

# Exploiting Communication Opportunities in Disrupted Network Environments

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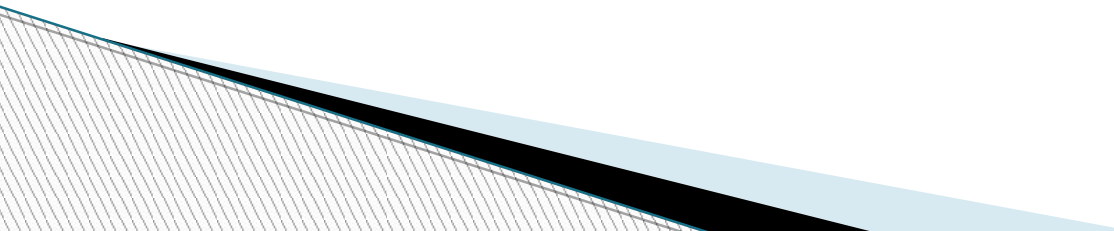
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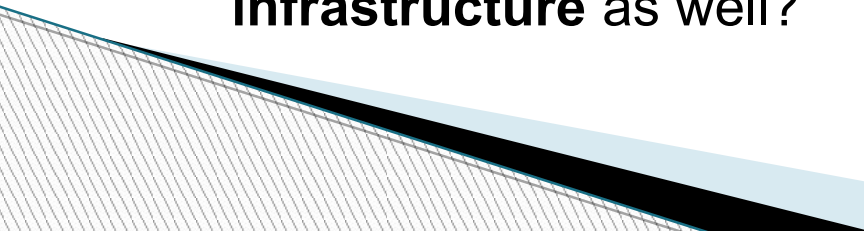
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# Outline

- ▶ DTN deployment considerations
  - ▶ Identifying research challenges
  - ▶ The proposed platform & mobility model
  - ▶ Indicative results
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# Where DTNs can be deployed

- ▶ When other network technologies fail, DTNs can still work.
  - ▶ Connectivity may not be available:
    - Disaster environments
    - It is there, but not for me, i.e., expensive
    - Extreme conditions (e.g., space)
  - ▶ An infrastructure deployment may exist in all above cases.
  - ▶ The slightest communication opportunity should be exploited.
    - Why not **exploit resources from the surrounding infrastructure** as well?
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# Infrastructure is changing

- ▶ **Software-Defined Networks (SDNs)**

- Flexible Network Infrastructure



- ▶ **Virtualization & Clouds**

- Flexible Data Centers



- ▶ **Information-Centric Networking**

- Flexible Content Flow

# Closing the gap with the infrastructure

- ▶ **Infrastructure provides new ways to support DTNs:**
  - *SDNs & OpenFlow*: Move traffic near the mobile devices, mobility handling, resources' offloading etc.
  - *Mobile Clouds*: Mobile devices as essential cloud components, migrate VMs close to mobiles etc.
  - *ICNs*: Organize content close to the mobile devices
- ▶ **DTNs can adopt new ideas and support infrastructure better:**
  - Extending network connectivity to areas that was not possible before

# Centralizing Control Elements for DTNs



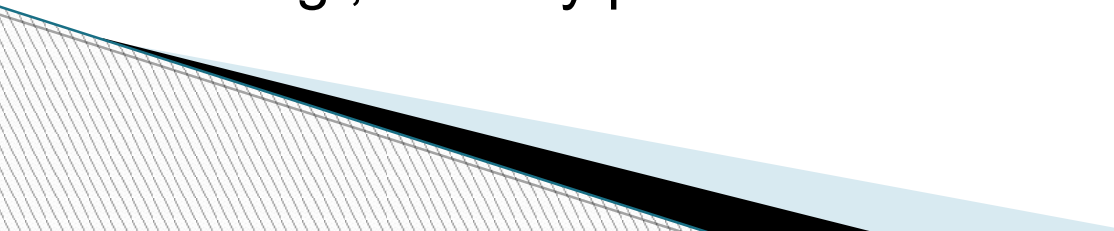
## Events from mobile devices

Mobility behavior,  
Traffic statistics,  
Application requirements,  
Resources availability,  
Resource offloading

