Information Technology and Intelligent Transportation: A Marriage Made in Heaven

Ouri Wolfson
University of Illinois
Chicago
wolfson@uic.edu

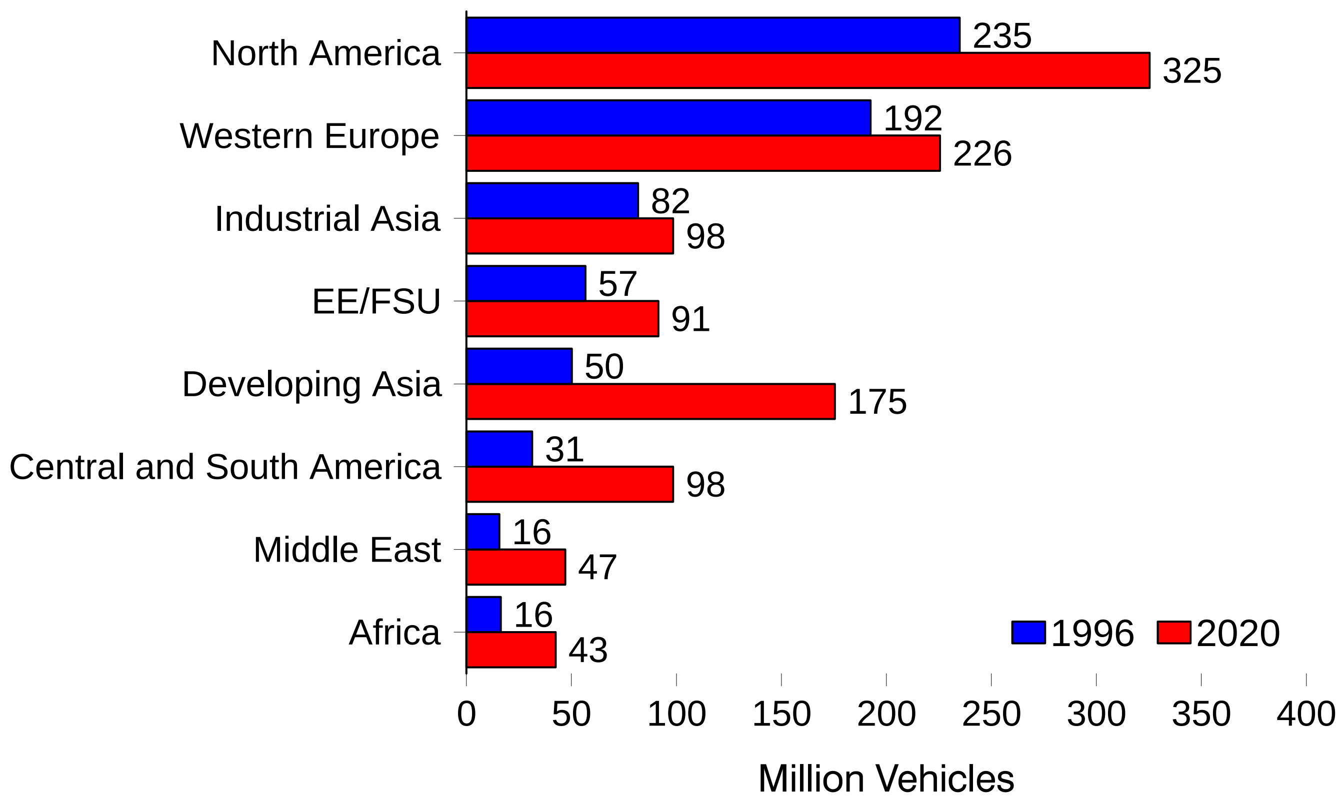
The Problem

- **Safety:**
  - **43,000 deaths per year in the USA;**
  - **3 million+ accidents;**
  - **$250+ billion cost to the economy**

- **Congestion:**
  - **2.9 billion gals of fuel wasted per year;**
  - **$78 billion cost to the economy;**
  - **4.2 billion hours extra travel every year**

- **Environmental:**
  - **> 50% of hazardous air pollutants in U.S.,**
  - **up to 90% of the carbon monoxide in urban air**

Motorization Growth: Road Vehicle Populations by Region, 1996 and 2020



Source: EIA, International Energy Outlook 1999

Traditional approach to address problem

- construct more highways/roadways
- Greater investment in public “mass” transit.

Information Technology impact on society

- Impact on economy
  - Financial industry
  - Insurance industry
  - Entertainment industry (games)
  - Utilities
- Impact on science and engineering
  - Biology (bioinformatics, human genome project)
  - Environmental science (weather prediction)
  - High energy physics
  - CAD/CAM
  - Operations research
  - Mathematics

IT impact on Transportation

- Car navigation systems, web-routing

IT impact on Transportation

- Car navigation systems, web-routing
- Traffic information systems

IT impact on Transportation

- Car navigation systems, web-routing
- Traffic information systems
- Autonomous/assisted driving
  - sponsored by military
  - Successful in areas W/O traffic

IT impact on Transportation

- Car navigation systems, web-routing
- Traffic information systems
- Autonomous/assisted driving
  - sponsored by mainly by dod
  - Successful in areas W/O traffic
- Fleet management software

Why?

