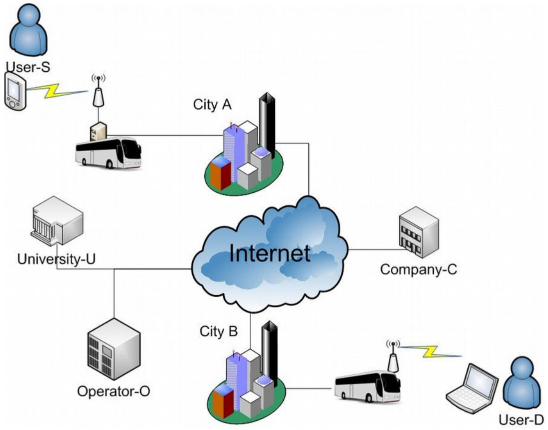

Exploiting Communication Opportunities in Disrupted Network Environments

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Outline

- DTN deployment considerations
- Identifying research challenges
- The proposed platform & mobility model
- Indicative results

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?

Infrastructure is changing

- **Software-Defined Networks (SDNs)**
  - Flexible Network Infrastructure

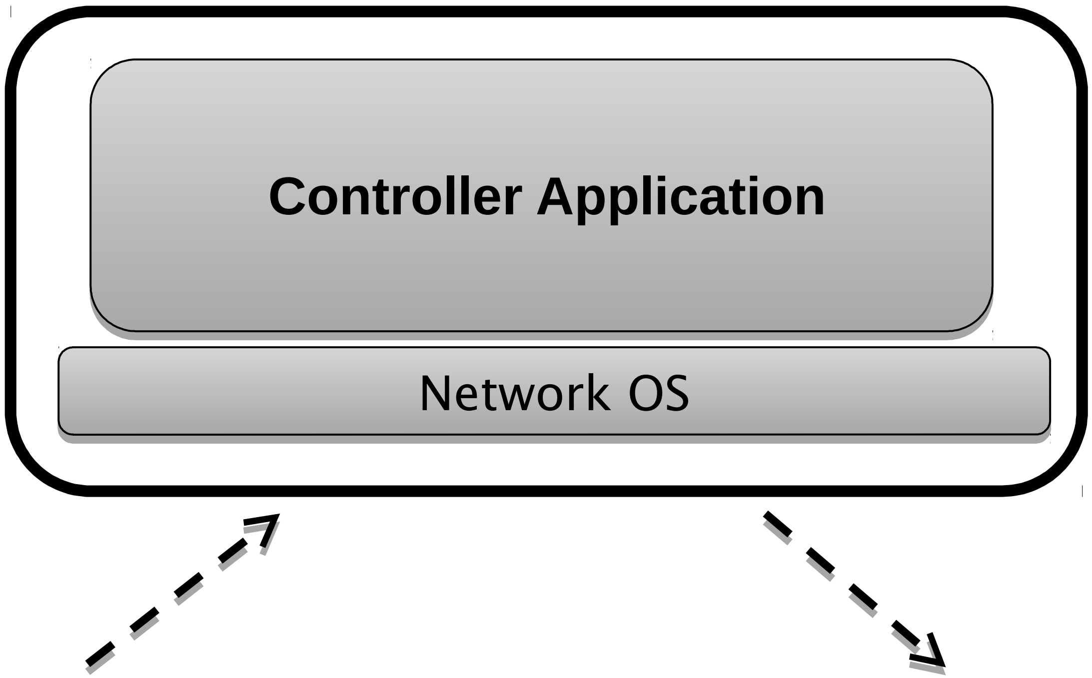
- **Virtualization & Clouds**
  - Flexible Data Centers

- **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

(based on slide from Nick McKeown, Stanford University)

