MORA Routing and Capacity Building in Disruption-Tolerant Networks

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February 15, 2009
DTN

- mobile ad hoc wireless network
- end-to-end routing
- depends on the number of participants, their storage capacity, communication and movement patterns
- paper: focus is on performance
Goal

- improve performance by using MORA (=Multi-Objective Robotic Assistance)
- autonomous agents to balance the network demand

- adapt the motion of the agents to bandwidth and latency
end to end communication
mobile nodes
nodes store and pass
Communication

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MORA in DTN
Routing

routing algorithm "Drop-Least Encountered"

- estimate the distance by Likelihood
- peer = 0
- exchange by meeting
- peer=1 and send
- values sink by time and increas by frequently meetings
optimal motion of an agent

- NP hard
- reduce "dial-a-ride problem" a Traveling-Salesman-Problem
- a graph and the peers present participants
- message from A to B
- agent transfer if there is no communication
Multi-objective Control

to get optimzed motion in praxis

- multi-objective control methods
- generate complex behavior by put together simple
- controller present the behavoir with a control function
Control methods

Subsumption:

- include one or more controllers per layer
- status information and can give commands
- Higher level controller can grasp status information of lower controller and overwrite their commands
Nullspace:
- concurrent execution of multiple controllers
- hierarchy
- lower-level controller have no effect of higher-level
- consists of all vectors \( x \) so that \( Ax = 0 \)
- collection of control commands
Nullspace example

- point \( p = (x/y) \)
- controller \( \phi_1 \) changing state to achieve \( x = 0 \)
- controller \( \phi_2 \) changing state to achieve \( y = 0 \)
- controller \( \phi_2 \) orthogonal
- controller \( \phi_2 \) operates in nullspace of controller \( \phi_1 \)

At each level of hierarchy the controller optimizes its action in nullspace of higher controllers.
Performance Metrics

- Bandwidth
- Unique Bandwidth
- Message Latency
- Peer Latency
Bandwidth:
- total number of messages at a point in time
- schedule motion of agents to increase bandwidth
- space of transfer message should be used effectively
- agents have to consider their travel time for delivery
Performance Metrics

Unique Bandwidth:
- total number of unique messages which are currently active
- bandwidth should be used effectively
- agents should transmit messages not already in transmit
Performance Metrics

Message Latency:
- average amount for a message delivery
- for reducing agents should move towards peers which are sending or receiving many messages

Peer Latency:
- average time since a peer was last visited by agent
- participants should be visited intermittently
• real network no global information available
• each peer has information about their own state
• all participants should have synchronized clocks
• each agent have information about participants
• two agents meet and exchange packages and routing protocol
Movement Controllers for Performance Metrics

- Total Bandwidth Controller $\phi_T$
- Unique Bandwidth Controller $\phi_U$
- Message Latency Controller $\phi_D$
- Peer Latency Controller $\phi_p$
Movement Controllers for Performance Metrics

Total Bandwidth Controller $\phi_T$:
- the chosen peer has the largest number of messages not seen by agent

Unique Bandwidth Controller $\phi_U$:
- choose peer which have the largest number of messages not present
Message Latency Controller $\phi \ D$:
- choose peer whose average delivery time is the largest

Peer Latency Controller $\phi \ p$:
- choose location $n_i$ (last visited)
- $\Delta \ t_{n_i}$ time since $n_i$ has been visited
- $n = \text{argmin}_{n_i} \Delta \ t_{n_i} + t_{n_i}$
these controllers consider only a single performance metric
generate conflicts for agents
for example

- two peers with a large number of messages
- Total Bandwidth Controller $\phi T$ only maximize these peers
- other peers wouldn’t be visited
- not possible to combine bandwidth and latency controller
- solution: coordinate controllers and select parameters
Multi-Objective Control

hierarchy

- $\phi_p < \phi_D < \phi_U < \phi_T$
- $\phi_i < \phi_j$ means $j$ more important than $i$
- example Subsumption:
Controller with highest priority decides
lower priority get only a chance if all higher optimized their metric
Controller $\phi_T$ optimize its bandwidth and give the next lower controller $\phi_U$ a chance
if $\phi_U$ violated the total bandwidth $\phi_T$ get the control back
Comparison of Nullspace and Subsumption