- Distributed/mobile system of unprecedented scale

- Incentive mechanisms / business models

Outline

- Introduction – the problem
- Vehicular Infrastructure Integration (VII) Initiative
- Graduate Program in Computational Transportation Science
- Conductive IT trends

Intelligent Transportation Systems

- Increase transportation system
  - Safety
  - Efficiency
- With the use of
  - electronics and sensors
  - communications
  - information systems

Vehicle Infrastructure Integration (VII): A Federal Initiative

- **Vision**
  - Information about all roads, all the time
    - To control center
    - To individual vehicles
  - To enable a broad range of safety and mobility services
- **Approach:** Convene a “VII Coalition”—
  - auto manufacturers,
  - state transportation authorities,
  - USDOT

Application examples

- Safety
  - Vehicle in front has a malfunctioning brake light
  - Vehicle is about to run a red light
  - Patch of ice at milepost 305
  - Vehicle 100 meters ahead has suddenly stopped

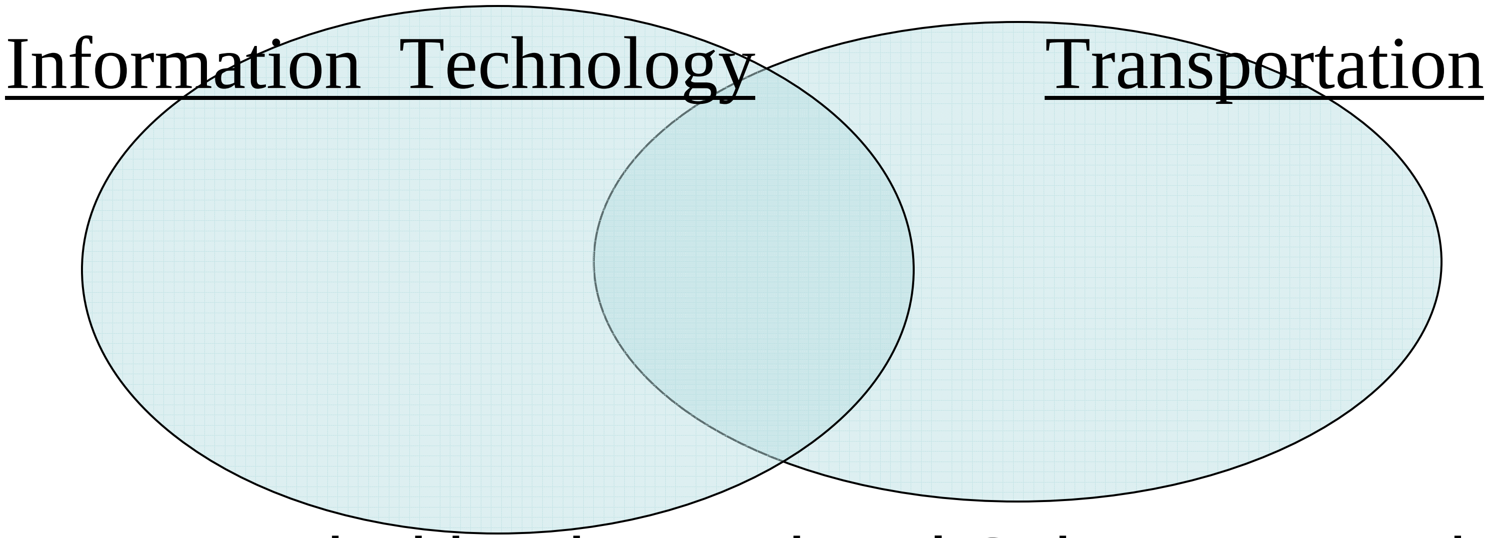
Application examples (cont.)

- Improve efficiency/convenience/mobility:
  - What is the average speed a mile ahead of me?
  - Are there any accidents ahead?
  - What parking slots are available around me?
  - Taxi cab: what customers around me need service?
  - Customer: What Taxi cabs are available around me?
  - Cab/ride sharing opportunities
  - During the past year, how many times was bus#5 late by more than 10 minutes at station 20, or at some station

Outline

- Introduction – the problem
- Vehicular Infrastructure Integration (VII) Initiative
- Graduate Program in Computational Transportation Science
- Conductive IT trends

IGERT Ph.D. program in Computational Transportation Science



- Funded by the National Science Foundation ($3M+)
- Will train about 30 Scientists
  - Will develop novel classes of applications
- Colleges: engineering, business, urban planning

VII +

- Traveler/pedestrian focus
  - What Taxi cabs are available around me? (pedestrian)

- Non real-time issues
  - Query-language: During the past year, how many times was a bus on route #5 late by more than 10 minutes at some station (given gps traces)
  - Visualize accident based on sensors

- Data Management issues (above communication)
  - Parking slots (discovery, auctions)

Sample Research Problems

Platform to develop VII applications

Traffic simulations from perspective of computer science – computational problems, complexity, parallelization