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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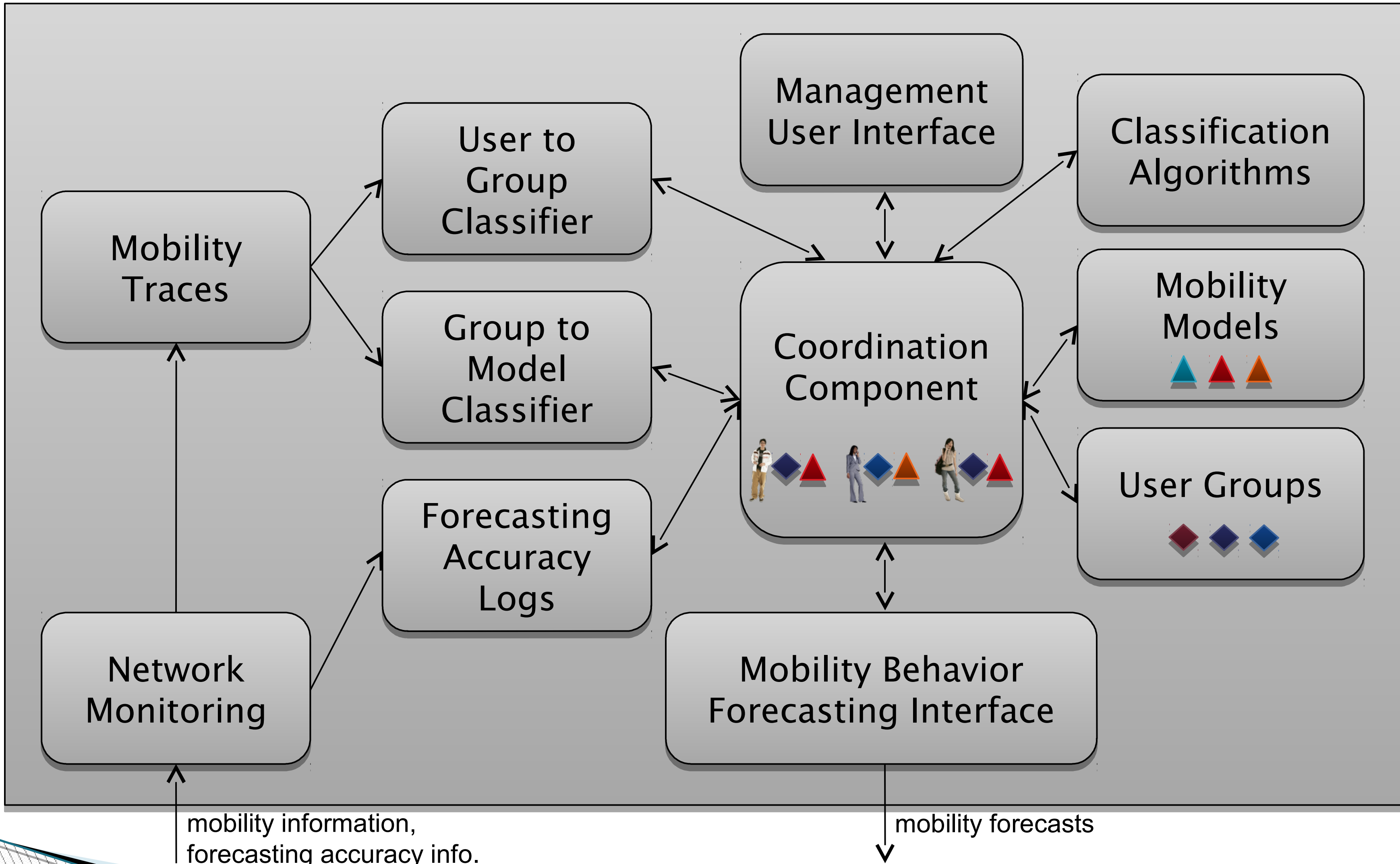
Context Sensitive Solutions

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.