- nullspace controller execute concurrently and subsumption at a time
- low nullspace controller can’t influence higher controller
Experimental Evaluation

based on
- DTN
- 30 buses
- GPS devices on each bus
- location of each bus available
Experimental Evaluation

trace generator

- use GPS to reconstruct movement and timing of 9 buses routes in area of 8.24 km
- each route is presented by trace days
- advantage: buses can be varied
default values for each simulation:

- unlimited buffer
- load of 36 pkts/hour
- 10-Kbyte packets
- 9 buses, each on distinct routes
- agents increase the buffersource, so random choice 3 buses without free storage capacity
Experimental Evaluation

Protocols:
- Random: first packets to B and the rest by chance
- MaxProp: Each packet get a number, the packet with the lowest number is send first
- ME/DLE: packets get priority, lowest first
- FIFO: First in First out
Comparing Supsumption and Nullspace:

![Bar chart comparing average delivered fraction of Threshold Nullspace and Subsumption across different numbers of robot agents.](chart.png)
Experimental Evaluation

Comparing Supsumption and Nullspace:

![Bar chart comparing average latency for different number of robot agents. The chart shows a comparison between Threshold Nullspace and Subsumption.]
Experimental Evaluation

Comparison of MORA to movement using random selection

![Graph showing comparison of MORA to movement using random selection. The graph plots the average fraction of packets delivered against packets per hour per bus. The MORA+MaxProp line is shown in black, and the random destination selection + MaxProp line is shown in blue. The graph indicates that MORA+MaxProp performs better than random destination selection + MaxProp as the number of packets increases.]
Comparison of MORA to movement using random selection
Comparison of MORA+MaxProp by varied speeds of agents

![Graph showing performance of MORA+MaxProp under different speeds of agents. The x-axis represents Packets per Hour per Bus, and the y-axis represents the Avg Fraction of Packets Delivered. Lines indicate different speeds: half speed, normal speed, and twice speed.]
Experimental Evaluation

Comparison of MORA+MaxProp by varied speeds of agents
Experimental Evaluation

packet delivery rate as network load increases

![Graph showing packet delivery rate as network load increases.](image-url)
Experimental Evaluation

packet latency as network load increases

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MORA in DTN
Experimental Evaluation

packet delivery rate as local buffer size increase
Experimental Evaluation

packet latency as local buffer size increase

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packet delivery rate with an increasing number of buses

![Graph showing the packet delivery rate with an increasing number of buses.](image)
Experimental Evaluation

packet latency with an increasing number of buses
Experimental Evaluation

packet delivery rate as packet size increases

![Graph showing the relationship between packet delivery rate and packet size for different algorithms and packet sizes.](image-url)
Experimental Evaluation

packet latency as packet size increases

![Graph showing packet latency vs. packet size for different protocols.](image-url)
Synthetic mobility model: delivery rate as packet load increases
Experimental Evaluation

Synthetic mobility model: latency as packet load increases

![Graph showing latency as packet load increases]
Experimental Evaluation

Synthetic mobility model: delivery rate as number of nodes increases

![Graph showing delivery rate vs. number of nodes](Image)
Experimental Evaluation

Synthetic mobility model: latency as number of nodes increases
Bandwidth error

![Bandwidth Error Graph](image)

(a) Bandwidth Error
Bandwidth error

![Graph showing bandwidth error over time for one, three, and six agents.](image)
Experimental Evaluation

latency error

(c) Latency Error
Experimental Evaluation

latency error

(d) Last Visited Error

Time (Seconds)

Last Visit Error (Minutes)

One Agent
Three Agents
Six Agents
Experimental Evaluation

Agent longitude error

(e) Agent Longitude Error
Experimental Evaluation

Agent longitude error

![Graph showing agent longitude error over time for one, three, and six agents.](image)

(f) Agent Latitude Error
To improve the performance of DTN use MORA
MORA sets autonomous agents in the DTN
To get the optimize movement use control methods
Thank you for your attention