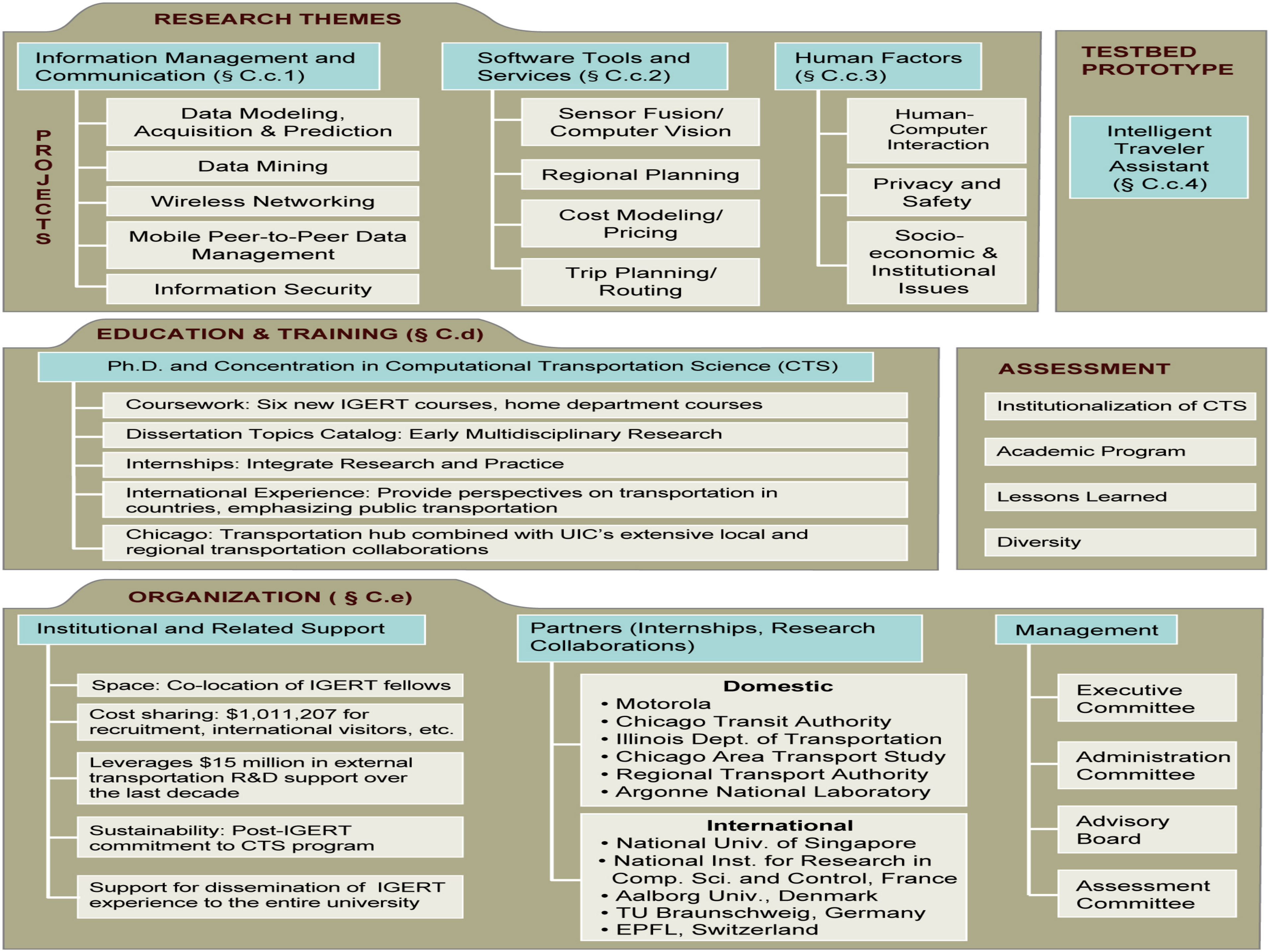
Realistic/practical simulation testbed for purpose of evaluating VII algorithms

Discovery of novel VII applications

Human/social aspects of VII deployment

Integrating methodologies from the 2 fields

Human Computer Interaction – driving simulators


RESEARCH THEMES
Information Management and Communication (§ C.c.1)
Software Tools and Services (§ C.c.2)
Human Factors (§ C.c.3)
PROJECTS
Data Modeling, Acquisition & Prediction
Data Mining
Wireless Networking
Mobile Peer-to-Peer Data Management
Information Security
Sensor Fusion/ Computer Vision
Regional Planning
Cost Modeling/ Pricing
Trip Planning/ Routing
Human-Computer Interaction
Privacy and Safety
Socio-economic & Institutional Issues
TESTBED PROTOTYPE
Intelligent Traveler Assistant (§ C.c.4)
EDUCATION & TRAINING (§ C.d)
Ph.D. and Concentration in Computational Transportation Science (CTS)
Coursework: Six new IGERT courses, home department courses
Dissertation Topics Catalog: Early Multidisciplinary Research
Internships: Integrate Research and Practice
International Experience: Provide perspectives on transportation in countries, emphasizing public transportation
Chicago: Transportation hub combined with UIC's extensive local and regional transportation collaborations
ASSESSMENT
Institutionalization of CTS
Academic Program
Lessons Learned
Diversity
ORGANIZATION (§ C.e)
Institutional and Related Support
Space: Co-location of IGERT fellows
Cost sharing: $1,011,207 for recruitment, international visitors, etc.
Leverages $15 million in external transportation R&D support over the last decade
Sustainability: Post-IGERT commitment to CTS program
Support for dissemination of IGERT experience to the entire university
Partners (Internships, Research Collaborations)
Domestic
• Motorola
• Chicago Transit Authority
• Illinois Dept. of Transportation
• Chicago Area Transport Study
• Regional Transport Authority
• Argonne National Laboratory
International
• National Univ. of Singapore
• National Inst. for Research in Comp. Sci. and Control, France
• Aalborg Univ., Denmark
• TU Braunschweig, Germany
• EPFL, Switzerland
Management
Executive Committee
Administration Committee
Advisory Board
Assessment Committee

Research Issues in Data Management and Communication

- Data modeling and Uncertainty Management
- Data mining
- Wireless Networking
- Mobile P2P
- Security

Data Modeling

– Basic construct <u>trajectory</u>: location = f(time)
– Novel built-in mechanisms for
  - trajectory approximation
  - trajectory matching
  - trajectory aggregation
  - compression of spatial-temporal information
  - aging of spatial-temporal information
  - Location prediction
– Encapsulate in a trajectory data-blade

