Message Routing & Event Notification in Sparse Mobile Networks

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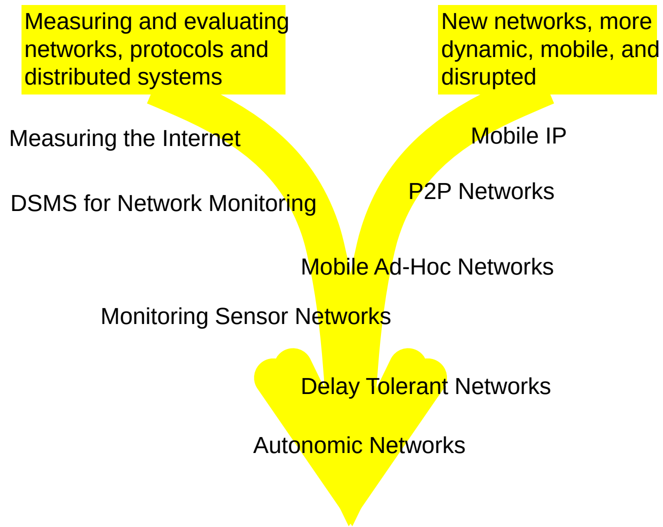
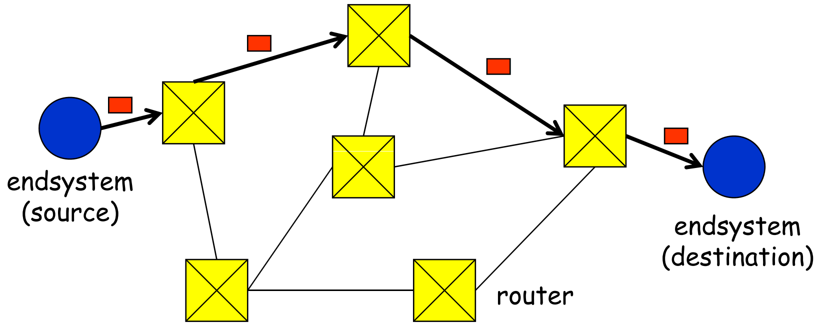
What are we teaching?



Outline

- Part I: Message routing
  - Background, motivation, overview
  - Epidemic routing
  - Message ferrying
  - Mobility/density space
  - Acknowledgement: Many transparencies are from Mustafar Ammar's keynote talk at Co-Next 2005
- Part II: Event notification
  - PhD work from Katrine S. Skjelsvik

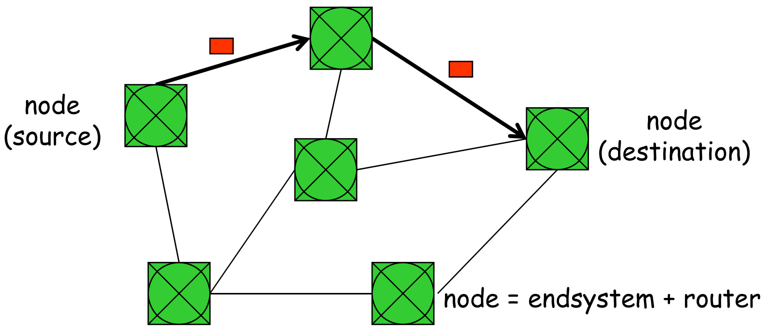
Traditional Wired Networks



- separation between endsystems and routers
- routers responsible for finding stable path

[M. Ammar, Co-Next 2005]

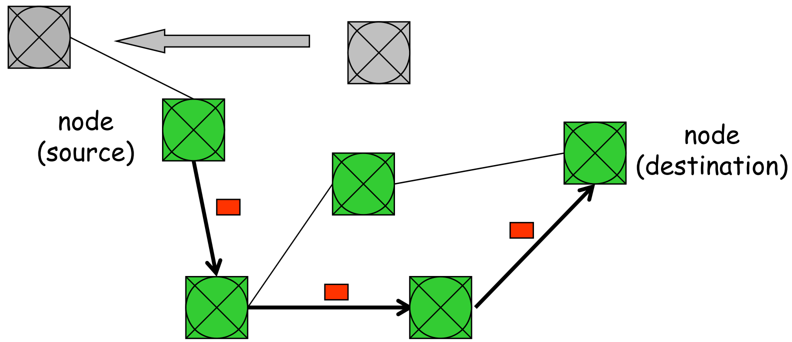
"Traditional" Mobile Ad-hoc Wireless Networks (MANET)



- no separation between endsystems and routers
- nodes responsible for finding stable path

[M. Ammar, Co-Next 2005]

"Traditional" Mobile Ad-hoc Wireless Networks (MANET)



- nodes may move
- routing layer responsible for reconstructing (repairing) stable paths when movement occurs

[M. Ammar, Co-Next 2005]

The "Traditional" MANET Wireless Paradigm

- The Network is "Connected"
  - There exists a (possibly multi-hop) path from any source to any destination
  - The path exists for a long-enough period of time to allow meaningful communication
  - If the path is disrupted it can be repaired in short order
  - "Looks like the Internet" above the network layer

[M. Ammar, Co-Next 2005]

The Rise of Sparse Disconnected Networks

[M. Ammar, Co-Next 2005]

Sparse Wireless Networks

- Disconnected
  - By Necessity
  - By Design (e.g. for power considerations)
- Mobile
  - With enough mobility to allow for some connectivity over time
  - Data paths may not exist at any one point in time but do exist *over time*

[M. Ammar, Co-Next 2005]

Mobility-Assisted Data Delivery: A New Communication Paradigm

- Mobility used for connectivity
- ***New Forwarding Paradigm***

Store

Carry for a while

forward

- Special nodes: Transport entities that are not sources or destinations

[M. Ammar, Co-Next 2005]

Data Applications

- Nicely suitable for Message-Switching
- Delay tolerance … but can work at multiple time scale

  (a.k.a. *Delay Tolerant Networks*)

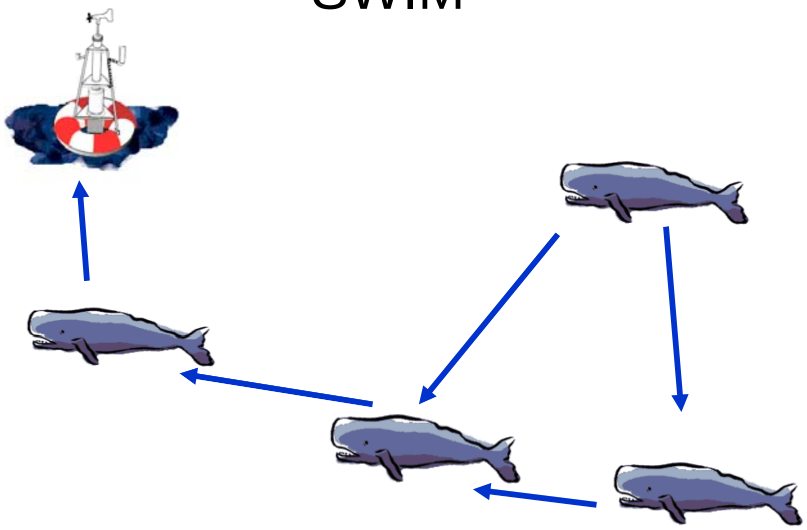
[M. Ammar, Co-Next 2005]

Some Delay-Tolerant Systems

- ZebraNet and SWIM
- Data MULE and Smart-Tags
- Vehicle-to-Vehicle Communication
- DakNet
- Epidemic Routing
- Message Ferrying

