# Relays, Base Stations, and Meshes: Enhancing Mobile Networks with Infrastructure

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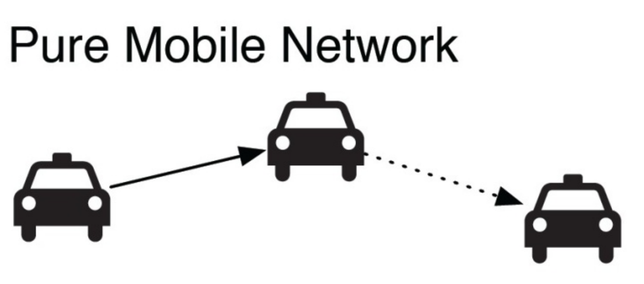
# Outline

- Introduction
- Network Model
- Deployment Study
- Analytical Study
- Results and Discussion

# Introduction I

- Infrastructure-enhanced mobile network
  - Mobile ad hoc networks incur higher delays and more frequent disconnections than tethered networks.
  - Recent efforts have proposed adding infrastructure /stationary resources to mobile networks to improve connectivity, delay and throughput.
    - Base station
    - Mesh
    - Relay



# Introduction II

- Cost-performance tradeoff
  - The costs of adding different types of infrastructure are highly variable.
    - Base station: US$5000; Wi-Fi radio: much cheaper.
    - Installing wired base stations connected to the Internet can lower delays; but they require costly installation of power and wired network connectivity. —**Tradeoff**
  - The relative performance enhancement of each kind of infrastructure is poorly understood.
    - How do these trade-offs scale as the network grows in size or density?

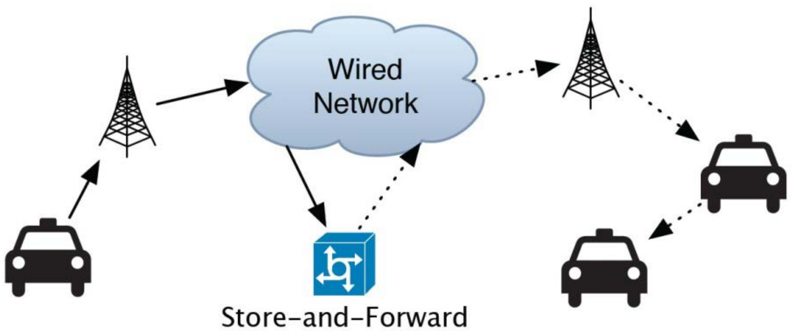
# Introduction III

- A deployment study
  - The paper conducts a set of field experiments that compares the benefits of each kind of hybrid mobile network.
    - A **vehicular network** is deployed for study.
    - Practical issues are involved—including stationary node placement, real world propagation, and dynamic routing protocols.
  - Cost-benefit analysis
- An analytical study
  - Asymptotic results
    - Provide insights when the network becomes large.

