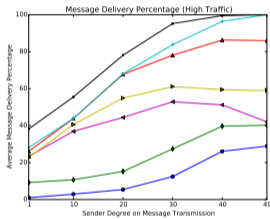
Baseline Results — Low Traffic



Baseline Results — Medium Traffic



Baseline Results — High Traffic



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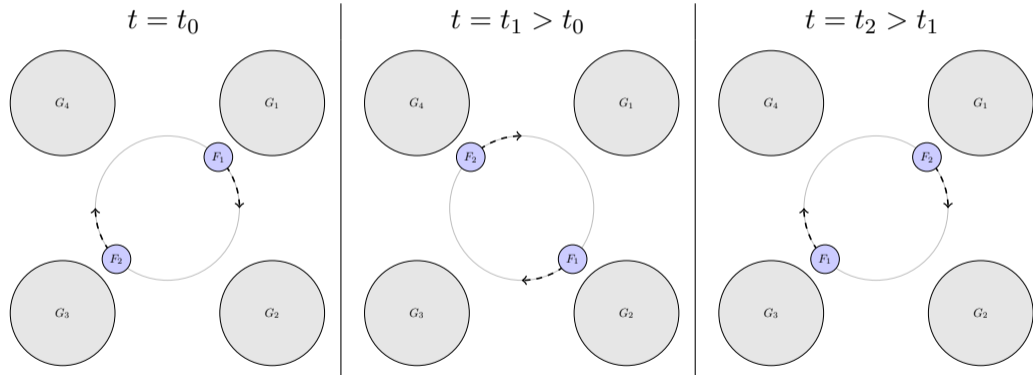
Real-World Scenarios

- ▶ 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

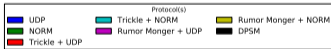
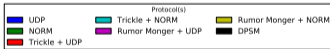
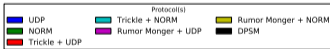
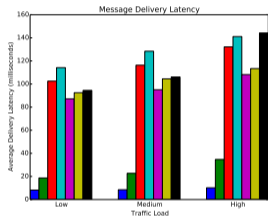
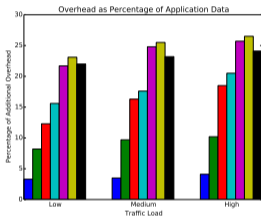
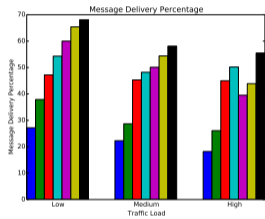
Message Ferrying

- ▶ 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



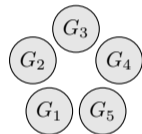
Message Ferrying — Results



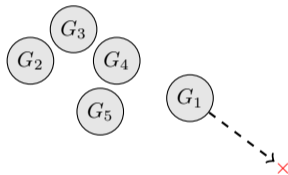
Group Following

- ▶ 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.

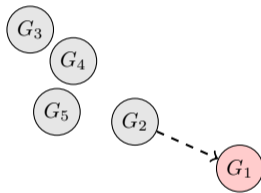
Group Following — Example



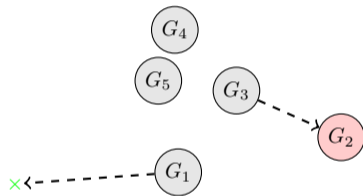
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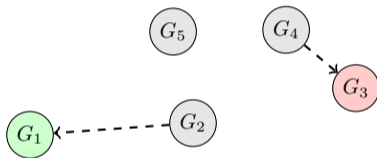
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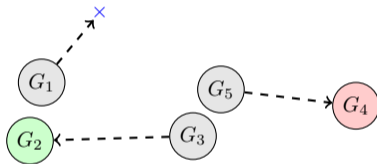
Group Following — Example



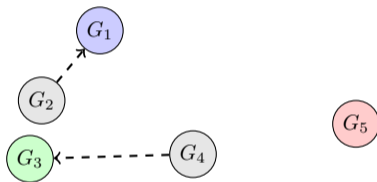
Group Following — Example



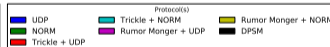
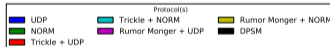
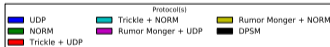
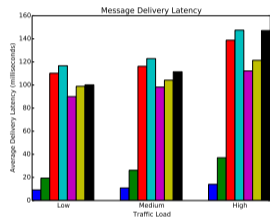
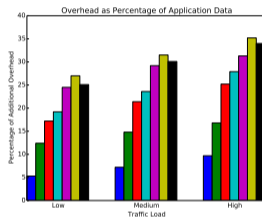
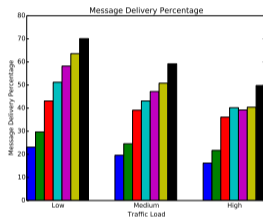
Group Following — Example



Group Following — Example



Group Following — Results



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Summary

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Summary

- ▶ Motivated the need for dynamic protocol selection with an example and empirical results
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- ▶ Proposed a generic solution to problem using local and remote network state information
- ▶ 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

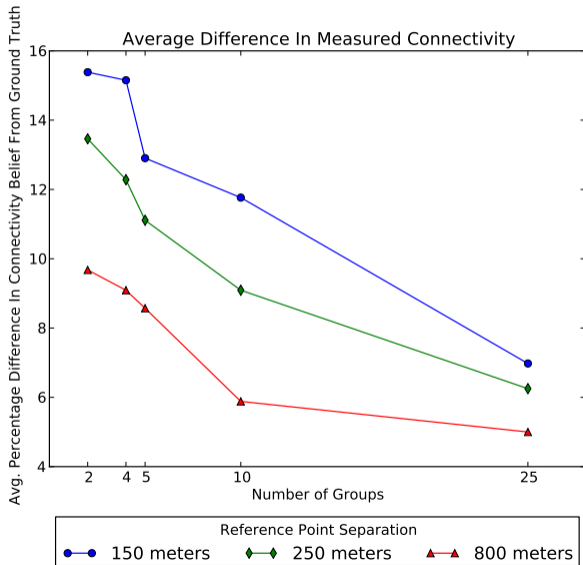
Questions?

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Advisor: Prof. William C. Regli — regli@drexel.edu

Local Labelling Effectiveness



Local Labelling Effectiveness

