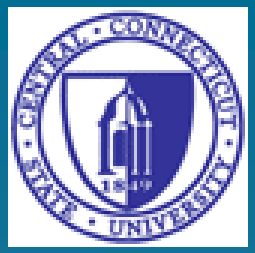


Central Connecticut
State University

Delay Tolerant Networks: Challenges and Applications

Dr. Farid Farahmand

The Advanced Internet Technology in the Interests of Society Laboratory

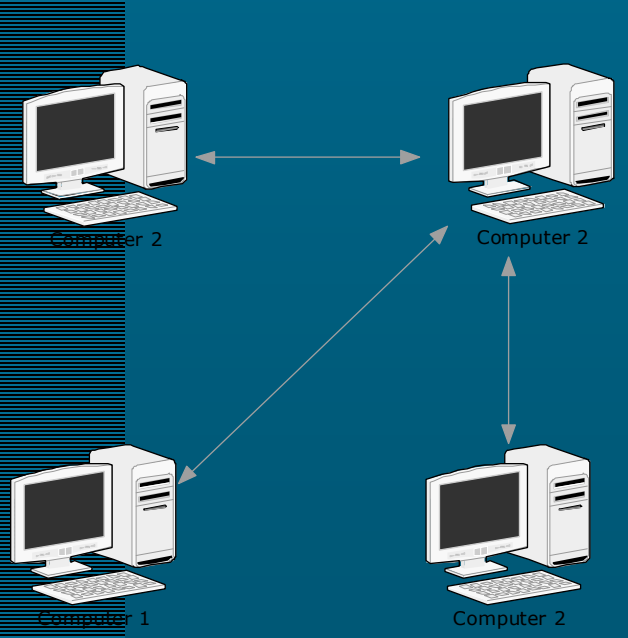
Presentation Outline

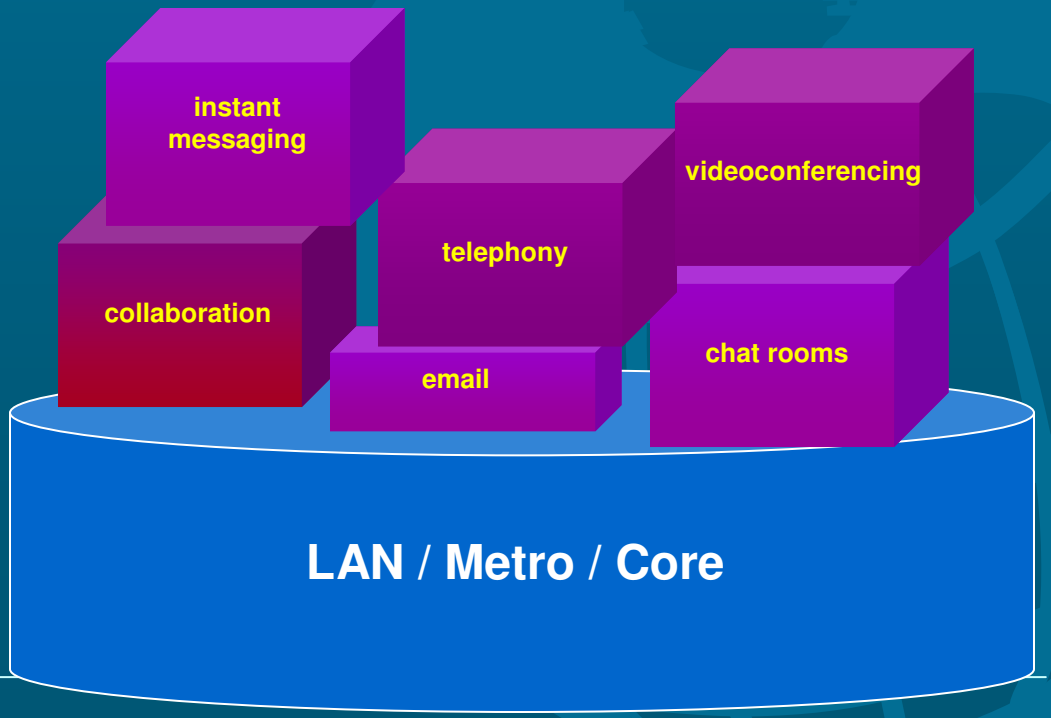
- Future networks & their characteristics
- Delay tolerant networks
- Our research focus in DTN
- Open research areas in DTN
- Available resources

Basic Applications and Networks

Before

- The Internet: the largest network
  - Interconnecting communication devices across the globe using TCP/IP protocol suite
  - Designed based on a number assumptions…..