[M. Ammar, Co-Next 2005]

SWIM

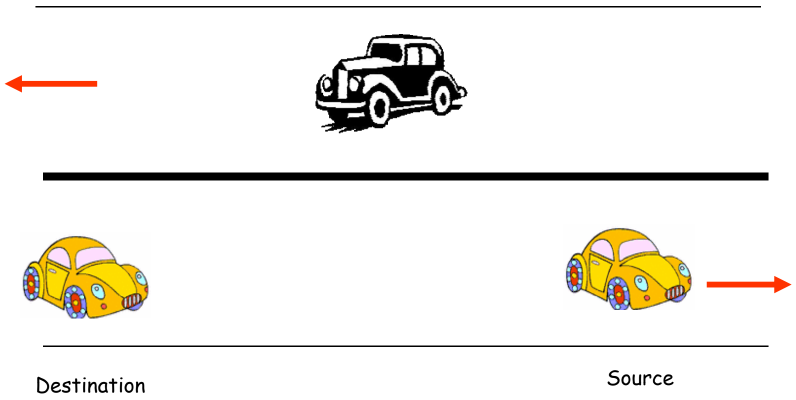


[M. Ammar, Co-Next 2005]

Vehicles on Highways Networks

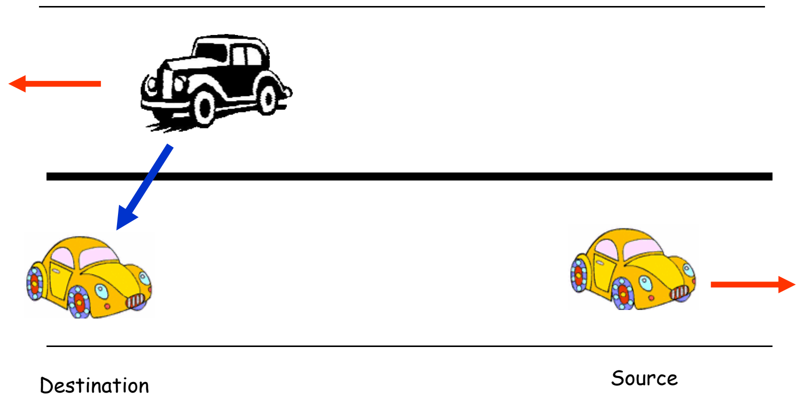
[M. Ammar, Co-Next 2005]

Vehicles on Highways Networks



[M. Ammar, Co-Next 2005]

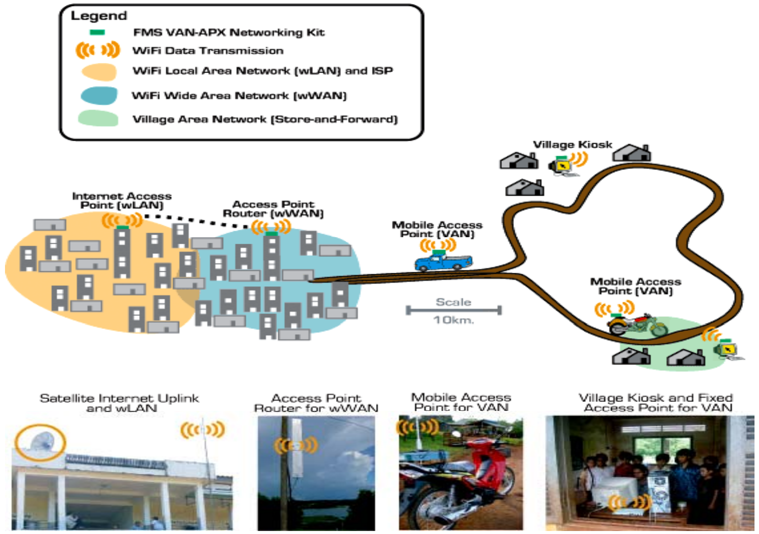
Vehicles on Highways Networks



[M. Ammar, Co-Next 2005]

DakNet

(Pentland. Fletcher. and Hasson)



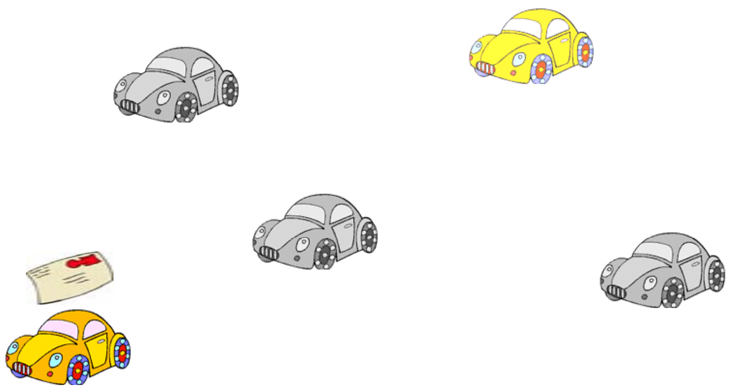
[M. Ammar, Co-Next 2005]

Epidemic Routing

- Vahdat and Becker
- Utilize physical motion of devices to transport data
- *Store-carry-forward* paradigm
  - Nodes buffer and carry data when disconnected
  - Nodes exchange data when met
  - data is replicated throughout the network
- Robust to disconnections
- Scalability and resource usage problems

[M. Ammar, Co-Next 2005]

Epidemic Routing – The Idea



[M. Ammar, Co-Next 2005]

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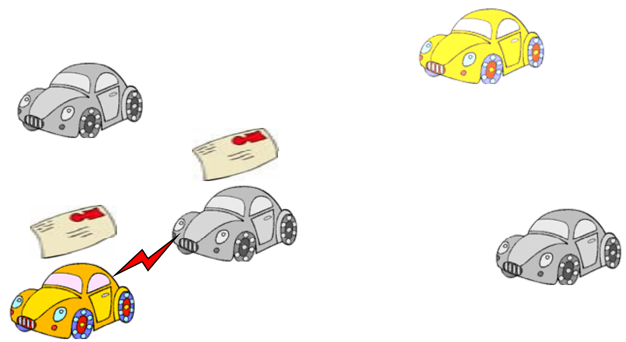

[M. Ammar, Co-Next 2005]

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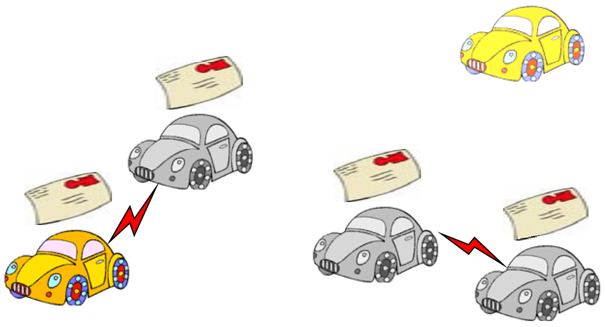

[M. Ammar, Co-Next 2005]