Uncertainty/imprecision Management

- Innovative approach: Optimize the tradeoff cost/imprecision

- Linguistic approach:
  – retrieve the average speed with 30% confidence

Research Thrusts

- Data Management and communication
- Software tools and services
- Human factors and sociological issues
  - Human-computer interaction (multimodal)
  - Privacy (particularly location information)
  - Socio-economic issues (e.g. air-quality implications of adaptive speed limits)

Prototype

ITA

- Intelligent traveler assistant –
  - on handheld computers
  - networked to
    - Traffic information center
    - Neighboring vehicles
  - plan multi-modal routes for its user

ITA modes

- Multi-modal trip planning
  – Possible optimization criteria: cost, time, predictability

- Trip execution (plan adjustment)
  – taxi/ride-sharing opportunities

Trip execution experiment

- 20 vehicles with ITA’s receiving sensor information in real-time

- demonstrate simple query processing in a mobile environment

Main differences from other transportation centers

- Focus on Computer Science and IT

- Focus on traveler rather than vehicular technology

- Focus on applications above communication layer

Outline

- Introduction – the problem
- Vehicular Infrastructure Integration (VII) Initiative
- Graduate Program in Computational Transportation Science
- Conducive IT trends

IT trends => Transportation

- Wireless networking
- Mobile computing
  - Fault tolerance, connectivity, longevity
  - Resource management
  - Programming paradigms (randomization)
- Information systems:
  - Spatial-temporal data management
  - Moving object databases
- Sensor networks
- Positioning technologies (GPS, cellular, anchor/less)
- Computer vision
  - Scene understanding (what the operator sees, and doesn't)

IT trends => Transportation (cont.)

- Context awareness
  - Computer is aware of profile, location, activity, biometric information of user
- GIS
- Human-computer interaction
  - Speech processing
  - Natural language processing
  - Effectiveness (present only information operator does not already know)
  - Multimodal interface
- Security, privacy, trust management
  - Maliciously creating havoc, self serving information

IT trends => Transportation

- Wireless networking
- Mobile computing
  - Fault tolerance, connectivity, longevity
  - Resource management
  - Programming paradigms (randomization)
- Information systems:
  - Spatial-temporal data management
  - Moving object databases
- Sensor networks
- Positioning technologies (GPS, cellular)
- Computer vision
  - Scene understanding (what the operator sees, and doesn't)