Traditional Characteristics

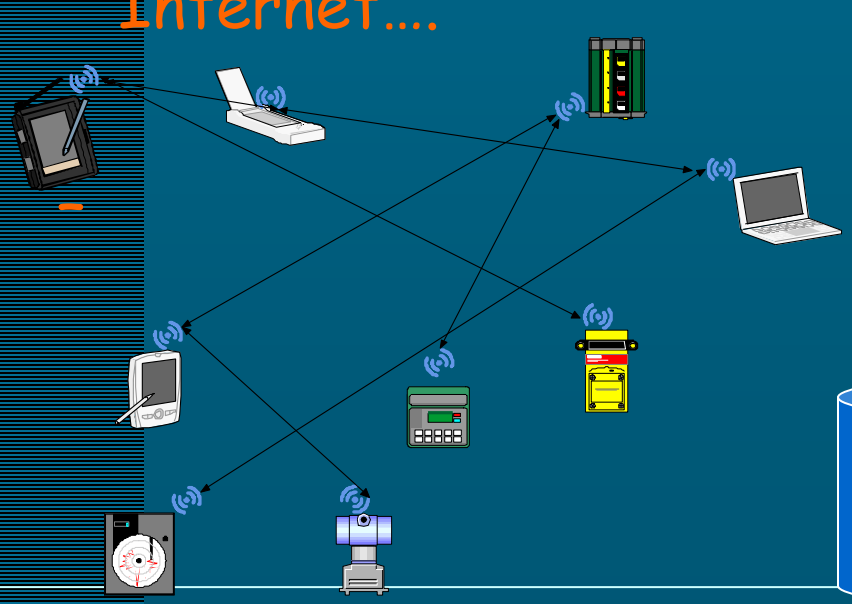
Before

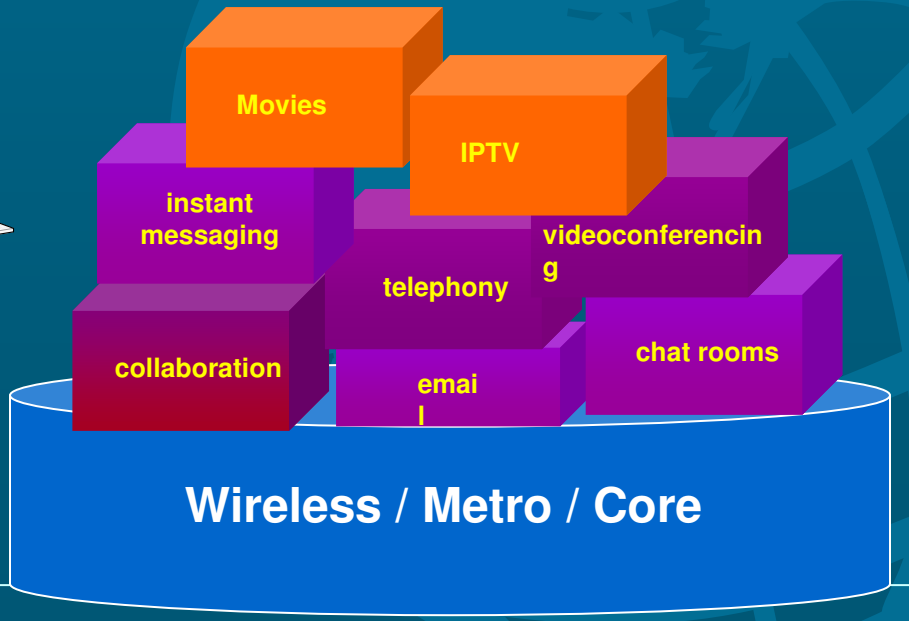
- Guaranteed end-to-end connectivity
- Short and fixed delays
- Symmetric data rates
- Low error rates
- Existing Infrustructure

Emerging Networks and Apps

Future

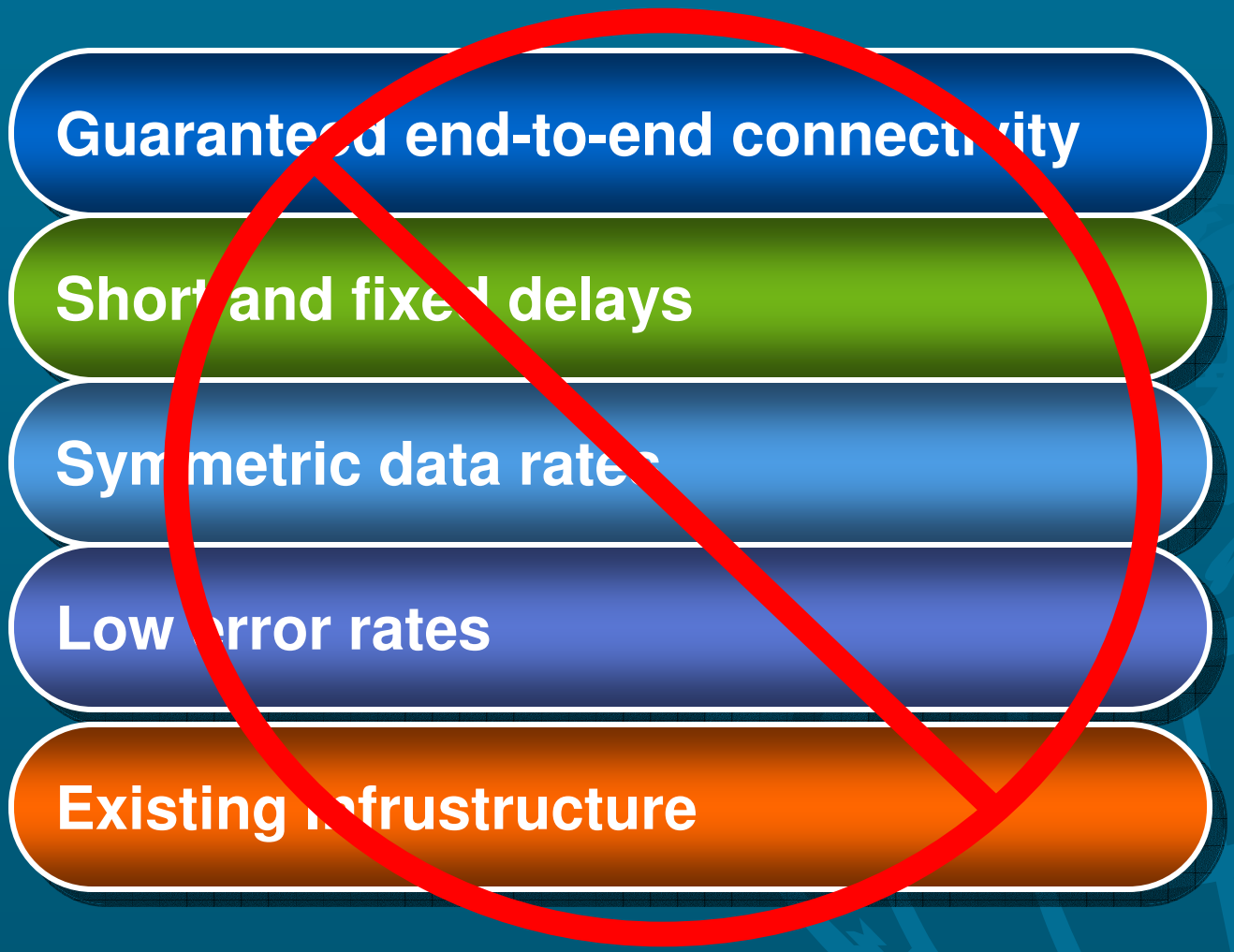
- Connecting heterogeneous networks operating on different transmission media
  - Different protocols and characteristics
- Communication is not limited to the Internet
  - Violating many of basic assumptions in the Internet….