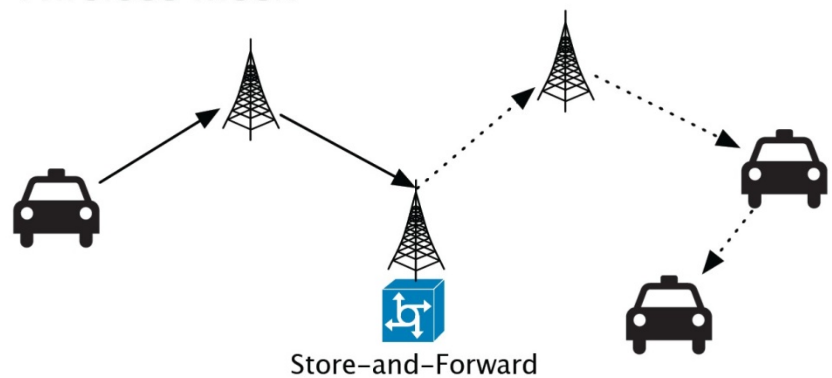
# Network Model

- Three options for enhancement

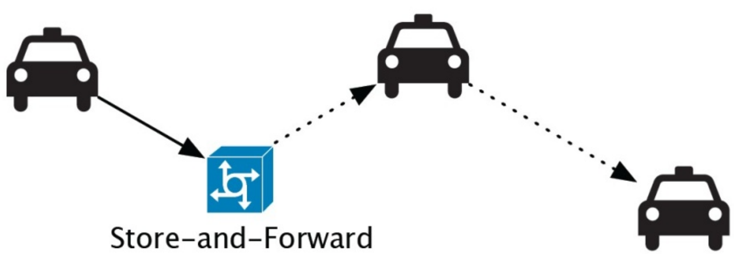
Basestations/Infostations




Wireless Mesh




Disconnected Relays



# Vehicular Network Deployment I

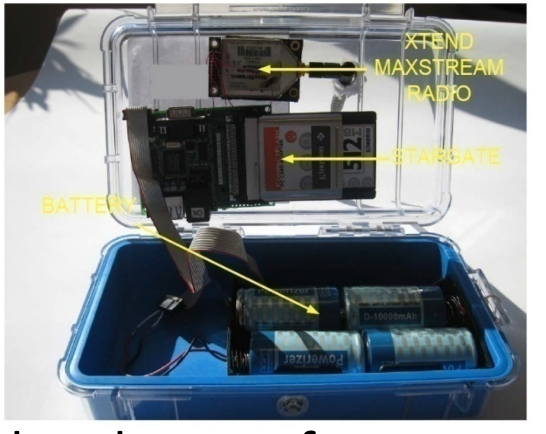
- Testbed Overview — **UMass DieselNet** [1]
  - The network consists of an average of 20 transit buses in use on the road 18 hours/day everyday in an area of about 360 square kilometers.
  - The buses are equipped with a Linux box, a Wi-Fi radio, a GPS unit, and a long-range, low bandwidth 900MHz XTend radio.
    - Wi-Fi radio: 100 meters
    - Digi-XTend radio: 1650 meters

  - The buses communicate with each other over TCP connections using Wi-Fi radios.

[1] Burgess, J., Gallagher, b., Jensen, d., And levine, B. N., MaxProp: Routing for Vehicle-Based Disruption-Tolerant Networks. In Proceedings of Infocom (April 2006).

# Vehicular Network Deployment II

- Relays
  - Six stationary relay nodes are placed in the network for a period of 20 days.
  - The nodes consist of a PDA-class Stargate device equipped with a Wi-Fi CF card and 64 MB of storage.
  - Store-and-Forward.



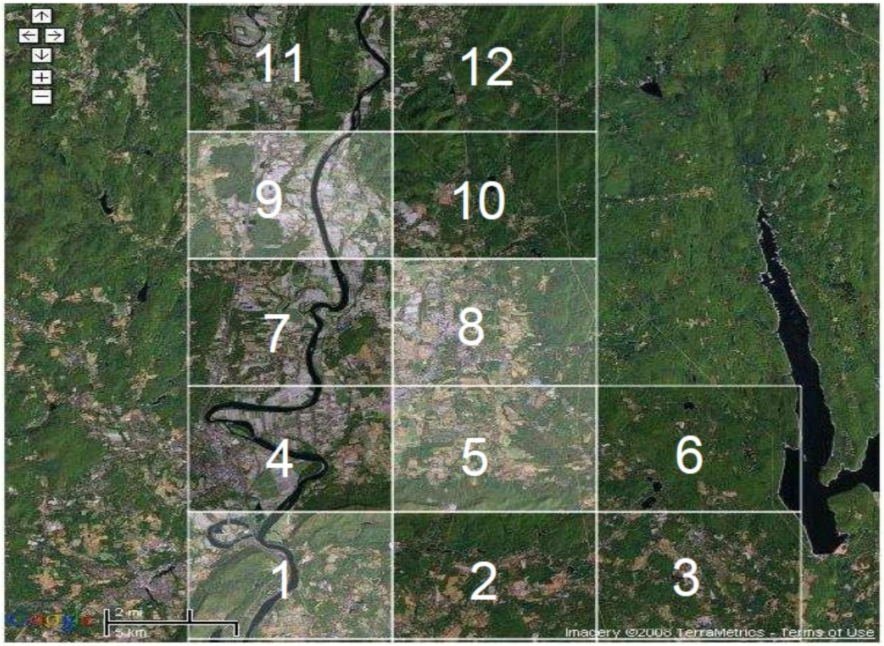

- Mesh Nodes
  - Relay plus an XTend radio.
  - Forms the mesh network.
- Base Stations
  - A combination of APs that they deployed and a set of open-access points set up by third parties.
  - The base station traces were collected from Oct. – Nov. 2007.

# Vehicular Network Deployment III

- Data Collection
  - Each node, both mobile and stationary, collected
    - The duration of time and when it was in contact with other nodes;
    - The amount of data it transferred
  - The mesh nodes collected data on the Wi-Fi based bus-to-mesh and the XTend-based mesh-to-mesh connections.
  - The mobile nodes collected detailed mobility traces from GPS units.