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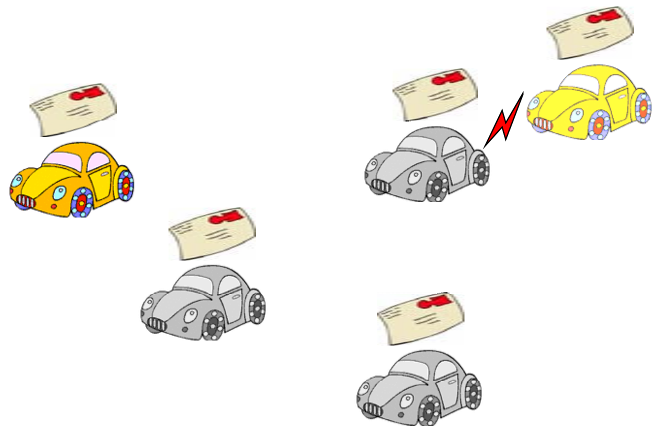
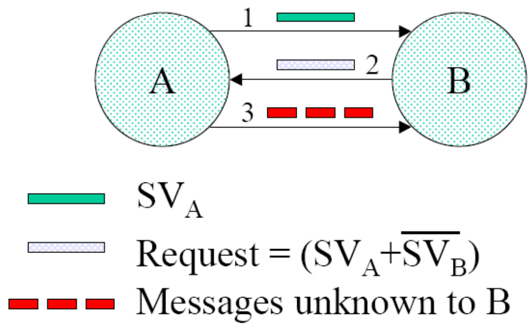


[M. Ammar, Co-Next 2005]

Epidemic Routing – Basic Elements

- Each node contains
  – Message buffer
  – Hash table
  – Summary vector
  – List of last seen nodes

Epidemic Routing – The Protocol



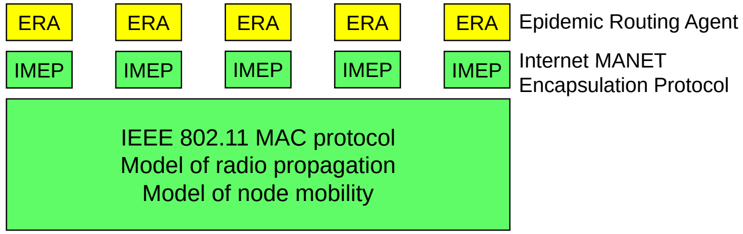
[Vahdat & Becker, TechReport 200]

Epidemic Routing – Multiple Hops

- Each message contains:
  - Unique message ID
  - Hop count
  - Ack request (optional)
- Tradeoff buffer size vs. message delivery

Epidemic Routing – Evaluation

- Implementation in ns-2



  - 50 mobile nodes
  - Area 1500m x 300m
  - Random waypoint
  - Speed 0 – 20 m/s (uniformly distributed)
  - Message size 1 KB
  - 45 message sources/sinks (each sends one message to the others)
  - Each second 1 message

Epidemic Routing – Evaluation

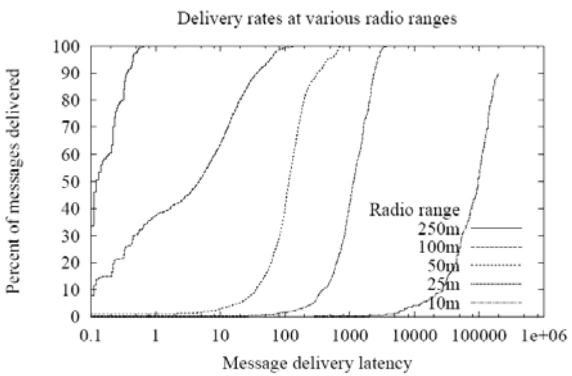


Figure 3: CDF for message delivery as a function of transmission range.

[Vahdat & Becker, TechReport 2000]

Epidemic Routing – Evaluation

Range	Delivery Rate (%)	Baseline Rate	Latency		Hops		Coverage Floor
			Avg (s)	Max (s)	Avg	Max	
250 m	100.0	98.2	0.2	1	2.4	8	10.91%
100 m	100.0	34.3	12.8	177	6.3	21	1.75%
50 m	100.0	0.9	153.0	760	3.7	14	0.44%
25 m	100.0	0.0	618.9	3758	3.3	9	0.11%
10 m	89.9	0.0	44829.7	198107	3.4	9	0.02%

Table 1: Characteristics of Epidemic Routing as a function of transmission range.

[Vahdat & Becker, TechReport 200]

Epidemic Routing – Evaluation

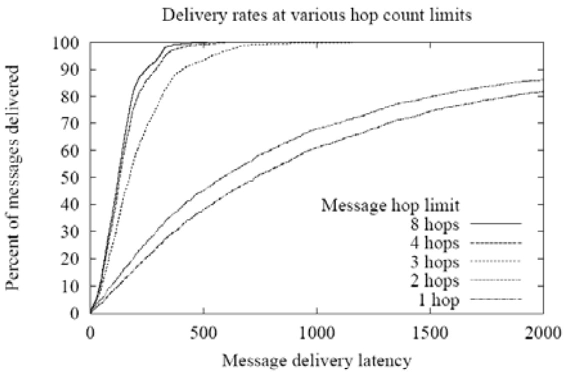


Figure 4: CDF for message delivery as a function of maximum number of hops in packet delivery for 50 m transmission range.

[Vahdat & Becker, TechReport 2000]

Epidemic Routing – Evaluation

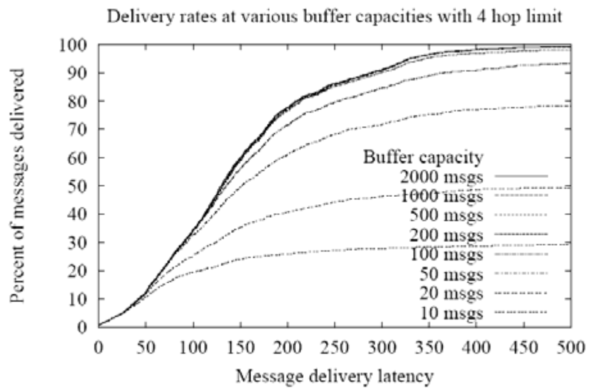


Figure 5: CDF for message delivery as a function of available buffer space for 50 m transmission range.

[Vahdat & Becker, TechReport 2000]

Epidemic Routing – Evaluation

Buffer Size	Delivery Rate (%)	Latency Avg (s)	Buffer Utilization				
			Dead	Buffers	Lifetime (s)	Live	Buffers
2000	100.0	147.3	0	N/A	N/A	1980	44.6
1000	100.0	148.7	178	23.3	2721	1802	30.3
500	100.0	149.2	992	18.0	1664	988	25.4
200	99.6	152.0	1479	12.1	967	501	19.2
100	95.2	157.5	1708	8.4	691	272	16.9
50	79.7	148.2	1826	5.9	491	154	14.9
20	50.2	129.5	1897	3.9	298	83	11.0
10	29.3	98.9	1935	2.9	198	45	9.9

Table 2: Resource consumption characteristics of Epidemic Routing for 50 m transmission range, 4 hops, and variable buffer size.