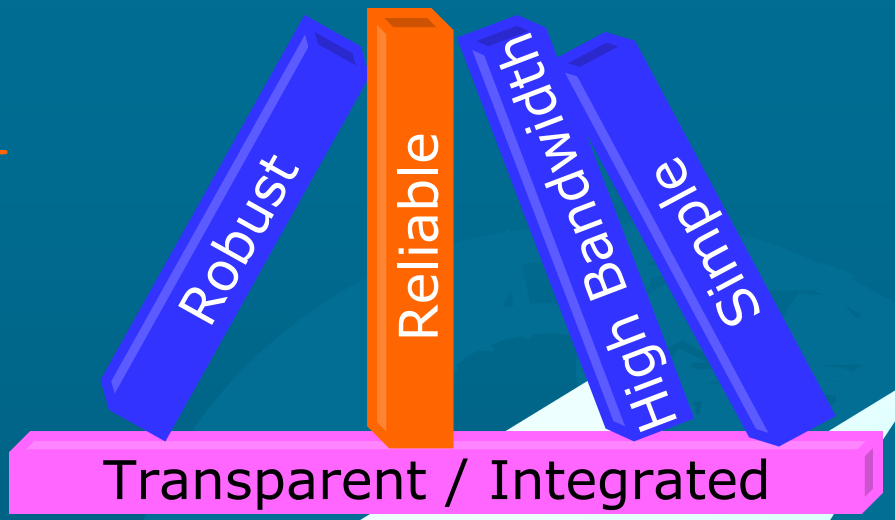
New Network Characteristics

Future



Future Networks

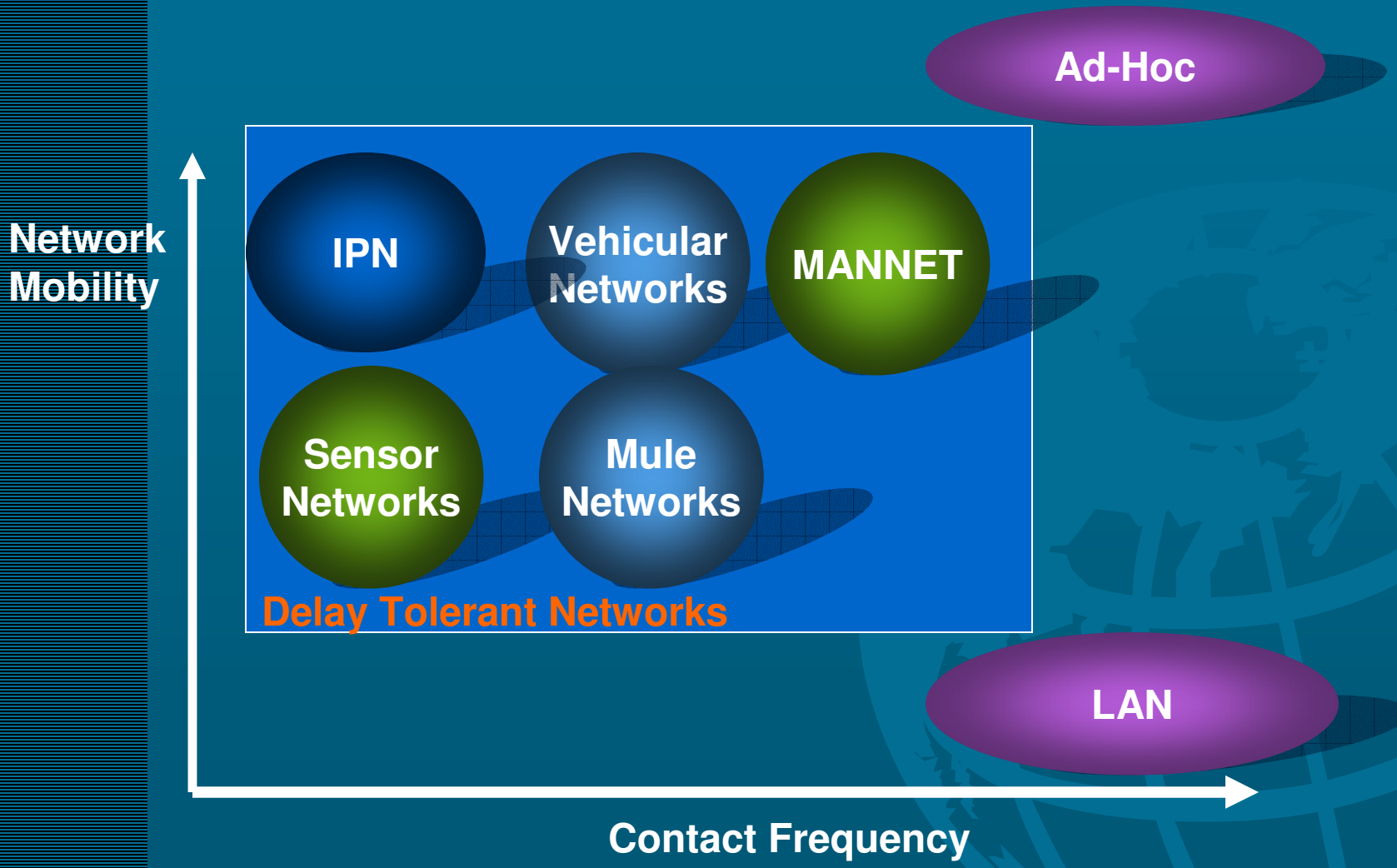
- Node constraints
  - Highly integrated, low-power, low-cost devices
- Network dynamics
  - Host mobility, network mobility, dynamic membership,
- No guaranteed end-to-end connectivity
  - Link and node failures → network with intermittent connectivity
- Long & variable propagation delays
  - Asymmetric data rates
- Heterogenious networks seamlessly connected
  - Decentralized