# Vehicular Network Deployment IV

- Network Characteristics
  - The bipartition of the network area.
    - Network core
    - Network periphery

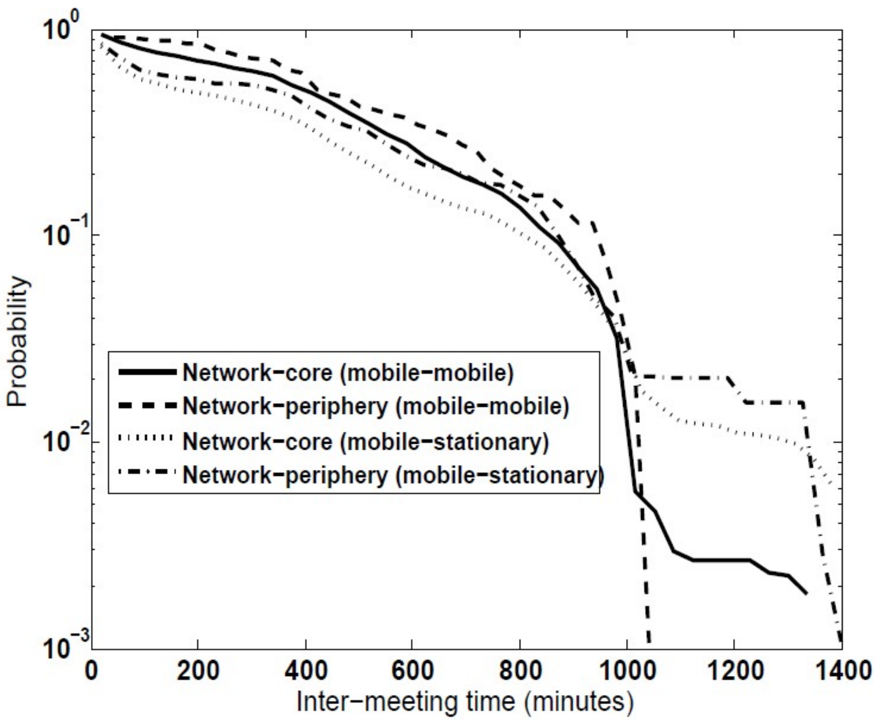



Heatmap showing the amount of time vehicles spend in different regions of the network during a day

| Characteristics | Network-core | Network-periphery |
|---|---|---|
| average pairwise inter-contact time | 434 min | 506 min |
| average contact duration | 8590 ms | 2802 ms |
| number of contacts (per day) | 145 | 7 |

# Vehicular Network Deployment V

- Network Characteristics
  - The two regions exhibit different absolute contact statistics.
  - 90% of all pairwise inter-contact times approximately follows an **exponential** distribution.