[Vahdat & Becker, TechReport 2000]

The Trouble with ER

- Potentially high-failure rate
- Message duplication consumes nodal resources
- Some mobility patterns can cause disconnection
- Can be improved with contact probability information - Levine et al

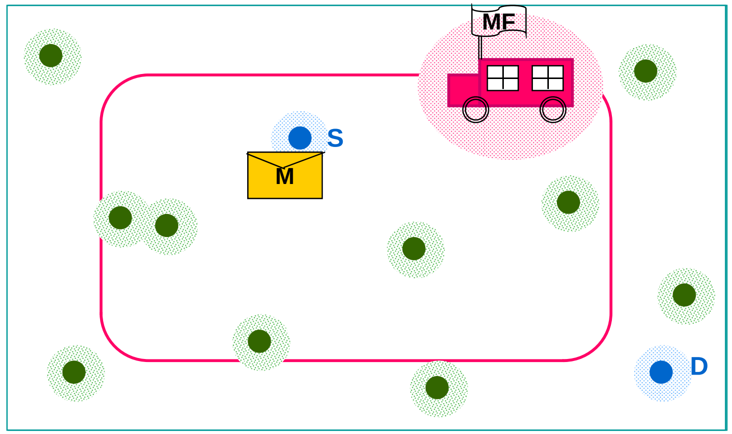
[M. Ammar, Co-Next 2005]

Message Ferrying (MF) @ GT

- Zhao and Ammar
- Exploit *non-randomness* in device movement to deliver data
  - A set of nodes called *ferries* responsible for carrying data for all nodes in the network
  - Store-carry-forward paradigm to accommodate disconnections
- Ferries act as a moving communication infrastructure for the network

[M. Ammar, Co-Next 2005]

Message Ferrying – The Idea



[M. Ammar, Co-Next 2005]

MF Variations

- Ferry Mobility
  - Task-oriented, e.g., bus movement
  - Messaging-oriented, e.g., robot movement
- Regular Node Mobility
  - Stationary
  - Mobile: task-oriented or messaging-oriented
- Number of ferries and level of coordination
- Level of regular node coordination
- Ferry designation
  - Switching roles as ferry or regular node

[M. Ammar, Co-Next 2005]

MF for Networks with Mobile Nodes

- Nodes are mobile and limited in resources, e.g., buffer, energy
- Single ferry is used
  - Not limited in buffer or energy
  - Trajectory of the ferry is known to all nodes
- Data communication in messages
  - Application layer data unit
  - Message timeout

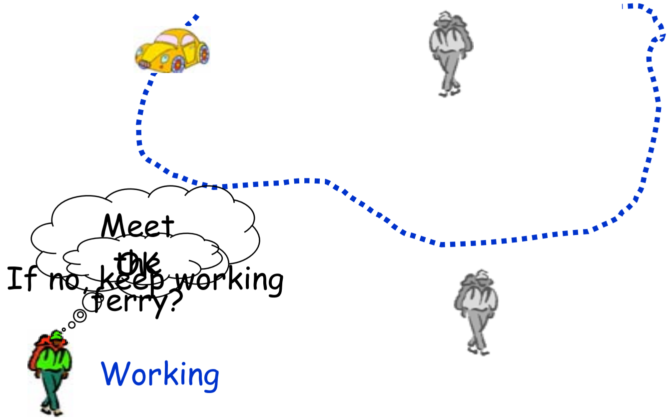
[M. Ammar, Co-Next 2005]

Four Approaches

- Non-Proactive (= Messaging-Specific) mobility
  - Ferrying without Epidemic Routing
  - Ferrying with Epidemic Routing
- Proactive Routing Schemes
  - Node-Initiated MF(NIMF)
    - Nodes move to meet ferry
  - Ferry-Initiated MF (FIMF)
    - Ferry moves to meet nodes

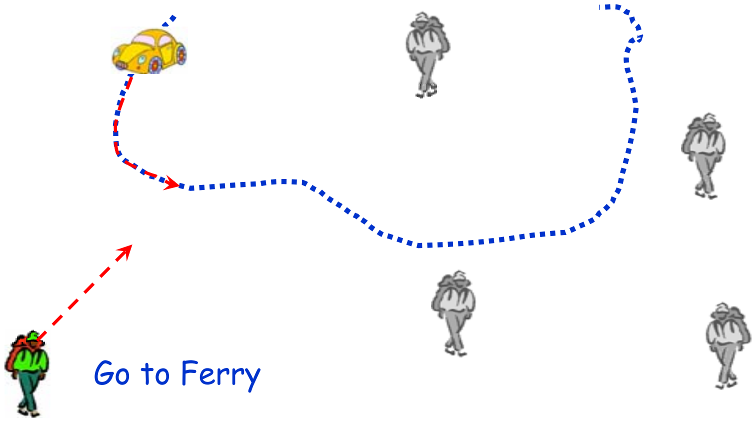
[M. Ammar, Co-Next 2005]

Node-Initiated Message Ferrying



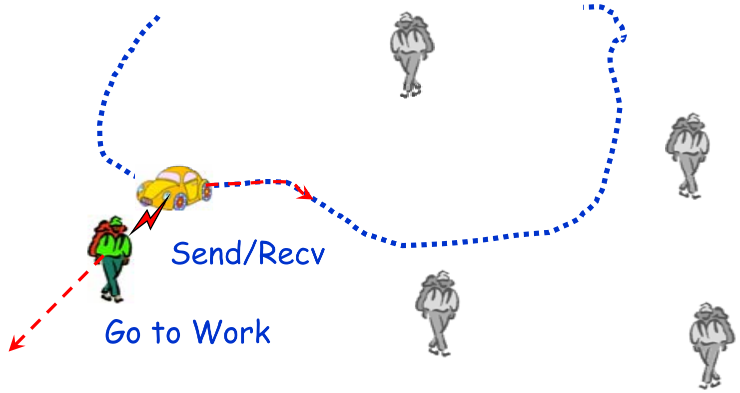
[M. Ammar, Co-Next 2005]

Node-Initiated Message Ferrying



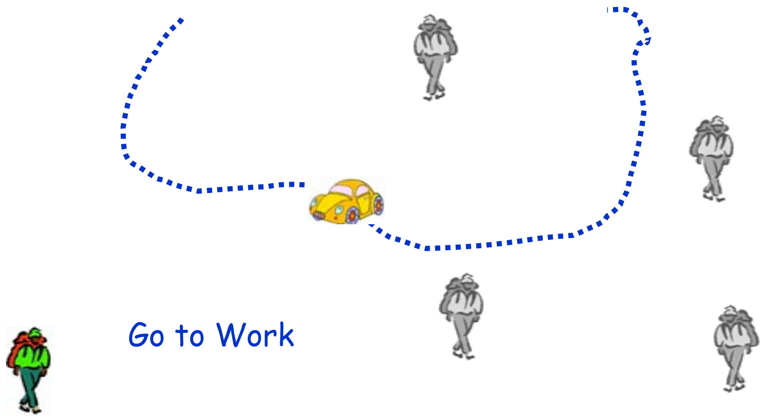
[M. Ammar, Co-Next 2005]

Node-Initiated Message Ferrying



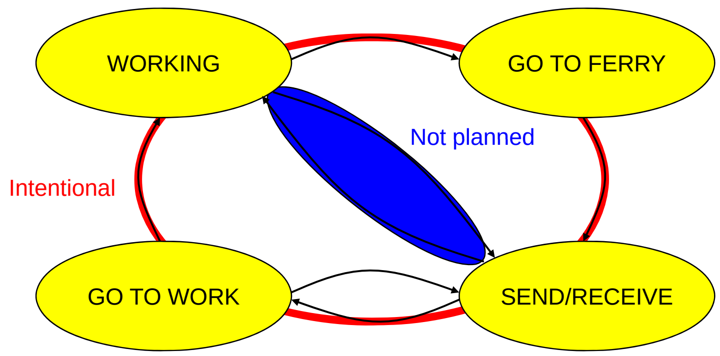
[M. Ammar, Co-Next 2005]

Node-Initiated Message Ferrying



[M. Ammar, Co-Next 2005]

Mode Transition



Node Operation in NIMF

detour: whether the node is detouring;
mode: which mode the node is in;