Architecture
Challenges
Research

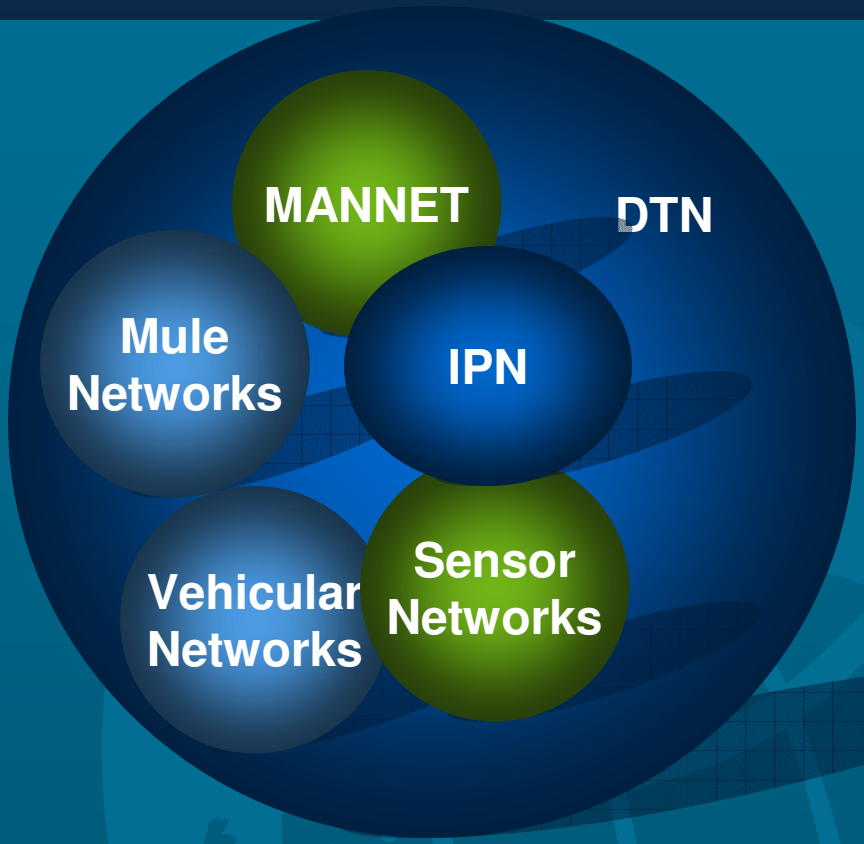
Delay Tolerant Networks

Networks Categories



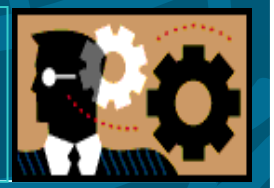
D* Tolerant Networks

- Disruption
- Delay
- Disconnection



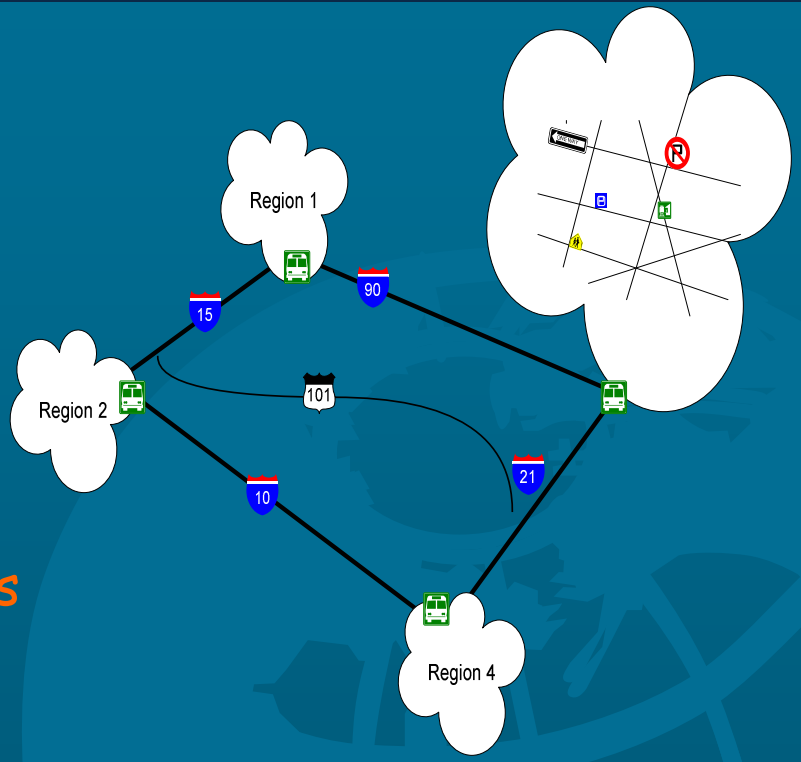
Delay-Tolerant Networking Architecture," *RFC 4838*, April 2007. V. Cerf et al.,

When TCP Breaks:
Turn to Delay- and Disruption-Tolerant Networking



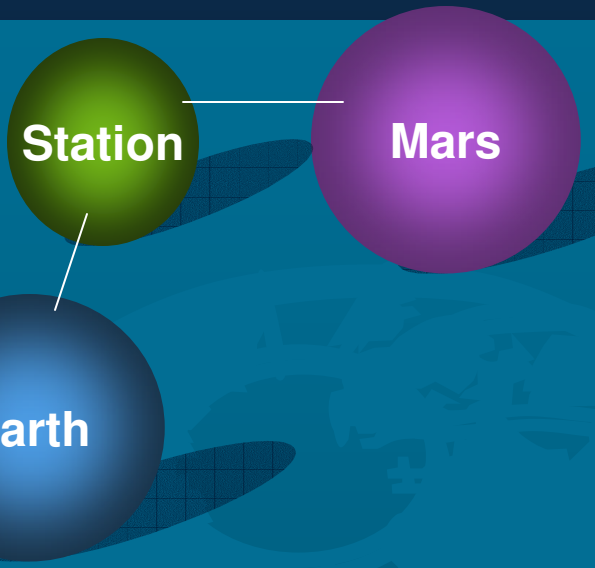
Network Examples of DTN

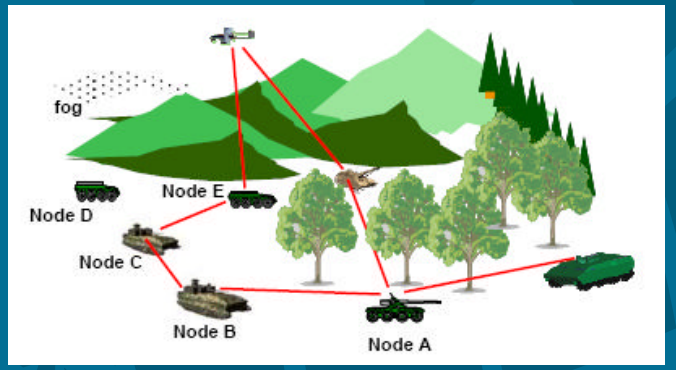
- Vehicular Networks
  - DakNet
  - Message ferry
  - Village network
- Mule Networks
  - Zebranet
    - The goal is tracking of zebras in wildlife
  - Sámi Network Connectivity
  - Carrier Pigeons
    - RFC 1149, RFC 2549 - Implemented by Bergen Linux users group



Network Examples of DTN

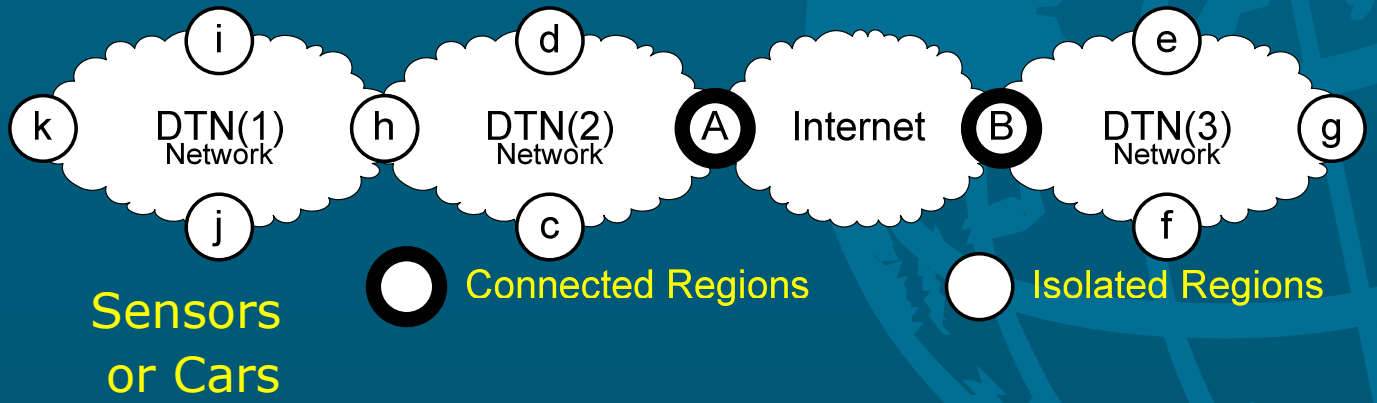
- Inter Planetary Networks
  - Deep space networks
- Sensor Networks
  - Acoustic underwater networks
- Ad hoc Networks (MANET)
  - Military tactical networks





DTN Architectural Objectives

- Asynchronously interconnecting different networks
  - Network of regional networks
- Each networks can have
  - Arbitrary underlying technologies
  - Different administrative controls
  - No accessible infrastructure