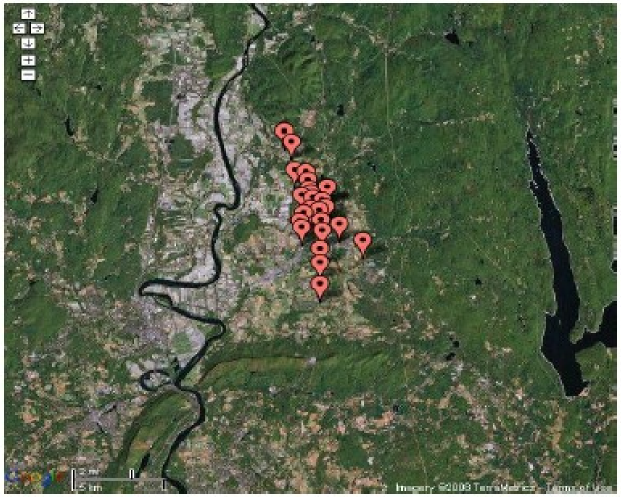


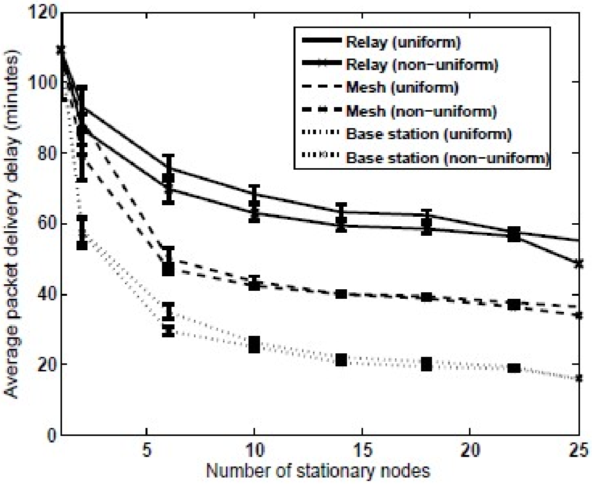
# Vehicular Network Deployment VI

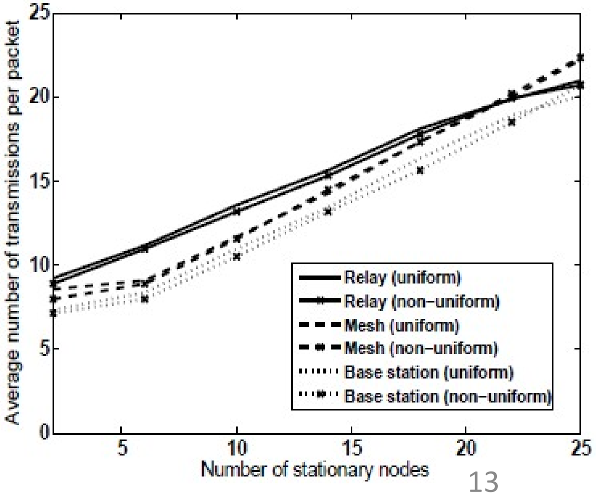
- Trace-driven Simulator
  - Using the traces of the deployment, a trace-driven simulator was built.
  - The simulator can be used to examine three key factors that affect performance:
    - The type of infrastructure enhancement
      - To simulate different **communication path**
    - The placement of the infrastructure
      - Follow the placement **constraints** of each type
    - The choice of the routing protocol.

# Vehicular Network Deployment VII

- Stationary Node Placement
  – Two strategies for stationary node placement based on **regions** in the network.
    - Uniform placement
    - Non-uniform placement
  – Routing metric for performance evaluation
    - Average packet delivery delay
    - Average number of transmissions per packet

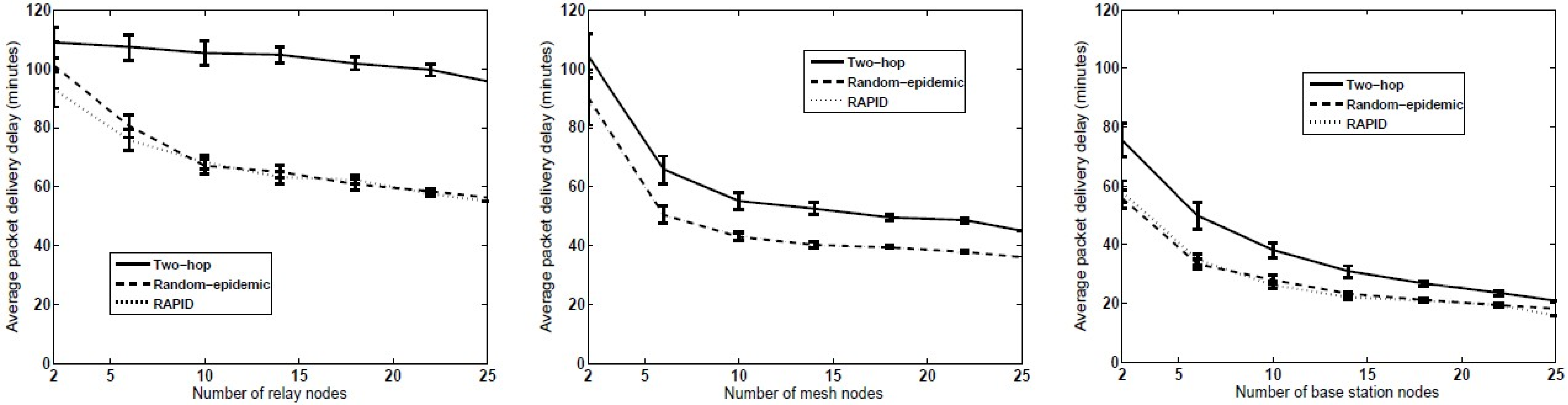




# Vehicular Network Deployment VIII

- The effect of routing schemes
  - RAPID[2]: performs close to optimal
  - Two-hop: no mobile-to-mobile routing
  - Random-epidemic: creates copies of a packet randomly