## Output to mobile devices

(Un)install rules,  
Predictions / forecasts,  
Support of routing decisions

# Different characteristics in DTNs

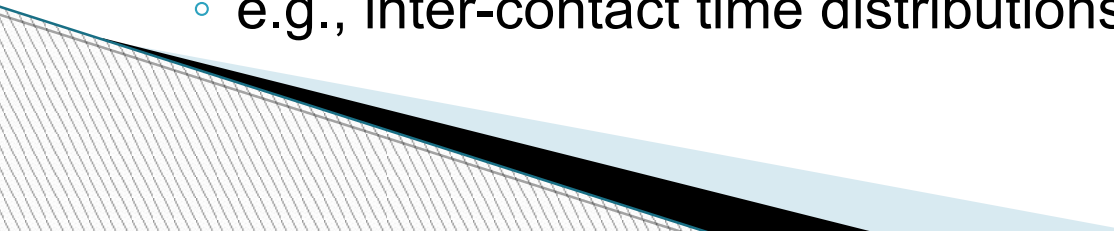
- ▶ Control information communication may be intermittent
    - Local control is needed as well
  - ▶ Control plane should have centralized & distributed control components.
  - ▶ A centralized control plane can be offloaded resource expensive tasks
    - e.g., mobility predictions.
- 

# Main targeted problem

- ▶ People mobility in urban environments is **characterized by certain patterns**:
  - Walking people have a high probability to pass from high streets or other points of interest
  - People inside buses pass from a predetermined number of stops
  - People inside cars pass through major roads with an increased probability
- ▶ Can we model user mobility in order to **detect such patterns**?
  - it helps us to select the most appropriate node to carry our data



# Patterns everywhere

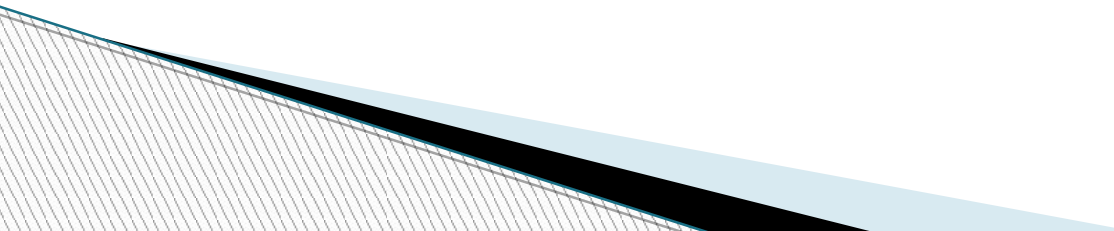
- ▶ How mobile users move
    - e.g., mobility patterns
  - ▶ How do they communicate between each other
    - e.g., social behavior.
  - ▶ .. and the Network
    - e.g., traffic patterns, application requirements.
  - ▶ How and how frequently do they interact
    - e.g., inter-contact time distributions etc.
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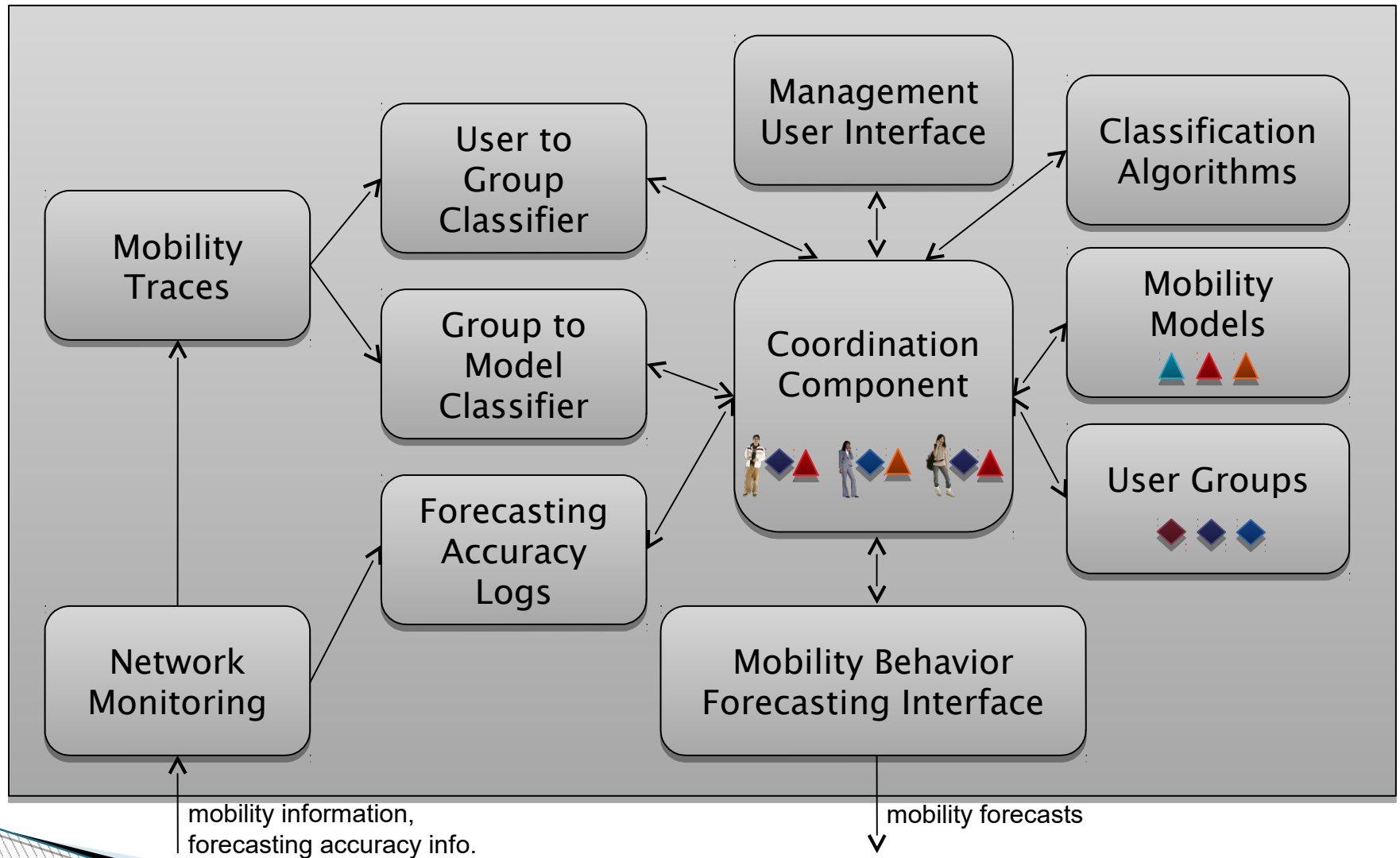
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Context Sensitive  
Solutions