Bundle Concept

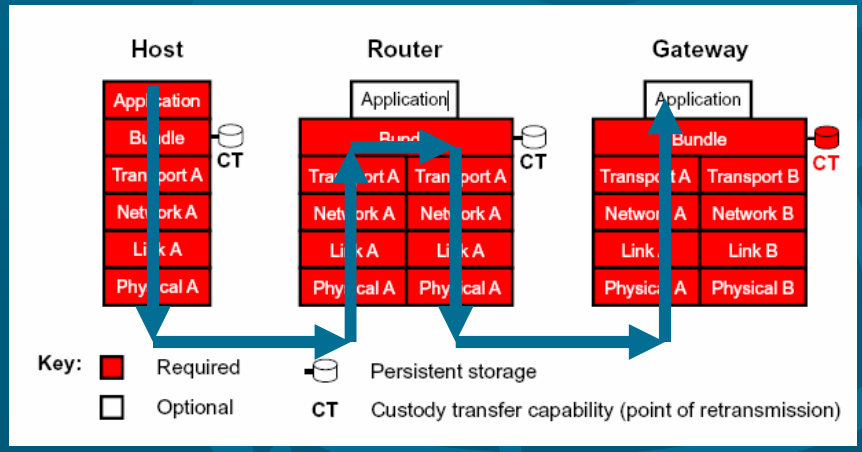
- Use of bundles instead of packets
- Bundle store & forward-routing
- Custody transfer by intermediate nodes

TCP/IP

Application
Transport
Network
Data Link
Physical

DTN

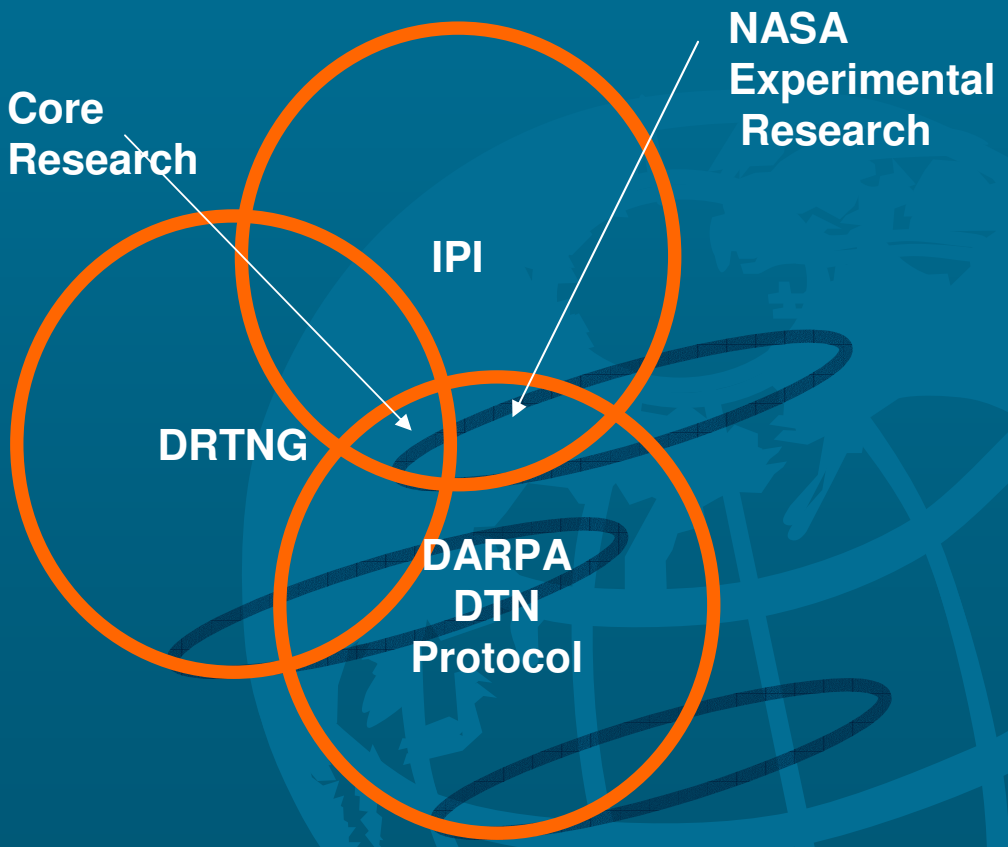
Application
Bundle
Transport
Network
Data Link
Physical



•Warthman, F. (2003). Delay-Tolerant Networks (DTNs) – A Tutorial. [Online] Available URL: http://www.ipnsig.org/reports/DTN_Tutorial11.pdf

DTN Origin

- Interplanetary Internet (IPI)
  - Development since late 1990s
  - Expanding internetworking to interplanetary scale

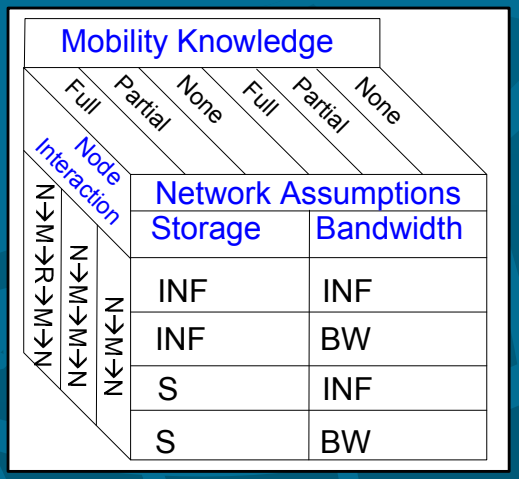


Pre-standardization efforts: DTN Research Group (DTN RG) in the IRTF

www.computer.org/.../dsonline/2006/08/w4spot.xml

Network Constraints

- Application
  - → Monitoring, communications, etc,
- Node types and interactions
  - → Mobile nodes, stationary nodes
- Mobility patters
  - → deterministic, stochastic, predictable, etc.
- Network topology
  - → known or not
- Scheduling Assumptions
  - → knowledge oracle type
- Energy level constraint
  - → similar to sensor network
- Physical constraints
  - → bandwidth, range, speed, etc.



(N=Node, MR=Mobile Node)

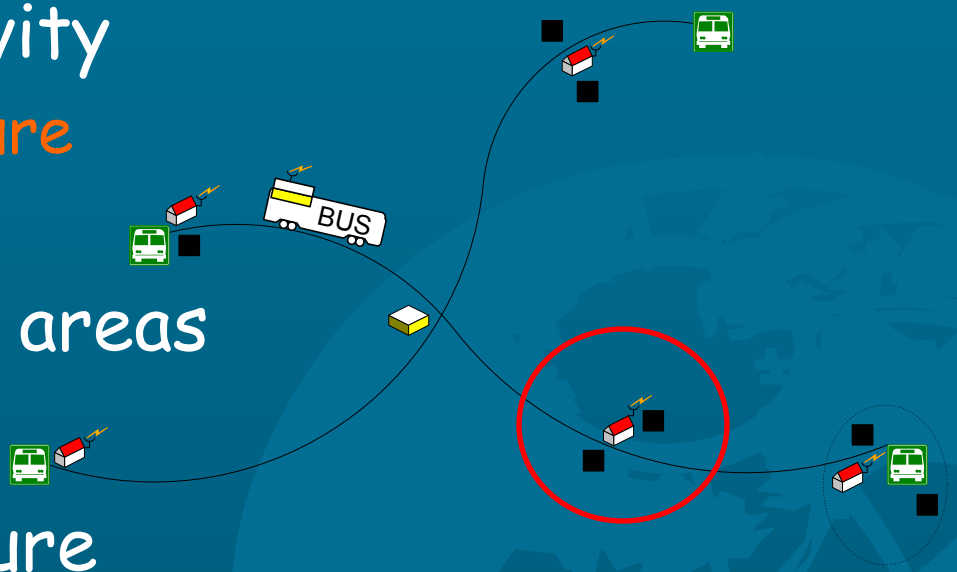
Our Research Focus

Challenges

- Architecture
  - Naming and addressing
- Routing protocols
  - Traditional end-to-end path may not exist
  - End-to-end routing will not work
  - Routes maybe time dependent
- Multi-layer conenctivity
  - Interconnecting DTNs
- Node design
  - Storage capacity, range, physical link