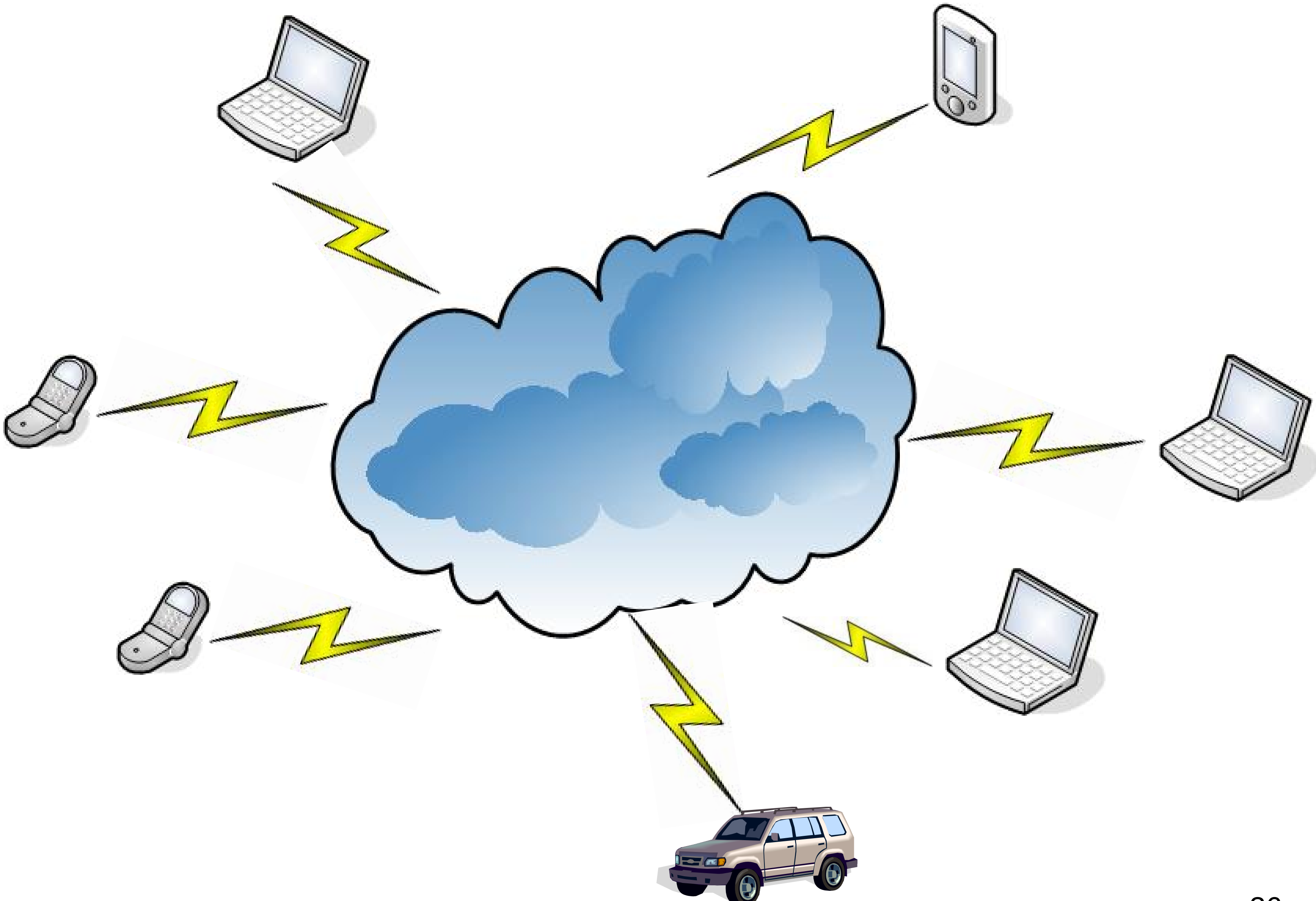
Wireless networking

- Technologies differ in
  - Bandwidth, range/license, power consumption
- Long range: licensed spectrum
  - Cellular (4G, WiMAX)
- Short range: unlicensed spectrum
  - Wi-fi (100-200meters, up to 54mbps)
  - Bluetooth (2-10meters, 2Mbps)
  - Zigbee (low power, .25Mbps)
  - Ultra-Wide-Band (675Mbps)

Wireless networking architectures

- Infrastructure-based
- Ad hoc networks
  - Mobile ad hoc networks (MANET's)
  - Vehicular ad hoc networks (VANET's)
- Mesh networks – involving both, static and mobile nodes