# A new platform is needed

- ▶ We propose an infrastructure that:
    - Collects data on the network and user behavior
    - Deploys, validates and audits a number of prediction models
    - Classifies users to the appropriate models
    - Groups users according to their behavior
  - ▶ The platform **creates and disseminates “global picture” information** to each communicating node.
  - ▶ It **handles resource-expensive prediction operations** on behalf of the mobiles.
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# Proposed platform

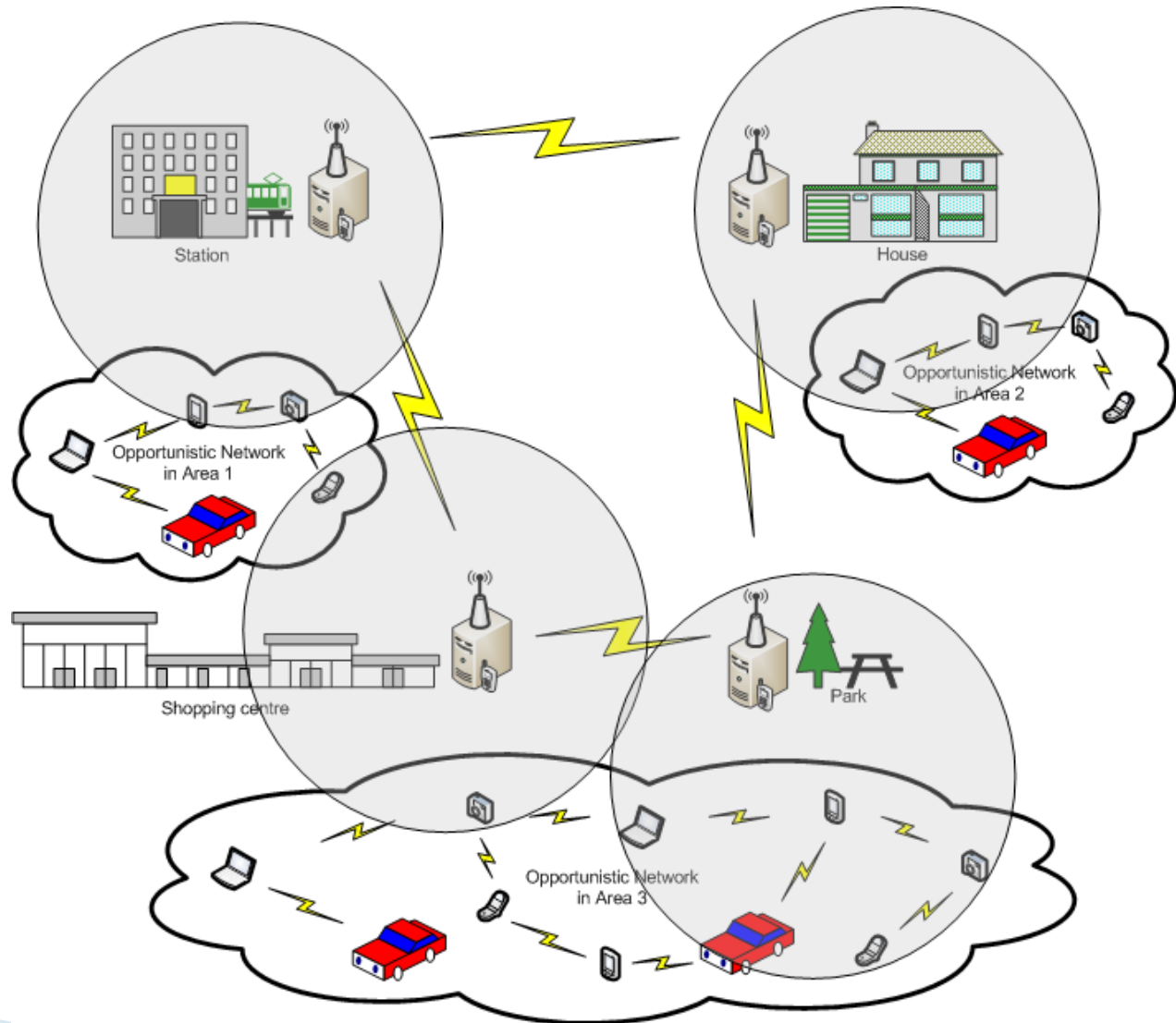


# Supporting opportunistic routing

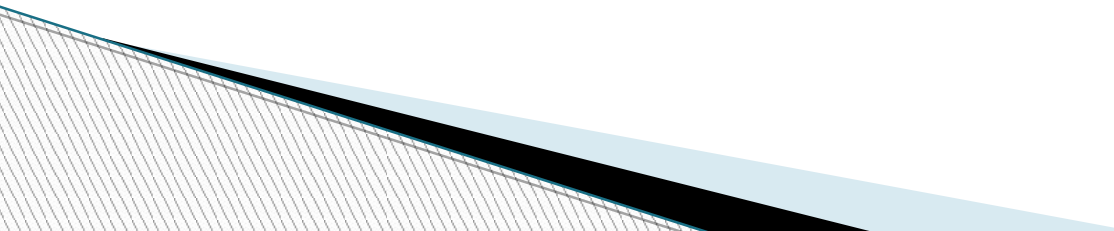
A routing mechanism:

- ▶ **should tune involved trade-offs, e.g.,**
  - Mobiles may offload resources to infrastructure nodes