A) Vehicular DTN – Village Networks

- Expanding connectivity
  - Lack of infrastructure
  - Lack of funding
- Villages and remote areas



- Network architecture
  - Stationary nodes
  - Mobile routers
  - Relay nodes – placed at intersections

A) Vehicular DTN – Village Networks

Objective

Network cost optimization by minimizing the number of relay nodes

Problem

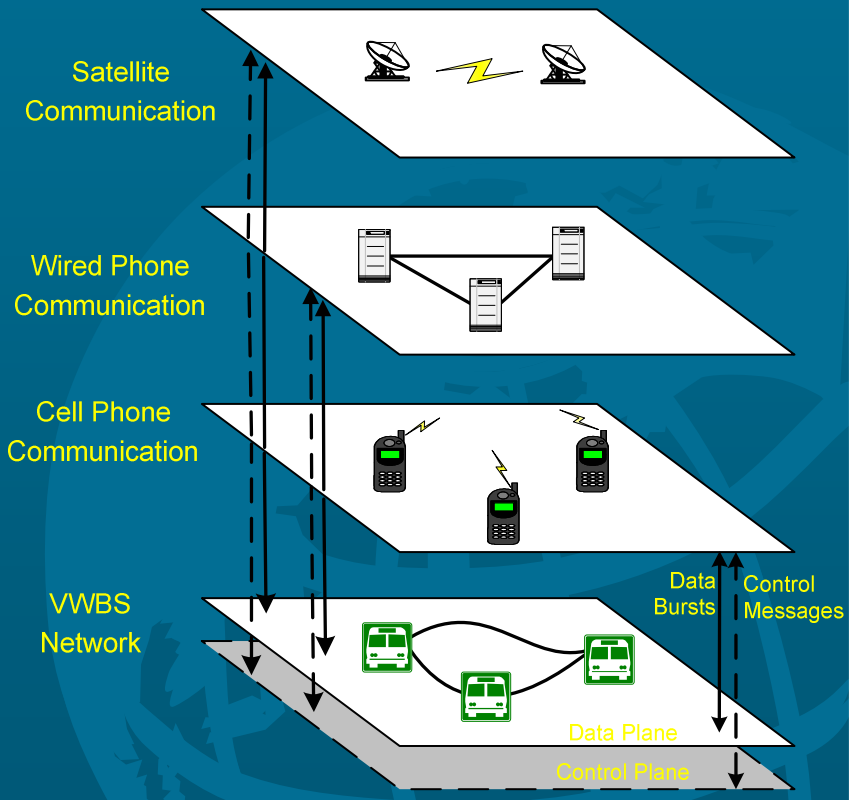
- Relay node placement to reduce network cost
- Developing various routing algorithms

Solution

Formulating the node placement as a cost optimization problem (ILP Problem) & developing heuristic algorithms

B) Vehicular DTN – Multi-Layer Interactions

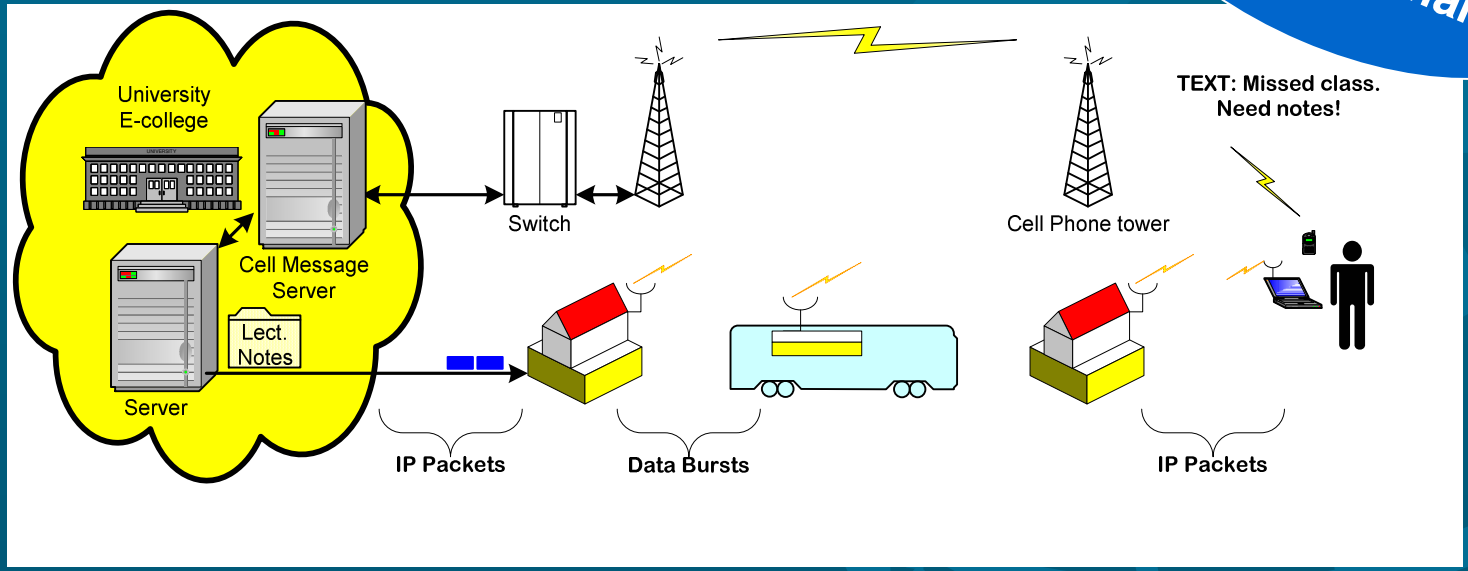
- Motivation
  - Protecting against catastrophic (regional) failures
- Cross-layer interaction
  - Integrating VDTN and other network layers
  - In-bad and out-of-band signaling
  - Using different media for data and control signals