Proposed platform



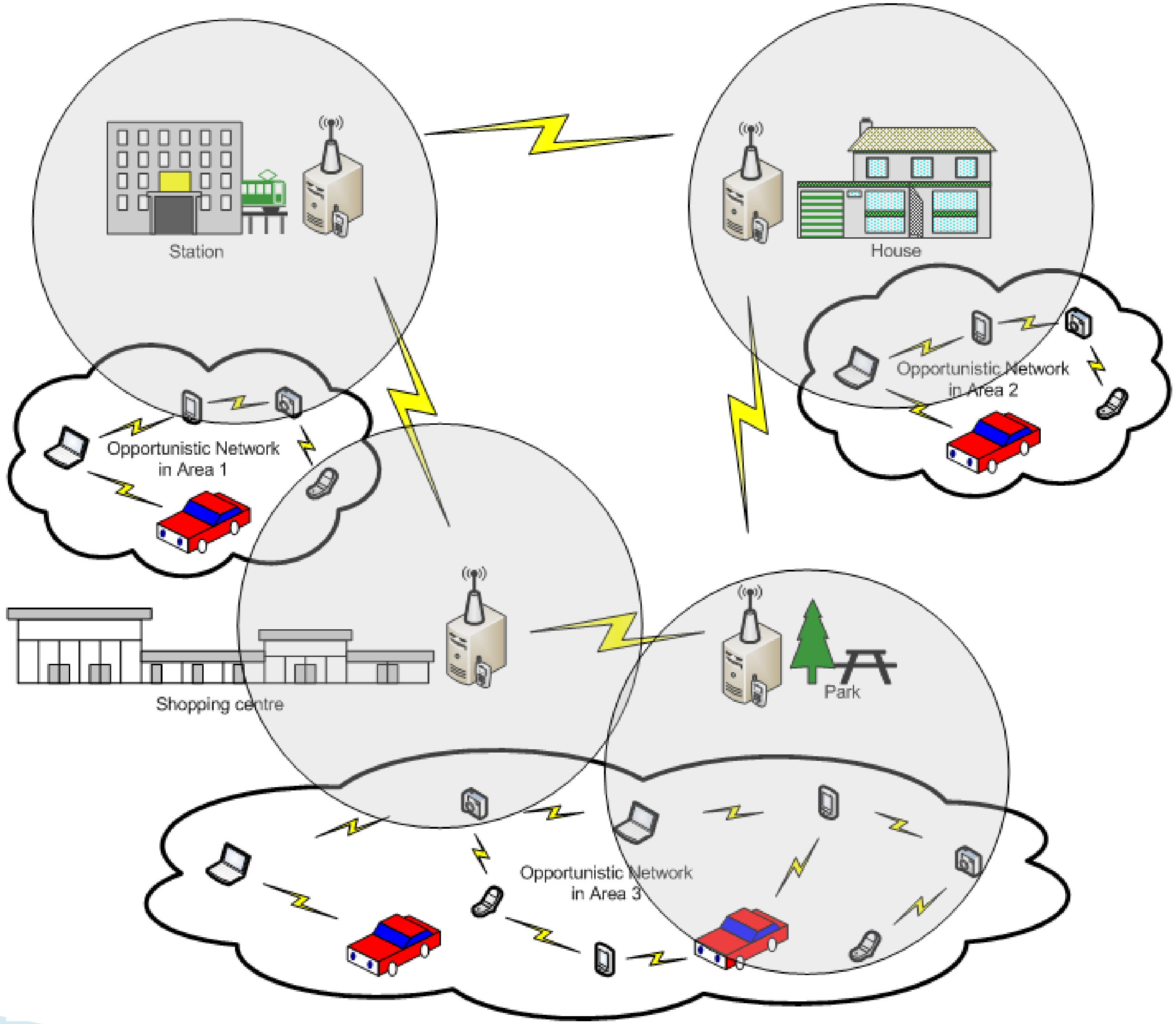
Supporting opportunistic routing

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 λ
  - 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

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

The Semi-Markov Model

- Discrete-Time Semi-Markov System (DTSMS)
- Assumptions:
  - users are stratified into a set of areas S = 1, 2, ..., 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 $N(n) = [N_1(n), N_2(n), \ldots, N_N(n)]$, where $N_i(n)$ is the expected number of users located at an area i, after n time slots.