  - Storage could be traded for communication overhead
  
- ▶ **each node should take appropriate decisions**
  - a mobility model could be parameterized / solved from the infrastructure nodes
    - example result: inter-contact times distribution is exponential with rate  $\lambda$
  - resulting parameters could be fed to mobiles, which in turn can take the decisions

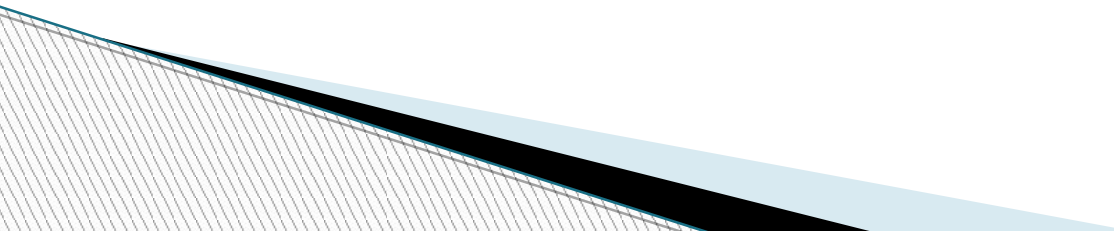
# An Internet access example



# Assumptions

- ▶ We assume a number of fixed nodes scattered in the city (e.g., at points of interest)
  - ▶ The fixed nodes track users passing-by
  - ▶ The infrastructure implements the proposed platform
  - ▶ Mobile devices:
    - retrieve forecasts for a number of mobility aspects.
    - take routing/forwarding decisions
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# Studied mobility model