1. WORKING mode
   detour = FALSE;
   IF *Trajectory Control* indicates time to go to the ferry,
   detour = TRUE;
   mode = GO TO FERRY;
   On reception of a Hello message from the ferry:
   mode = SEND/RECV;
2. GO TO FERRY mode
   Calculate a shortest path to meet the ferry;
   Move toward the ferry;
   On reception of a Hello message from the ferry:
   mode = SEND/RECV;
3. SEND/RECV mode
   Exchange messages with the ferry;
   On finish of message exchange or the ferry is out of range:
   IF *detour* is TRUE,
   mode = GO TO WORK;
   ELSE
   mode = WORKING;
4. GO TO WORK mode
   Move back to node's location prior to the detour;
   On return to the prior location:
   mode = WORKING;
   On reception of a Hello message from the ferry:
   mode = SEND/RECV;

[Zhao et al., MobiHoc04]

Ferry Operations in NIMF

1. Move according to a ferry route;
2. Broadcast Hello messages periodically;
3. On reception of an Echo message from a node:
   Exchange messages with the node;

[Zhao et al., MobiHoc04]

Node Trajectory Control

- Whether node should move to meet the ferry
- Goal: minimize message drops and reduce proactive movement
- Go to ferry if
  - Work-time percentage > threshold
  - and
  - Estimated message drop percentage > threshold

[M. Ammar, Co-Next 2005]

Simulations

- Ns simulations using 802.11 MAC and default energy model
- 40 nodes in 5km x 5km area
- 25 random (source, destination) pairs
- Node mobility
  - random-waypoint with max speed 5m/s
- Message timeout: 8000 sec
- Single ferry with speed 15m/s
  - Rectangle ferry route

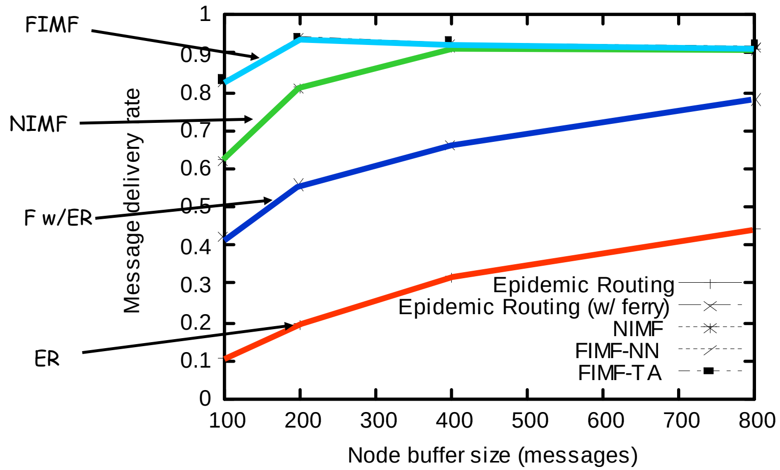
[M. Ammar, Co-Next 2005]

Performance Metrics

- Message delivery rate
- Message Delay
- Number of delivered messages per unit energy
  - Only count transmission energy in regular nodes

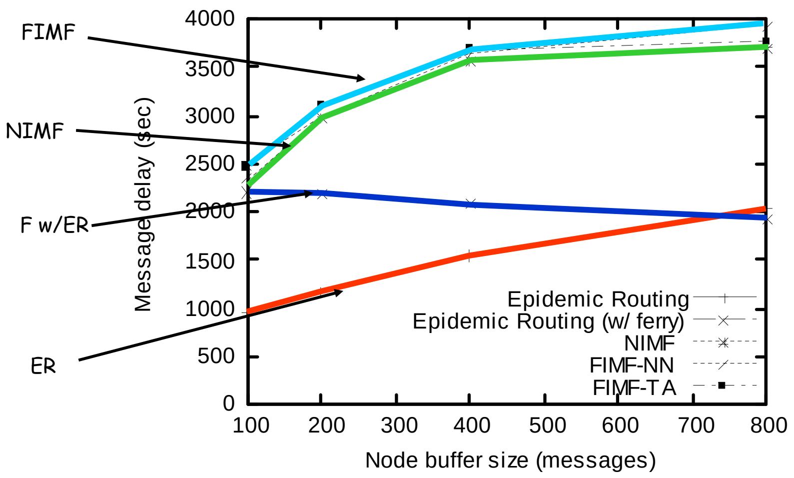
[M. Ammar, Co-Next 2005]

Message Delivery Rate



[M. Ammar, Co-Next 2005]

Message Delay



[M. Ammar, Co-Next 2005]

Impact of Node Mobility Pattern

Mobility Model	Scheme	Delivery Rate	Delay (sec)	Energy efficiency (KB/J)
Random Waypoint	NIMF	0.912	3569	300
	FIMF	0.931	3691	181
	ER(w/ ferry)	0.661	2084	14
	ER	0.316	1546	10
Limited Random Waypoint	NIMF	0.699	3896	267
	FIMF	0.850	4091	137
	ER(w/ ferry)	0.211	2851	11
	ER	0.061	2221	6

[M. Ammar, Co-Next 2005]

Where Does MF Fit?

- Consider the space of wireless mobile networks
- Two Important Dimensions
  - **Relative Mobility**
  - **Density**

[M. Ammar, Co-Next 2005]

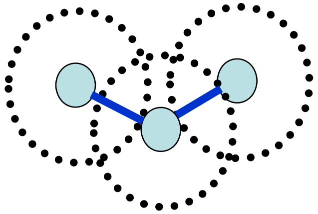
Some Terminology

- A Space Path: A multi-hop path where all the links are active at the same time
- A Space/Time Path: A multi-hop path that exists over time
- NOTE: S path is a special case of S/T path
- See

http://www.cc.gatech.edu/fac/Mostafa.Ammar/papers/STroute.ps

[M. Ammar, Co-Next 2005]

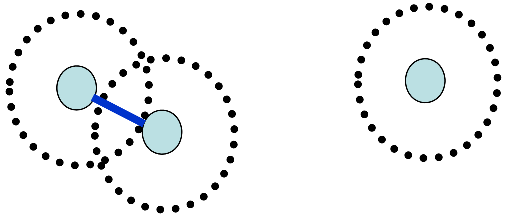
Example



A Space Paths Network

[M. Ammar, Co-Next 2005]

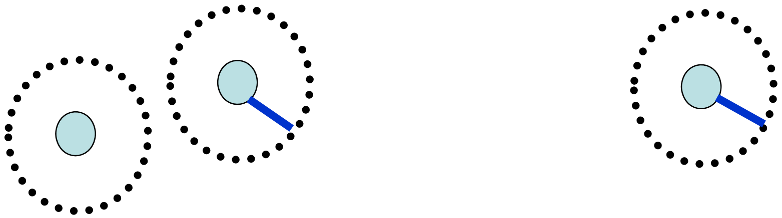
Example



A No Path Network

[M. Ammar, Co-Next 2005]

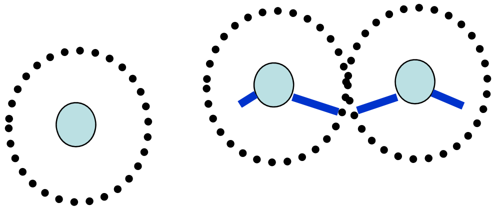
Example



A Space Time Path

[M. Ammar, Co-Next 2005]