B) Vehicular DTN – Multi-Layer Interactions

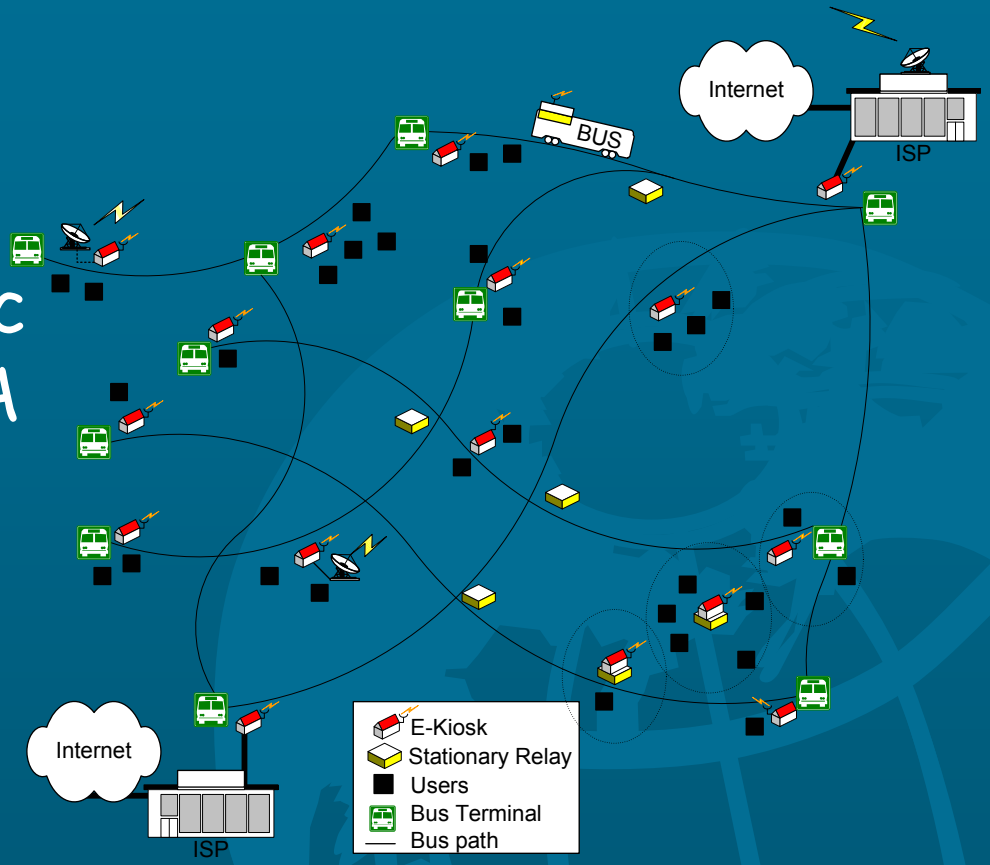
- Innovative applications
  - Distance learning
  - eHealth

University of Winneba, Ghana



C) Anycasting in VDTN

- Inter and intra-domain traffics
- Intra-domain traffic can go through ISPA or ISPB
- Objective
  - Optimizing the network to reduce cost (ILP formulation)
  - Designing heuristics

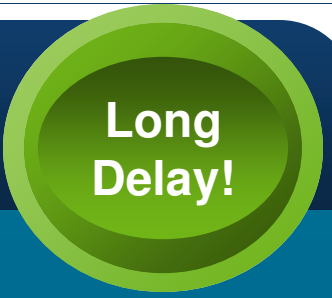


Supports & Collaborations

- Funding Supports
  - The Euro-NF Network of Excellence of Seven Framework Programme of EU
  - Networks and Multimedia Group of the Institute of Telecommunications – Covilhã Lab, Portugal
- Collaborating Institutions
  - Central Connecticut State University
  - Institute of Telecommunications, Networks and Multimedia Group, Portugal
  - University of Texas at Dallas
  - Scuola Superiore Sant'Anna, Pisa, Italy

Open Research Areas .....

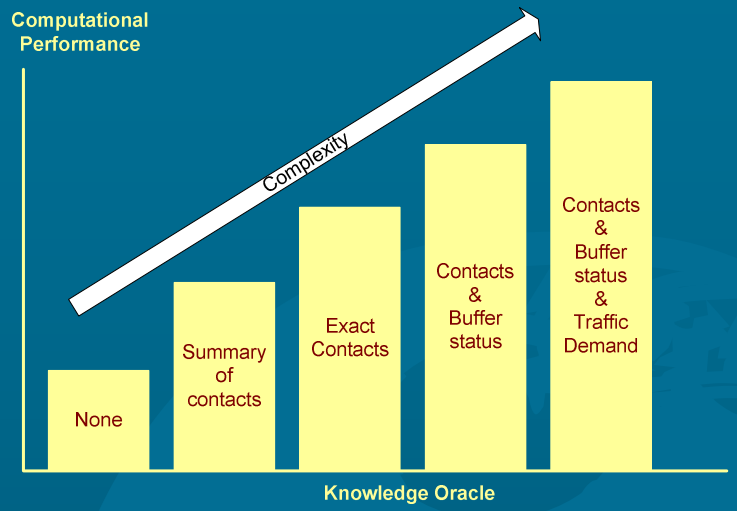
Naming and Addressing



- Unique end-point identifiers {region id, host id}
  - Defining regions
- Supporting unicasting, multicasting, anycasting
  - Shared addresses for multiple nodes
- The end user may be mobile and move between regions
  - Address mapping or resolution needed
  - Routing takes place based upon complete URI: sender "just sends"

Routing in DTN

- Routing depends on basic network assumptions
  - Mobility, mobility patterns, node capacity, scheduling knowledge, etc.
- Routes are time dependent
  - Requires long term storage
  - Long term storage can lead to buffer contention
- Routing objectives
  - Minimize the delay
  - Maximize the throughput
- Topology dynamics
  - Is the topology known (e.g., road, mobility patterns, etc.)
- Optimal routing solutions
  - Knowledge vs complexity



- Contacts Summary
  - Average link availability
  - Average bandwidth
- Contacts
  - Exact times of contact
  - Exact route
- Buffering
  - Available storage
  - Local vs Global
- Traffic Demand Oracle

Open Research Areas
Exact Vs. Partial Scheduling

- Show through simulation the relative performance between routing based on exact and partial scheduling information
  - Implementing the time-based shortest path: modified Dijkstra's Algorithm
- The general performance of the two routing algorithms can be expected to be as follow

Input: G=(V,E), s, T, w(e,t)

T: Start time
w (e,t) : edge cost function

Output: L[u]
The earliest time message reaches node u

Properties:
Loop free paths
Low complexity

?lgorithm :