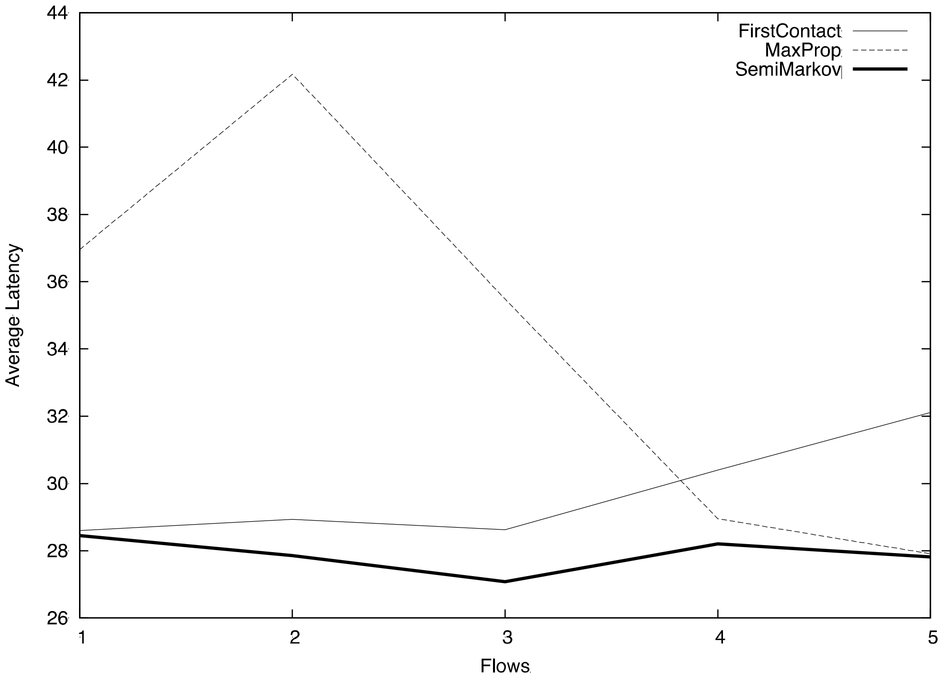
Supported forecasts

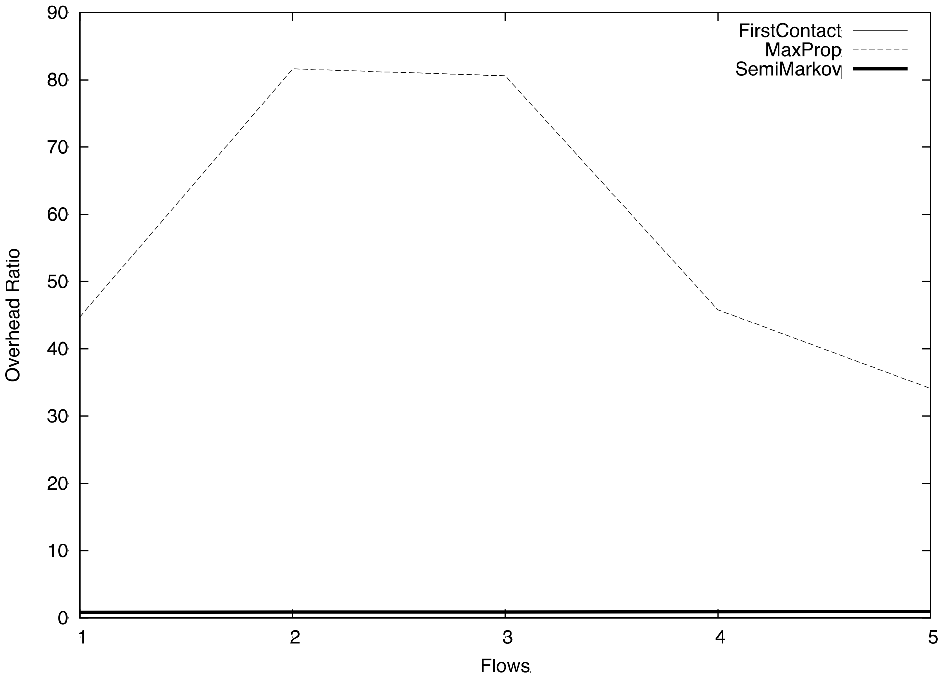
- The proposed model detects certain patterns regarding the spatial behavior of the users.
- Some examples are:
  - What is the **probability of a state transition** from some given state to any other target state.
  - Whether **some states** have a significantly **higher probability to be reached**.
  - 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.

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 evolvements** 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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