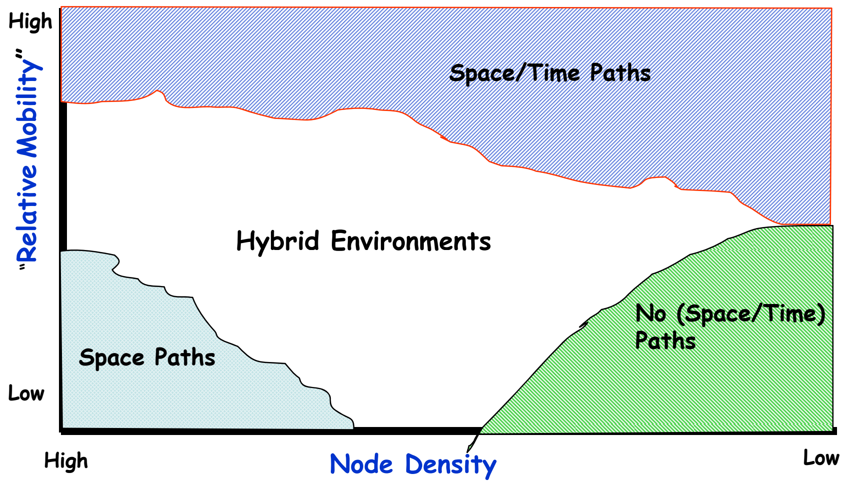
Example



A Hybrid Network

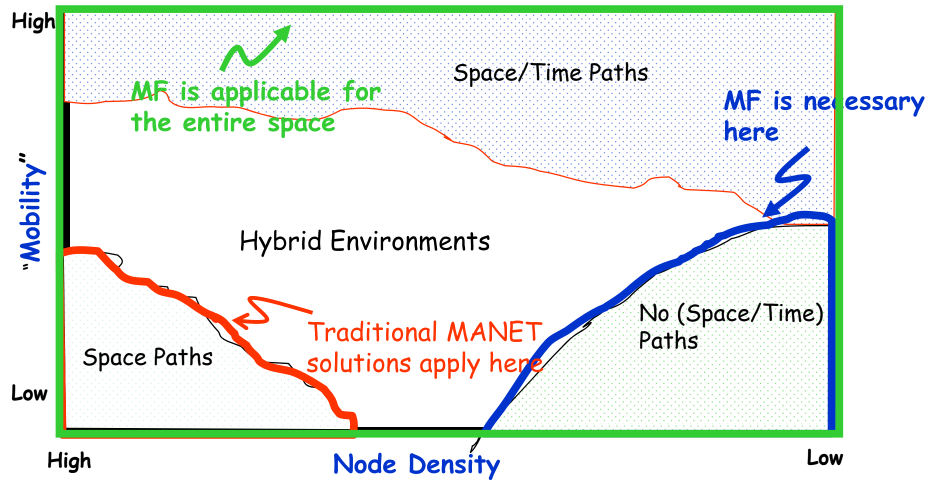
[M. Ammar, Co-Next 2005]

The Mobile Wireless Space



[M. Ammar, Co-Next 2005]

Mapping Solutions to Space



[M. Ammar, Co-Next 2005]

DT-Stream

Can we do video/audio streaming over such networks?

DT-Stream

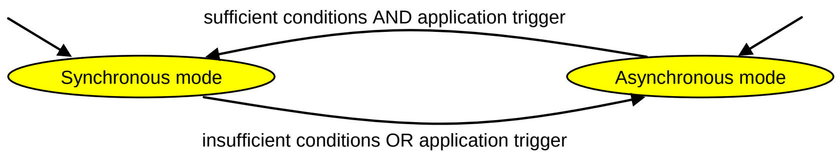
- Pre-project:
  - 2007 four Master Students
- Funding:
  - Norwegian Research Council (3PhDs & 1 PostDoc, +)
  - Spanish Governement (1PhD)
- Project participants:
  - University of Oslo
  - University of Oviedo

DT- Stream Goals

- Delay tolerant streaming applications that do not break when network partitions occur, but instead adapt their functionality, and which seamlessly proceed when connectivity is back
- A self-adaptive overlay that caches AV data at selected nodes to increase the resilience and performance of the AV services
- Autonomic resource management to discover, monitor and manage resources through distributed admission control and multi-path routing protocols.

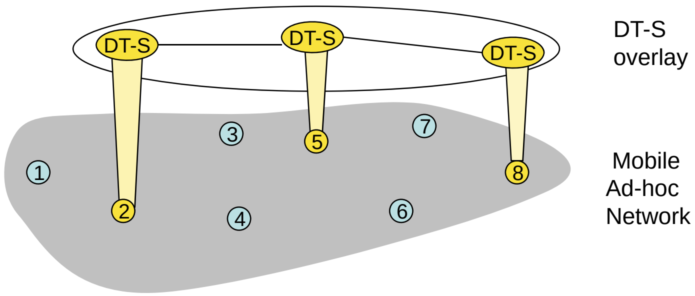
Synchronous and asynchronous mode

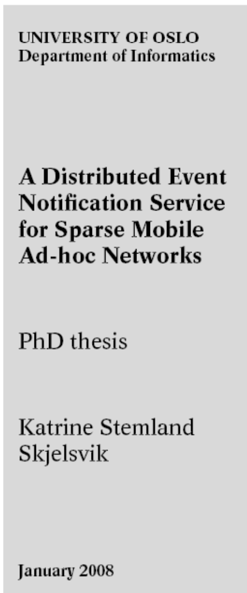
- Delay Tolerant AV Streaming Applications



Overlay

- Adaptive Overlay for Delay Tolerant Streaming





Context

- Ad-Hoc InfoWare: Design middleware services for sparse MANETs used for rescue operations
- Rescue operation goal: Save lives and limit damages on nature and infrastructure
- Distributed Event Notification Service (DENS): support asynchronous communication

Rescue and Emergency

Useful to set up a MANET for information exchange

Source: applica.no

Ad-Hoc InfoWare Building Blocks

- **DENS**
  – Support for asynchronous communication
- **Knowledge Manager**
  – What kind of information is available and where
  – Filter information to avoid information overload
- **Resource Manager**
  – Gather and register resources and make this information available
  – Network topology prediction
- **Security Manager**
  – Key management
  – Encryption of data
  – Access Control

Background: Event notification Service

- Decouples subscribers of information and publishers of information
- Subscriber: express interest in *events* in *subscriptions*
- Publisher: publishes *notifications* concerning *events of interest*
- Event notification service
  – Matching of notifications and subscriptions
  – Routing of notifications and subscriptions

Background: Event notification System II

- Subscription language
  - Subject-based
    - subj = health_sensor
  - Content-based
    - subj = health_sensor, pulse_data < 30 && pulse_data > 200
- Architecture
  - Centralized
  - Distributed
- Routing of subscriptions and notifications in a distributed service
  - Overlay layer
  - Network layer

Outline DENS

- Motivation
- Requirements
- Design
- Results
- Conclusions

Characteristics of Sparse MANETs

- Wireless
  - Low bandwidth
  - Vulnerable communication
- Sparsely connected
  - Disconnections caused by
    - Too large area
    - Physical hindrance of signals
    - Devices turned off to save power
  - Not always a route between a sender and a receiver

→ need asynchronous communication

Characteristics of rescue operations

Complicating factors	*Enabling Factors*
Hectic environment, short time to make decisions	**Preparation a priori**
Dynamic, movement of people, equipment, injured persons, etc	**Procedures and rules are defined**
Different organisations present	**High incentive for collaboration**
Fragile network	**Small to medium-scale**
Scarce resources	**Limited time span**

DENS Requirements

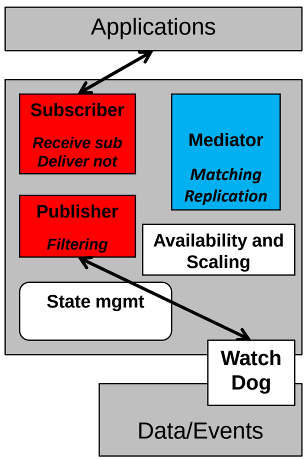
- **From application domain**
  - Reliable and highly available communication service
  - Various degrees of subscription expressiveness needed
- **From rescue operation scenarios**
  - Should cover different mobility scenarios
- **From network characteristics**
  - Aware of bandwidth consumption