Infrastructure-based Networking



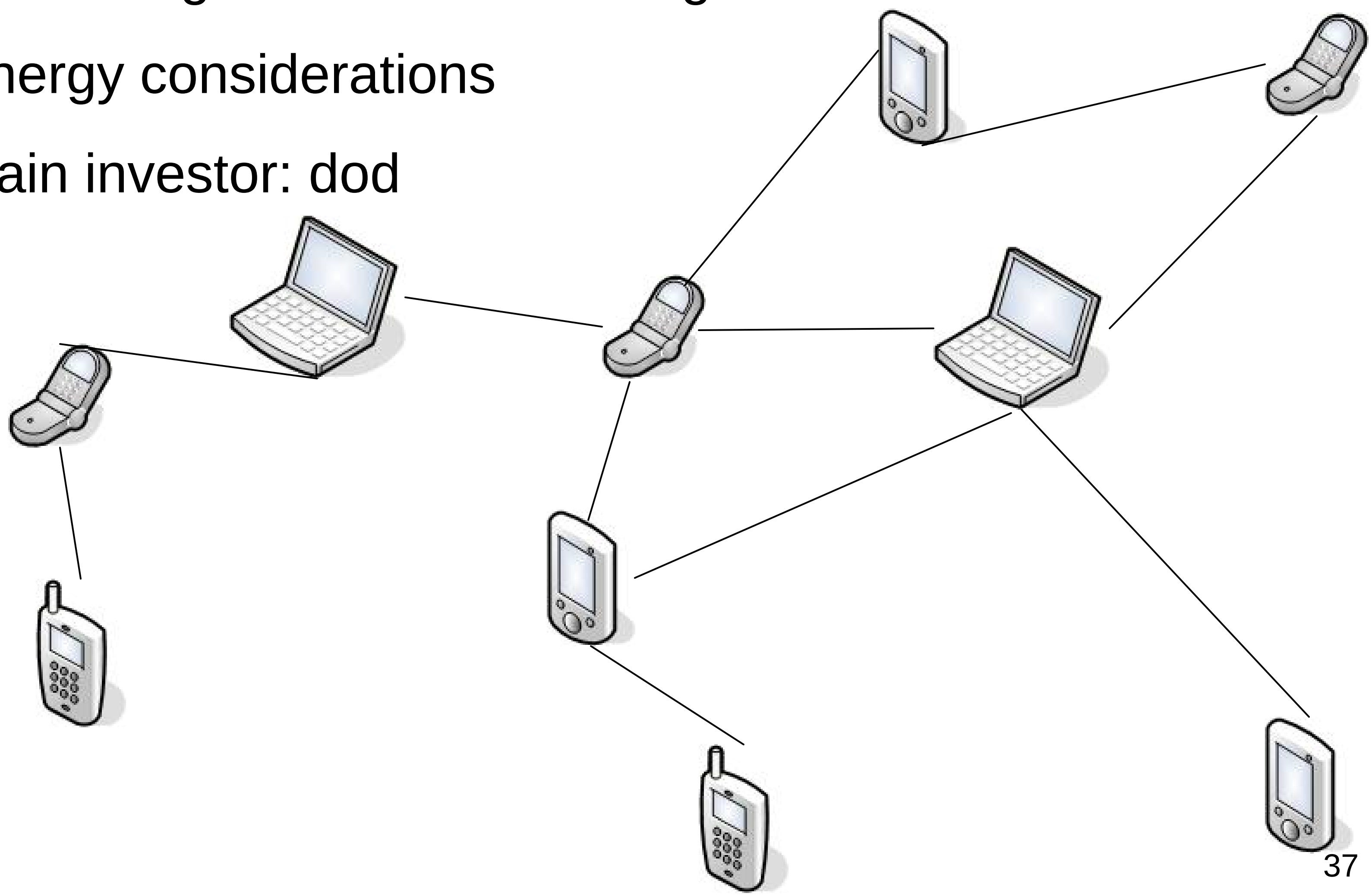
Mobile Ad Hoc Networks

Network nodes are routers – dynamic topology

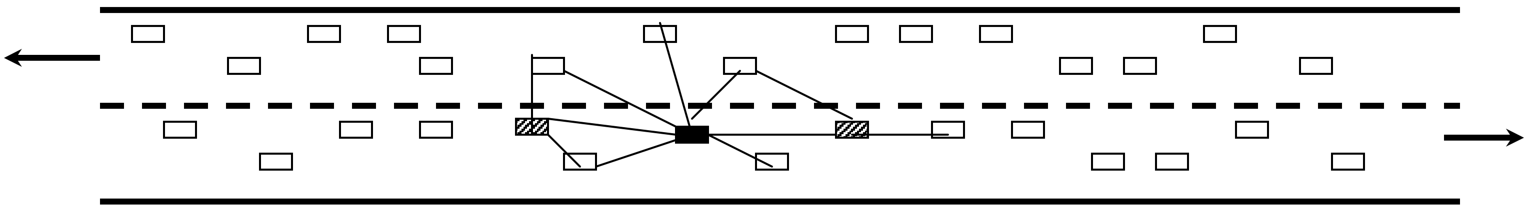
Short-range wireless technologies

Energy considerations

Main investor: dod



Vehicular Ad Hoc Networks



- Vehicles within transmission range can communicate
- Uses variants of 802.11 (Wi-fi)
- Dynamic topology, but constrained to road network
- No energy constraints

IT trends => Transportation

- Wireless networking
- Mobile computing
  - Fault tolerance, connectivity, longevity
  - Resource management
  - Programming paradigms (randomization)
- Information systems:
  - Spatial-temporal data management
  - Moving object databases
- Sensor networks
- Positioning technologies (GPS, cellular)
- Computer vision
  - Scene understanding (what the operator sees, and doesn't)

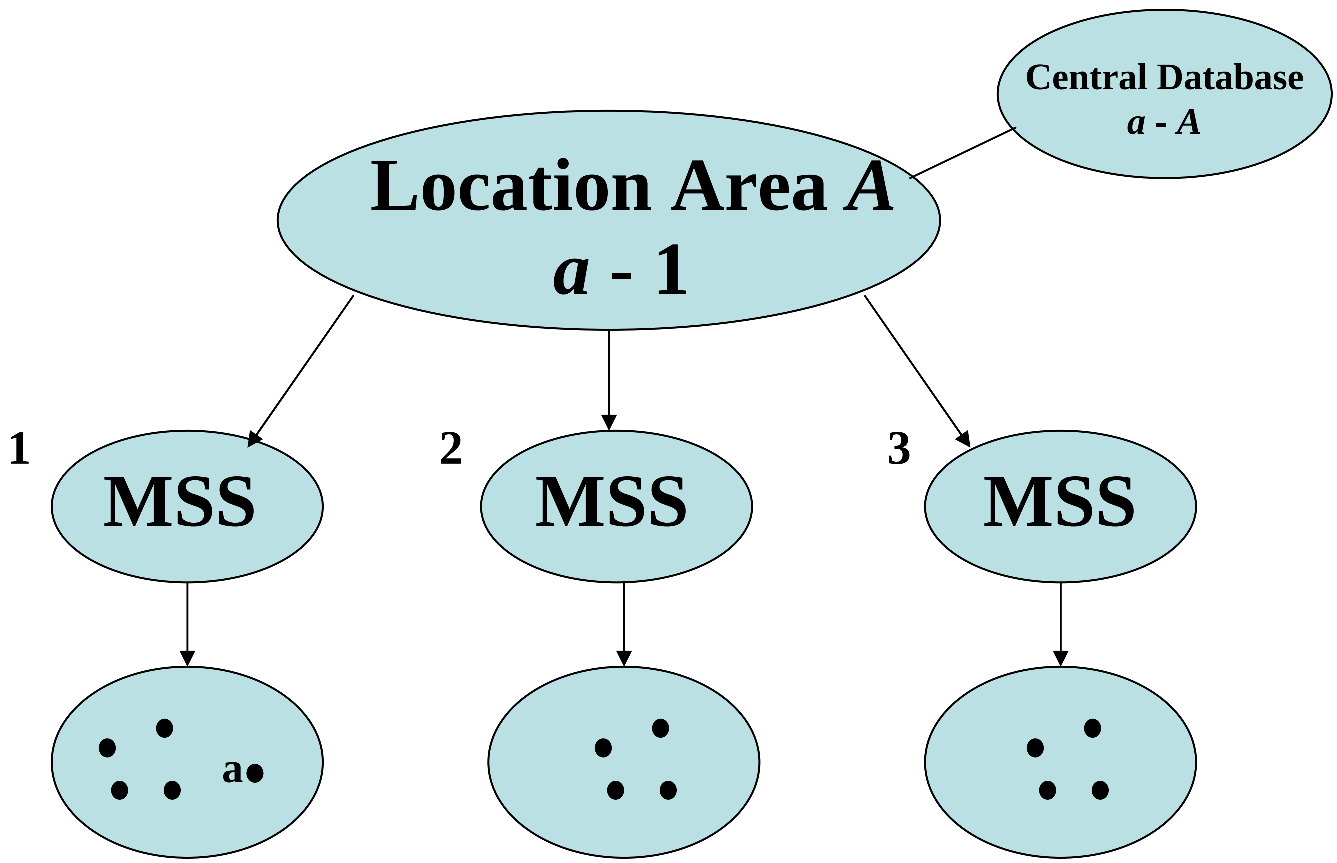
Mobile computing

- Resource constraints on nodes (devices)
  - Power
  - Bandwidth
  - Memory
  - Small screen
  - Small keyboard