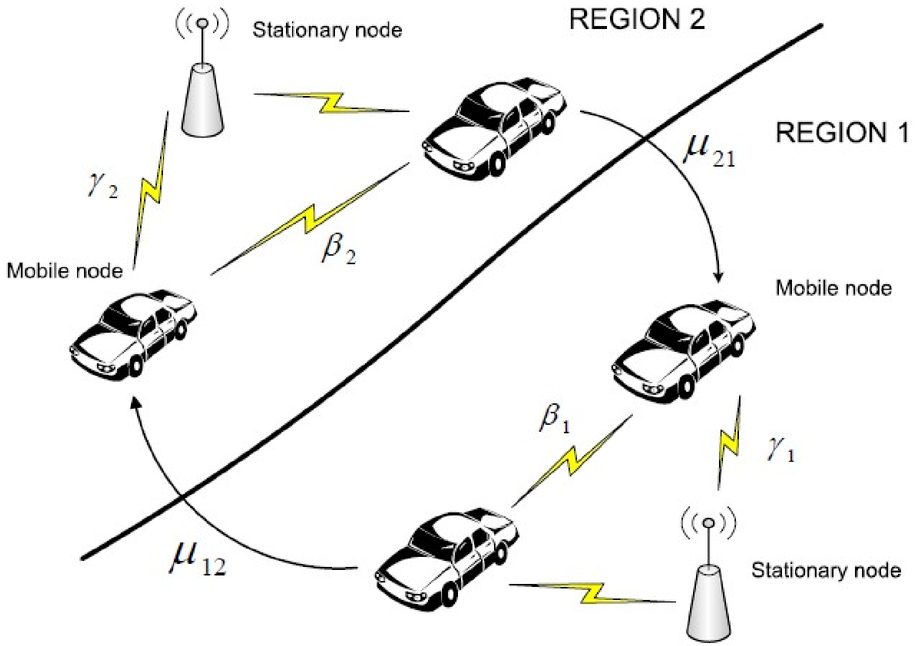

[2] Balasubramanian, A., Levine, B. N., And Venkataramani, A. DTN Routing as a Resource Allocation Problem. In Proceedings of ACM Sigcomm (2007).

# Analytical Model I

- Motivation
  - The deployment study suffers from two limitations.
    - The number of mobile nodes are **fixed**, hence the results cannot be validated for a large number of mobile and stationary nodes.
    - It is hard to infer anything about the **asymptotic** behavior of hybrid networks.
  - To address these limitations, detailed analytical models are developed for large-scale networks in the presence of infrastructure.

# Analytical Model II

- Model and Network Parameters
  - ***N*+1** mobile nodes, ***M*** stationary nodes
  - ***k*** disjoint regions
  - The mobile nodes spend time in each of the k regions.
  - The stationary nodes can either be placed uniformly or non-uniformly.
  - The **pairwise meeting times** follow exponential distribution[3][4].
  - The number of **nodes move from one region to another** follows exponential distribution.




k=2


[3] Groenevelt, R., Nain, P., And Koole, G. The Message Delay in Mobile Ad hoc Networks. In Proceedings of Performance (2005).

[4] Ibrahim, M., Hanbali, A. A., And Nain, P. Delay and Resource Analysis in MANETs in Presence of Throw boxes. In Proceedings of IFIP Performance (2007).

# Analytical Model III

- Epidemic Spread
  - The spread of a packet and its replicas is modeled as an epidemic infection among nodes.
    - The analytical tool is **ordinary differential equations** (ODE).
  - Performance Metrics
    - Average delivery delay $E[D] = \int_0^\infty (1 - P(t))dt.$
    - Average number of copies per packet

$$E[C] = \int_0^\infty (\sum_{i=1}^k (x_i(t) + y_i(t)))dP(t).$$

  - Analysis for each of the three cases
    - Mobile network with untethered relays
    - Mobile networks with base stations
    - Mobile network with meshes

# Results and Discussion I

- Cost-Benefit Analysis
  - From the experiments, if the average packet delivery delay in a vehicular deployment can be reduced by a factor of two by adding **x** base stations, the same reduction requires **2x** mesh nodes or **5x** relays.
  - The relay node costs less than US$800 and with a Digi-XTend radio the mesh node costs less than US$1000. An outdoor weather-proof base station with wiring and installation typically costs as high as US$5,000.
  - Therefore, in several situations using relay or mesh nodes is more cost effective than base stations.

# Results and Discussion II

- Mobile-to-mobile Routing
  - It is observed that a small amount of added base station or mesh infrastructure can quickly **obviate** the need for mobile-to-mobile routing schemes.
  - Simple **two-hop** forwarding algorithms provide excellent performance.
- Asymptotic Results
  - For N mobile nodes, the network needs $\omega(N)$ relays and $\omega(\sqrt{N})$ base stations before the stationary nodes substantially affect the average packet delivery delay for epidemic routing.

# Thanks!