Related Work

	Sparse MANETs	Support different SL	Adaptable	Source filtering
STEAM	No	-	No	Partly, filtering at source and destination
Q	No	No	No	Content-based routing, publishers advertise what kind of events they have
Probabilistic and deterministic information dissemination. [Costa et al. 2005]	No	No	Probabilistic routing, suitable for dynamic environments	-
Subject-based, no routing protocol. [Baehni et al. 2004]	Yes	No	Suitable for dynamic environments	-
EMMA	Yes	No	Switches between underlying routing protocol and epidemic routing	-
Message Ferrying	Yes	_	Different configurations for ferries	-

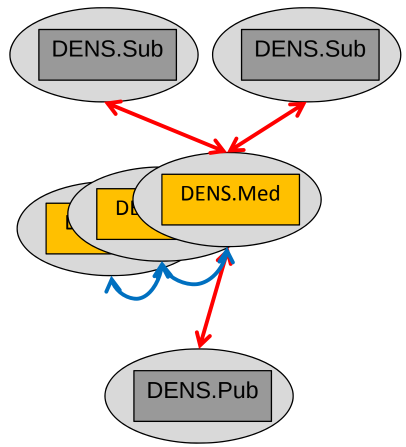
DENS Architecture

- Subscriber
  - Subscriber interface
  - Deliver notifications to local subscribers
  - Keep track of local subscribers and their subscriptions
- Publisher
  - Initiate monitoring
  - Receive filtered events
- Mediator
  - Send subscriptions to DENS on publisher nodes
  - Matching of subscriptions and notifications
  - Send notifications to DENS on subscribers nodes
  - Replication

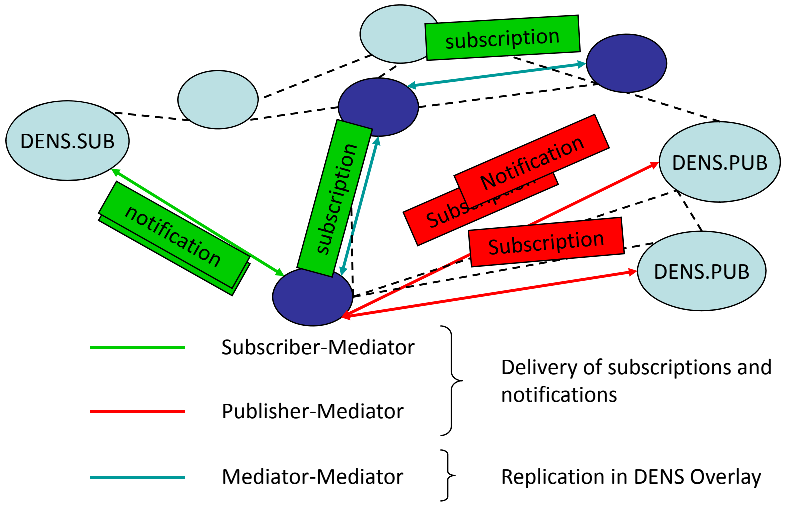


DENS Protocols

- **Delivery of subscriptions and notifications**
  - **Subscriber-Mediator**
  - **Publisher-Mediator**
- **Synchronisation and Replication in DENS overlay**



DENS Protocols



DENS Overlay Configuration

- Number of mediators
  - Number of clusters/groups and partitions
  - Mobility scenario – degree of node density and mobility
- Choose correct Synchronisation Protocol
  - Clustering stability, information from RM
  - Two protocols:
    - DENS Cluster Synchronisation
    - DENS Gossip
- Choose correct configuration of protocol
  - Mobility scenario

DENS Cluster Synchronisation

1. RM reports when there has been a change in the network membership and after the routing table has stabilized
2. Mediator-discovery phase:
   - Elected *partition-representatives* for each old partition floods a mediator-discovery message
   - Other mediators wait for this message
3. Global-synchronisation phase
   - The partition-representative picks one of them to become a *coordinator*
   - The partition-representatives synchronise DENS information
4. Local-update phase:
   - Partition-representatives send updates to mediators in their old partition

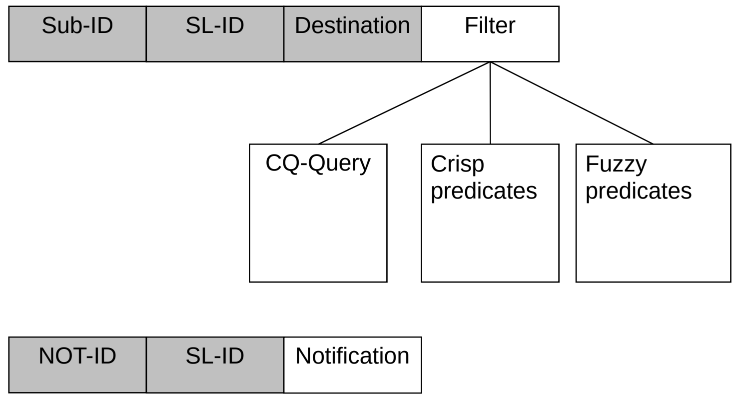
DENS Gossip

- Use when unstable partitions and frequent topology changes
- Mediators synchronise when they meet
- Stores previous synchronisation meeting time
- Send summaries of newer information
- Request missing data

Subscription language independence: 3 functions

- Parse
  - Returns concept terms used in the subscriptions
- Filter
  - Returns events that matches one or more subscriptions
- Match
  - Returns subscriber IDs of matching subscriptions

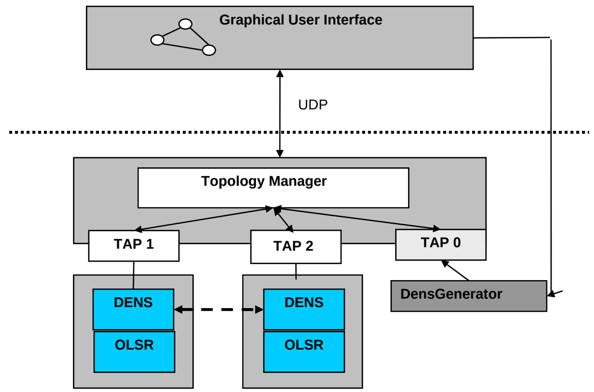
Subscriptions and Notifications



Evaluation: Approach

- Proof-of-concept implementation of parts of the DENS design
- Tested three DENS Gossip Protocol configurations:
  - Configuration 1:
    - Replicate subscriptions and notifications
    - All mediators try to deliver a subscription
    - All mediators try to deliver a notification
  - Configuration 2:
    - Replicate subscriptions and notifications
    - Only one mediator tries to deliver a subscription
    - All mediators try to deliver a notification
  - Configuration 3:
    - Replicate subscriptions
    - Only one mediator tries to deliver a subscription
    - Only one mediator tries to deliver a notification
- Tested Proof-of-concept Implementation with three subscription languages
  - Simple attribute – operator – value language
  - Continuous query using a data stream management system for filtering and matching
  - Fuzzy language where operators such as "more or less" is supported

NEMAN Emulator



Taken from [Pužar et al. 05]

Performance Metrics

- **Delivery ratio:** $\frac{\#notifications\ received}{\#notifications\ sent}$
- **Load:** $\sum_{i=1}^{\#messages} \#hops(message_i)$
- **Delivery time:** $t_{delivered} - t_{sent}$