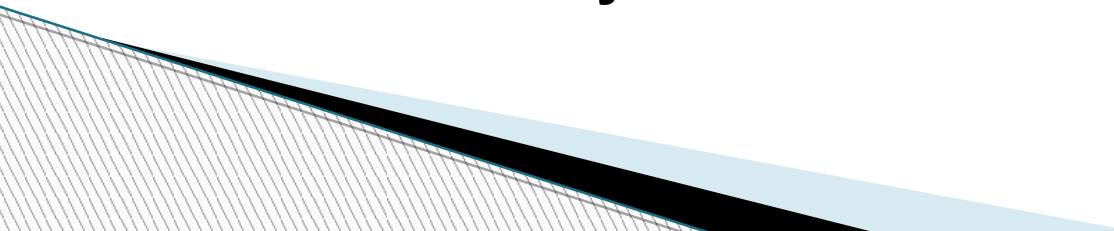
- ▶ The probability of a user to contact a Point of Interest isn't always exponential
  - ▶ We performed statistical analysis of results from:
    - simulations (theone)
    - other spatial models(results from real experiments will follow)
  - ▶ We defined the contact probability distributions in a wide range of scenarios
  - ▶ We introduced a Semi-Markov Model, based on the above results
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# The Semi-Markov Model

- ▶ Discrete-Time Semi-Markov System (DTSMS)
- ▶ Assumptions:
  - users are stratified into a set of areas  $S = 1, 2, \dots, N$ .
  - a number of areas have network coverage (e.g., 1 to  $K$ ) while other areas do not (e.g.,  $K$  to  $N$ ).
  - state of the system described by the vector  $N(n) = [N_1(n), N_2(n), \dots, N_N(n)]$ , where  $N_i(n)$  is the expected number of users located at an area  $i$ , after  $n$  time slots.

# Supported forecasts

- ▶ The proposed model detects certain patterns regarding the spatial behavior of the users.
  - ▶ Some examples are:
    - What is the **probability of a state transition** from some given state to any other target state.
    - Whether **some states** have a significantly **higher probability to be reached**.
    - What is the **number of areas** that need to be **crossed** by a mobile user walking across two predetermined areas.
    - **Node density at an area** after a given time.
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# Example protocol implementation

' This function is executed every time the  
' mobile node (e.g., node A) contacts any other  
' node (e.g., node B)

function **NewContact** (node B):

' Updates the local contact history of node A

**UpdateContactHistory** (node B)

if (**B is an infrastructure node**):

' Node A communicates its local contact

' history with the infrastructure

**CommunicateContactHistory** ()

' Retrieves fresh predictors from the

' infrastructure

**RetrievePredictors** ()

' Forwards the pending data to the Internet

**ForwardDataToInternet** ()

end if

if (**B is a mobile node**):

' Updates connection times

**UpdateConnectionTimes** ()

' Calculate probabilities of A and B to

' reach to the Internet

probA = **CalculateInternetAccessProb**  
(node A)

probB = **CalculateInternetAccessProb**  
(node B)

if (probA >= probB):