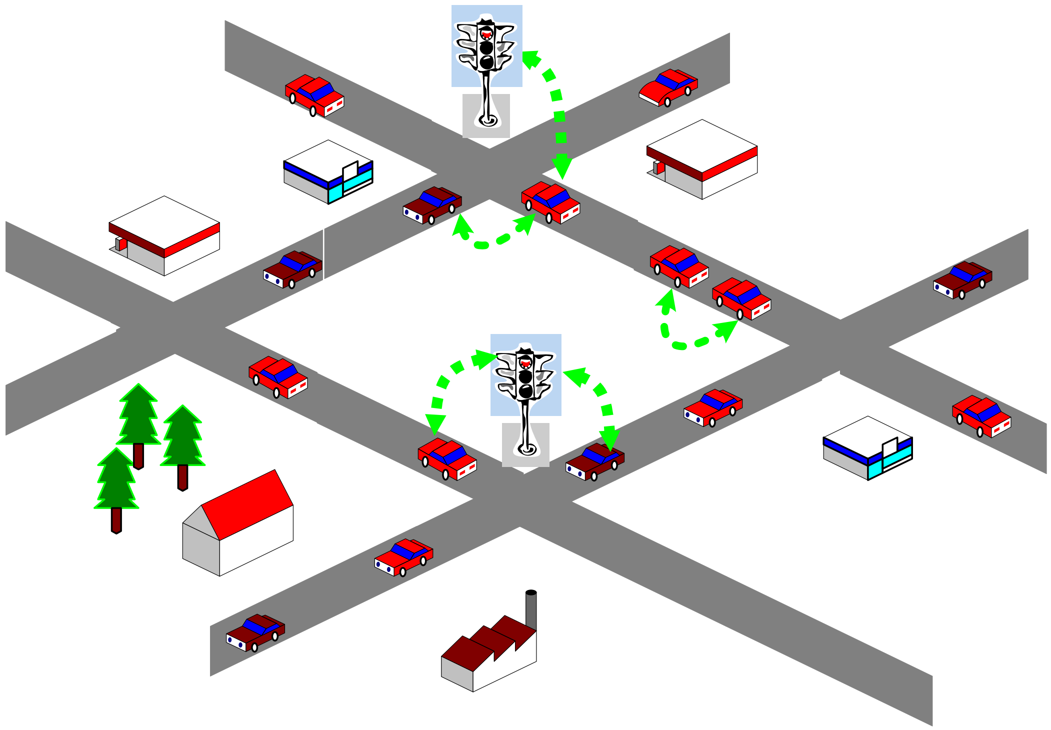
Mobile computing models

- Centralized information system
  - User interface
  - Minimizing communication
  - Data broadcasting
  - Disconnection
- Local Information system
  - Small footprint
  - Wireless update of local databases (disconnected operation)
  - Example: Real-time traffic updates of car navigation system
- Mobile P2P information system
  – Computing and data management in MANET/VANET without a central control point.

Centralized/Hierarchical model



Mobile P2P network



Technical Problems in Mobile P2P

- Data modeling –
  - lack of a common schema and naming conventions
  - sensor- and human-generated information
  - Semantic-web concepts (e.g. ontologies) become relevant
- Participation incentives for brokers
  - to achieve reasonable coverage
- Dynamic and adaptive use of fixed infrastructure
- Managing Heterogeneity

Mp2p vs. client-server

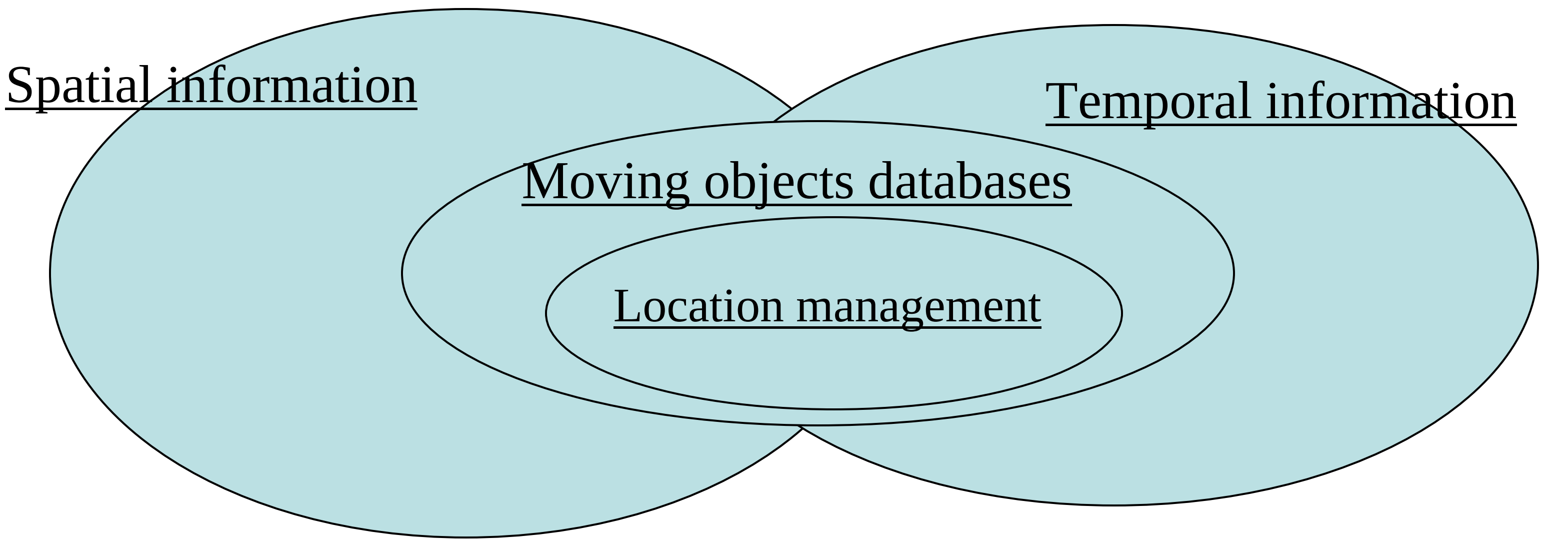
- Mp2p advantages
  - Zero cost
    - Unregulated communication
    - No central database to maintain
  - Independent of infrastructure
  - Higher reliability
  - Privacy preservation
  - Often higher speed
- Mp2p disadvantages
  - Weaker answer-completeness guarantees
  - Density requirements