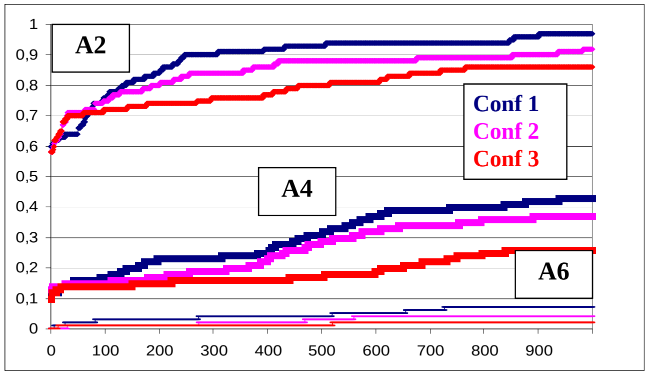
Overview of experiments

- Impact of density
  - Varying the area size
  - load
- Impact of speed
- Impact of number of mediators
- Impact of distribution of mediators

Emulation Parameters

- Number of nodes: 50
- Transmission range: 250 units
- Mobility Model:
  - Random Waypoint
  - Reference point group mobility
- Subscriptions and notifications:
  - 10 subscribers, 1 subscription each
    - All same
    - All different
  - 10 publishers, 1 to 25 notifications each
    - All same
    - All different
- Area:
  - A1: 1000 x 1000
  - A2: 1500 x 1500
  - A3: 2000 x 2000
  - A4: 2500 x 2500
  - A5: 3000 x 3000
  - A6: 3500 x 3500
- Mediators:
  - [5, 10, 15, 20, 25, 30] mediators
- Speed:
  - [1, 5, 10, 15] units per second

Varying area size (density)

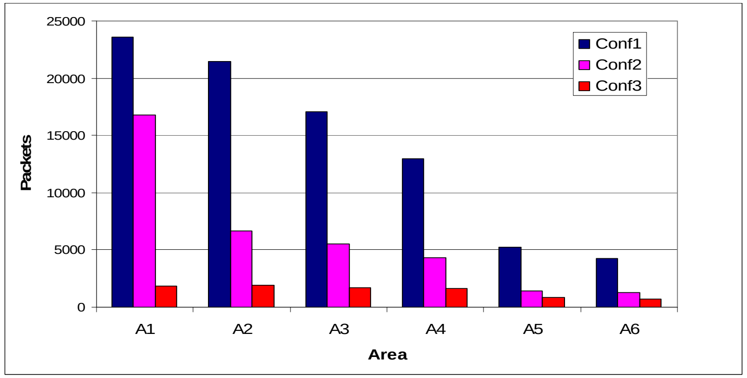


A2=1500x1500
A4=2500x2500
A6=3500x3500

20 mediators
Speed: 5 units/s

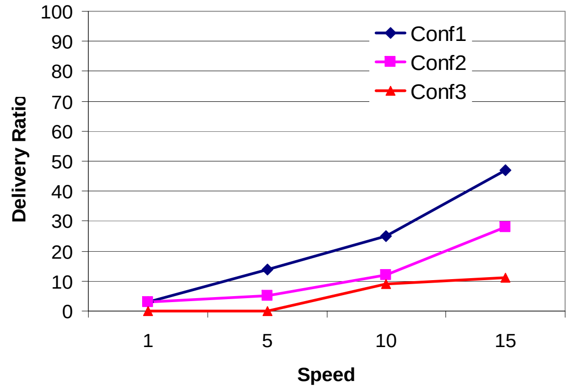
The lower density, the lower delivery ratio
Configuration 1 (*all_sub_all_notifications*) has best result

Load, number of packets



The more replication, the higher load

Varying speed I



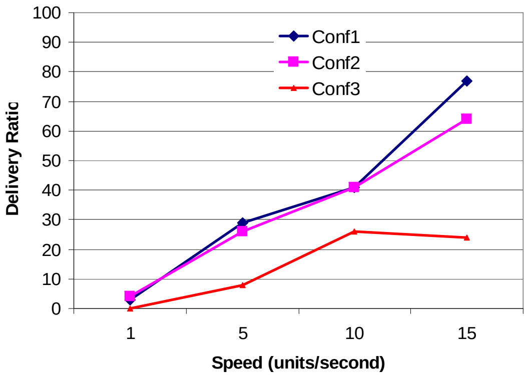
1=1 unit/sec
5= 5 units/sec
10=10 units/sec
15=15 units/sec

A6=3500x3500
20 mediators

All subscribers interested in different events

Higher speed result in higher delivery ratio
Configuration 1 has the steepest curve

Varying speed II



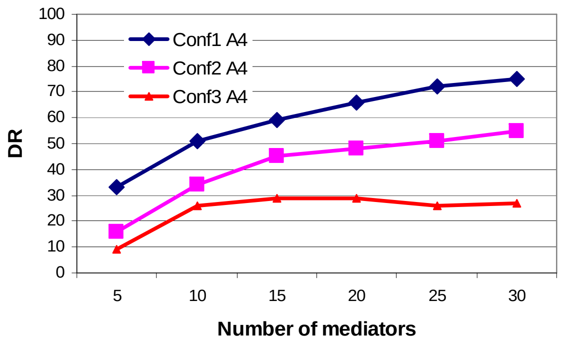
1=1 unit/sec
5= 5 units/sec
10=10 units/sec
15=15 units/sec

A6=3500x3500
20 mediators

All subscribers interested in same event

Small difference between Configuration 1 and 2 if high degree of subscription similarity

Number of mediators



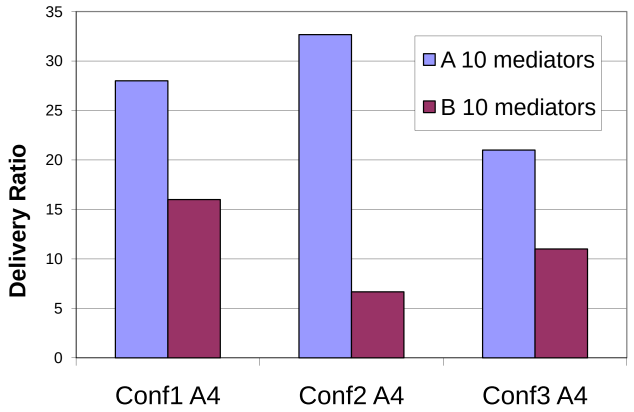
5 mediators
10 mediators
15 mediators
20 mediators
25 mediators
30 mediators

A6=3500x3500
Speed: 5 units/s

All subscribers interested in different events

Configuration 1 benefits the most from having more mediators

Clustering



Group mobility model

A4=2500x2500
Speed: S5

Which nodes are mediators has an impact on the delivery ratio when nodes move in groups

Conclusion

- Replicating DENS information on some of the nodes in the network increases delivery ratio
- DENS can support different subscription languages
- Testing of three DENS Gossip configurations has shown difference in behavior for various mobility scenarios
- Clustering tendencies are important to take into account for choosing correct Mediators

Future Work

- Testing
  - Use of test-bed
  - Use real traces from Red Cross in Vienna
  - Additional testing of the DENS Gossip protocol configurations
  - Testing of DENS Cluster Synchronisation
- Implementation
  - Other protocol configurations
  - Un-subscribe
- Optimisations
  - Use information from routing table
  - Adding DENS information to routing daemon beacons
- Research directions
  - *Availability and scaling* subcomponent – independent scaling of the DENS overlay
  - Handover process