$Q = V$

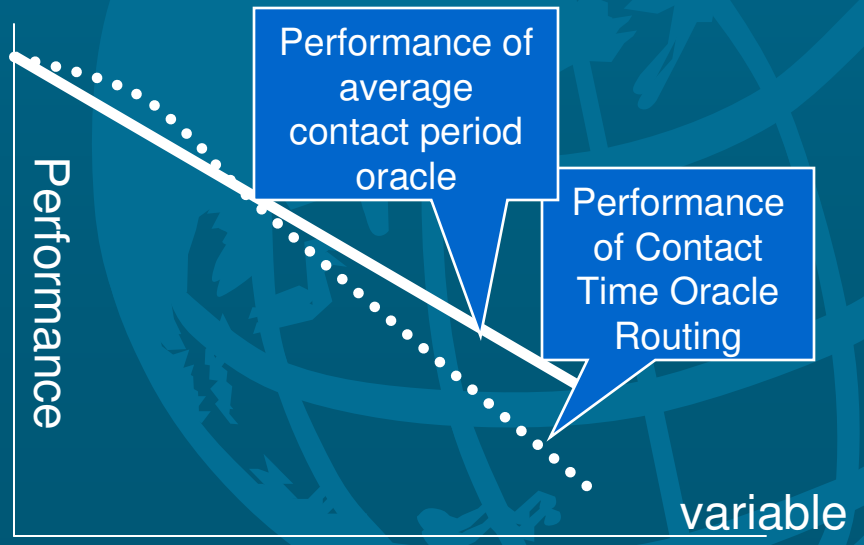
$L[s] = 0$, $L[v] = \infty \ \forall v \in \{V - s\}$

while $Q \neq \{\}$ do

Let $u \in Q$, s.t $L[u] = \min_{x \in Q} L[x]$

$Q = Q - \{u\}$

forall $e \in E$, s.t. $e = (u,v)$ do
  if $L[v] > L[u] + w(e, L[u] + T)$ then
    $L[v] = L[u] + w(e, L[u] + T)$
end



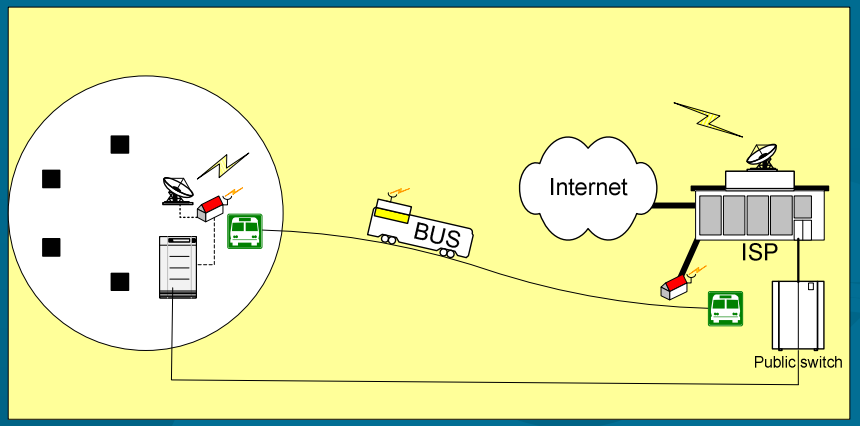
More….. click here

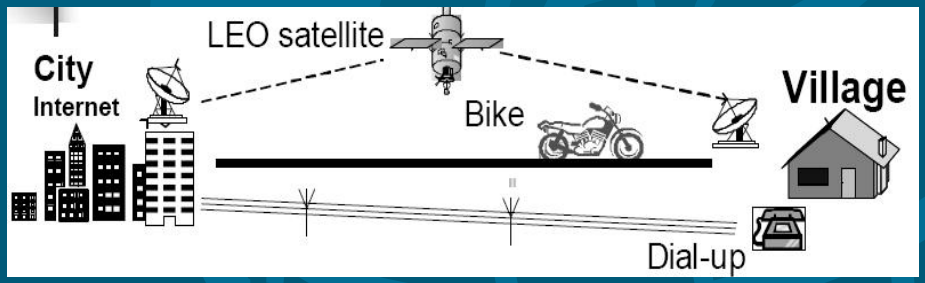
Open Research Areas
Multicasting efficiency in VDTN

- Multicasting is the simultaneous transmission of data from a source to a group of destinations
  - Warning system
  - Distance learning
- Maintaining reliable transmission in a timely manner is very critical
- Objective
  - Reducing resource demand of the application (storage, link utilization, etc.)
  - Minimizing the delivery time
- A common approach in route selection is link-sharing in the tree structure
  - Developing the time-variant Steiner multicast tree (TV-SMT) used for routing data in the network

Open Research Areas
Multi-layer Survivability

- Networks with mechanical backbone or limited energy levels can be highly susceptible to failures
  - Mechanical failures in buses, road blocks, traffic jams, etc.
- VDTN networks can also be considered as an alternative approach offer protection against catastrophic failures





LEGO Mindstorms Platform

- Motivation
  - Examining performance
    - Different protocols,
    - Examine blocking and constraints
- Possible extensions
  - Using GPS
  - Understanding random movements
  - Utilizing different link layer technology
  - Creating a colony network
  - Utilizing PDAs
  - Communication overheads

Creating a DTN platform

Lego Project: http://www.sm.luth.se/csee/courses/smd/147/pages05/projects/DTN_PROPHET_LEGO_project.pdf
Software: http://sourceforge.net/projects/dynamic-switch

Available Resources….

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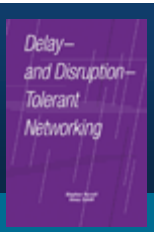

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Conferences

- WDTN Workshop Technical Program - http://www.sigcomm.org/sigcomm2005/w4-wdtn.html - papers all available
- 1st International Workshop on Decentralized Resource Sharing in Mobile Computing and Networking – 2006: http://www.mobishare.org/
- Other wireless conferences - http://www.prehofer.de/Research/Welcome.html
- IEEE International Symposium on a World of Wireless, Mobile and Multimedia Networks - http://ieee-wowmom.cse.buffalo.edu/
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Seminars / Universities

- Prof. Jens-Peter Redlich – Interplanetary Internet - http://sar.informatik.hu-berlin.de/teaching/_previous-years/2006-s%20Interplanetary%20Internet%20Seminar/index.htm
- Dr.-Ing. Dirk Kutscher - DTN http://www.tzi.de/~dku/research.html

Online Resources

- The Consultative Committee for Space Data Systems (CCSDS) - (deep space communication) http://public.ccsds.org/default.aspx
- Magic Bike Project - http://www.magicbike.net/
- The Delay-Tolerant Networking Research Group (DTNRG) - http://www.dtnrg.org/wiki
- Mitre Projects http://www.mitre.org/news/events/tech06/3.html

SIMULATORS

- QualNet - http://scalable-networks.com/
- DTNSIM2 https://styx.uwaterloo.ca/dtnsim2/
- A very good list of simulators http://homepage.ntlworld.com/myjamro/research/already_in_research/simulation_tools.htm

Internet to Rural Access

- Wizzy Project – South Africa - http://www.wizzy.org.za/link/category/5/
- TIER Project - http://tier.cs.berkeley.edu/wiki/Home - The aim of the TIER project is to address the challenges in bringing the Information Technology revolution to the masses of the developing regions of the world
- United Villages http://www.unitedvillages.com/

An online list: http://del.icio.us/faridfarahmand/rural