IT trends => Transportation

- Wireless networking
- Mobile computing
  - Fault tolerance, connectivity, longevity
  - Resource management
  - Programming paradigms (randomization)
- Information systems:
  - Spatial-temporal data management
  - Moving object databases
- Sensor networks
- Positioning technologies (GPS, cellular)
- Computer vision
  - Scene understanding (what the operator sees, and doesn’t)

Spatio-temporal data management

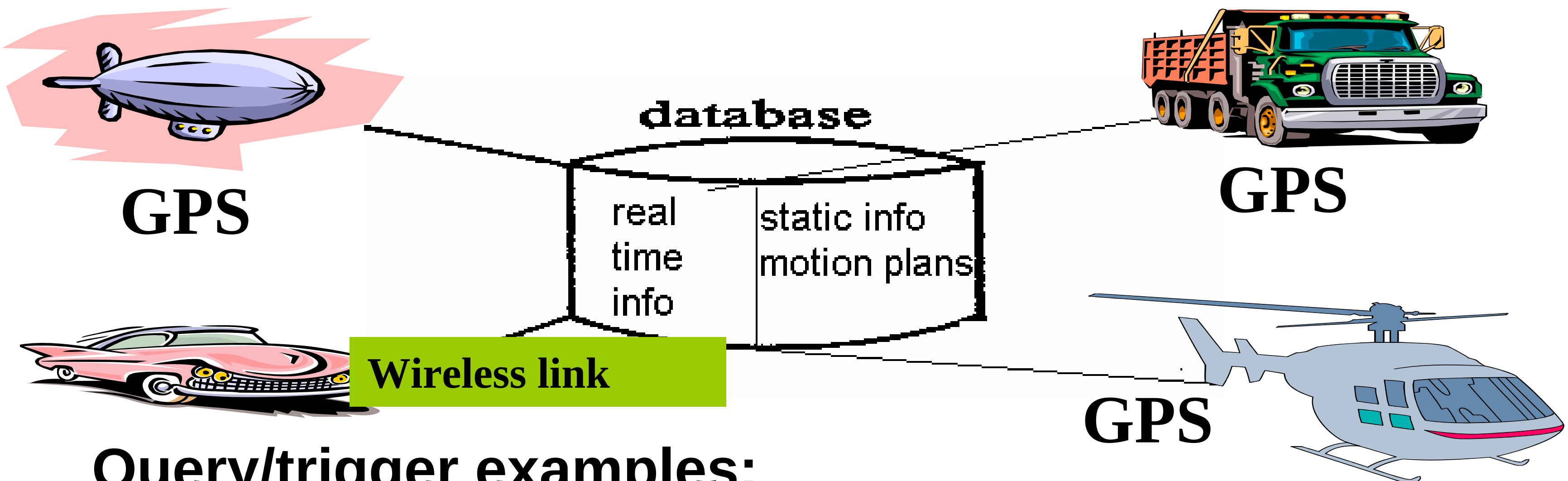
Initially database systems managed symbolic information (inventory)



Spatio-temporal databases handle discrete and continuous changes

Moving Objects Databases: continuous change in location

Moving Objects Database Technology



Query/trigger examples:

- Send me message when helicopter in a given geographic area
- Trucks that will reach destination within 20 minutes
- Where is the closest ATM/restaurant/hospital
- Bus on line #5 late

Basis for:

infrastructure provided location-based-services

Fleet management

IT trends => Transportation

- Wireless networking
- Mobile computing
  - Fault tolerance, connectivity, longevity
  - Resource management
  - Programming paradigms (randomization)
- Information systems:
  - Spatial-temporal data management
  - Moving object databases
- Sensor networks
- Positioning technologies (GPS, cellular)
- Computer vision
  - Scene understanding (what the operator sees, and doesn't)

Sensor networks

– **Vehicular sensors**:
  - speed,
  - fuel,
  - cameras,
  - airbag,
  - anti-lock brakes
– **Infrastructure sensors:**
  - speed detectors on road,
  - parking slots,
  - traffic lights,
  - toll booth

- Sensor information processing
  - Mostly static sensors
  - Sensor fusion (ladar and camera)
  - Protocols for sensor networks
  - Detection/classification/tracking of phenomena (trajectory of a vehicle going through a sensor net; sensors detect, assemble trajectory)
  - Distributed control and actuation

That's all Folks

- Transportation has big problems
- Small IT impact
- Vehicle Infrastructure integration
- Computational Transportation Science
- Enabling IT trends
  - Wireless networking
  - Mobile computing
  - Information systems:
  - Sensor networks
  - Other trends (computer vision, HCI, positioning)