' Keep the pending data at node A

**KeepData** ()

else

' Forward the pending data to node B

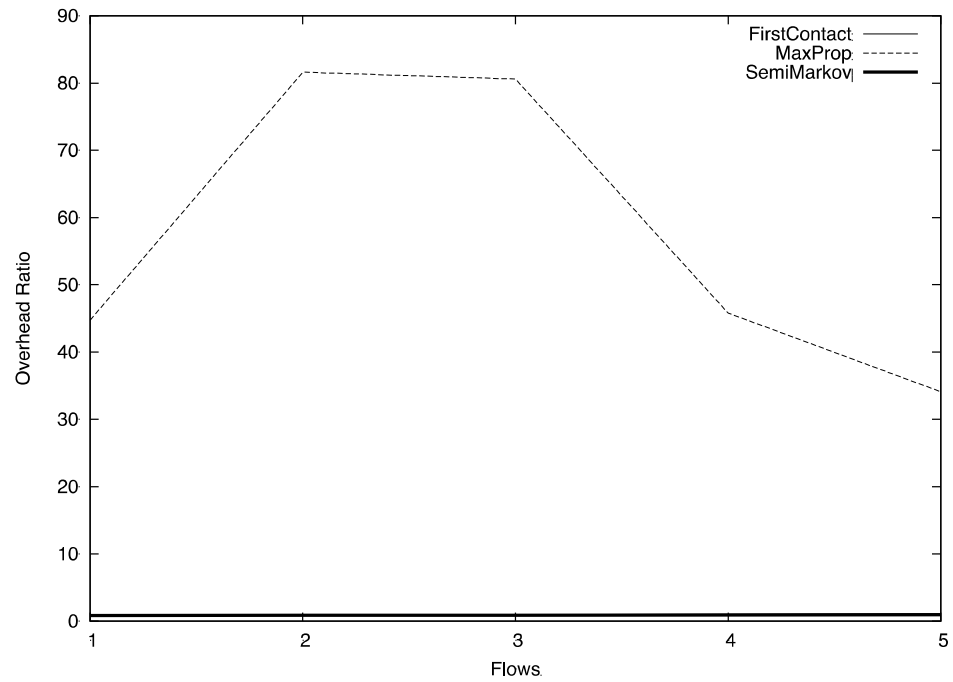
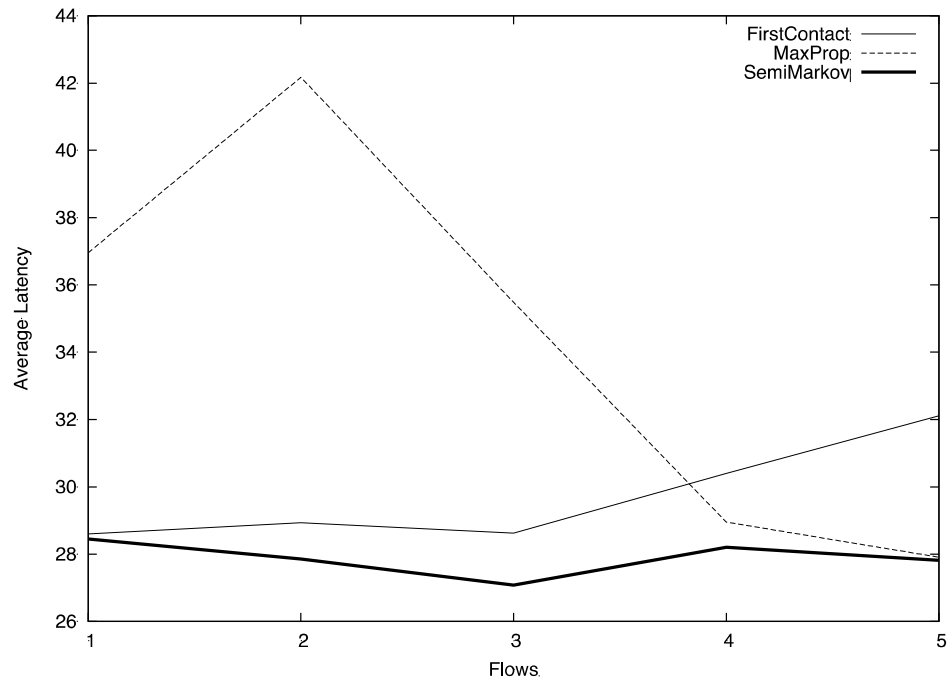
**ForwardData** (node B)

end if

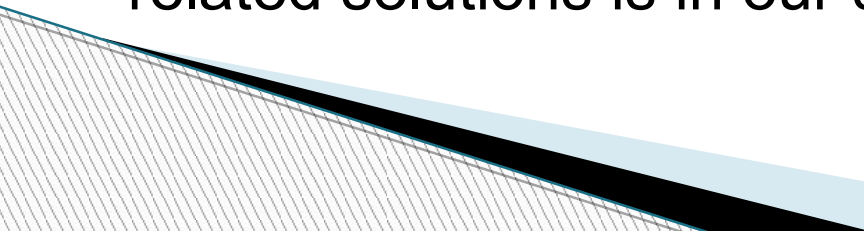
end if

end function

# Indicative results



# Conclusions

- ▶ We **revisited DTN research / deployment** issues with respect to the **recent evolvments** in the Internet infrastructure.
  - ▶ We suggest that:
    - Opportunistic networks can **bridge distant infrastructure networks**.
    - Infrastructure nodes can **support opportunistic communication** with mechanisms that:
      - detect **system - wide mobility patterns**
      - perform **resource - expensive estimation calculations** for the benefit of the mobile devices.
  - ▶ A more **sophisticated protocol** proposal contrasted with the related solutions is in our short-term plans.
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