Chapter I: Introduction

1. General Information

1.1 Instructor

Professor:

Nicholas F. Maxemchuk

Email: nick@ee.columbia.edu/ nick

Phone: 212 854 0580

Rm 809 Shapiro

Office Hours: Tue,Thurs 11:30-12:30

Teaching Assistant:
Shou-pon (Bryan) Lin bryan@ee.columbia.edu

1.2 Course

EE 6761: Computer Communications Networks

Prerequisite: CSEE 4119. EE 4710, or an equivalent undergraduate course

Primary Text: Course Notes on the Web

www.ee.columbia.edu/ nick/EE6761

Supplementary Texts:

D. Bertsekas, R. G. Gallager, **Data Networks**, [1].

A. Leon-Garcia, I. Widjaja **Communication Networks: Fundamental Concepts and Key Architectures,** [2].

A. S. Tanenbaum, **Computer Networks**, [3].

Selected Readings

1.3 Grading

- The final grade will be calculated as

$$Grade = \frac{1 * HW + 2 * Midterm + 3 * Final - MIN(HW, Midterm, Final)}{5}$$

- **Homework**
  - — Homework questions are imbedded in the class notes.
  - — They are due within 1 week after passing the question in the lectures.
  - — **Late homeworks will not be accepted.**
  - — At the top of each homework put your name, the chapter and page number on which the homework appears, and the problem number if there are multiple problems on the page.
  - — The homeworks should be placed on the table in the front of the class room at the beginning of the lecture in which they are due.
  - — The homeworks will be returned in the mailbox for 6761 in the student lounge on the 13th floor of the Mudd building. - Please check the box regularly. Homeworks left in the box for more than two weeks will be discarded.
  - — Homeworks will not be graded. If you make a reasonable attempt at the homework you will receive full credit.
  - — Homework solutions will not be handed out, you will be able to check your solutions during the sessions with the TA.
  - — Check course works to verify that you have received credit for all of the homeworks that you have submitted.
- **Question and Answer Periods**
  - — 2 hours a week will be announced to go over homeworks and ask questions of the TA.

2. Course Outline

Chapters:

I. Introduction

   1. General Information
   2. Course Outline
   3. Different Types of Networks
      A. Conventional Networks
      B. Mobile ad Hoc Networks, MANET's
      C. Sensor Networks
      D. Intelligent Transportation Networks
         - Vehicle Ad hoc Networks
      E. Intermittently Connected Networks
      F. Green Networks

II. Access Protocols

   1. Aloha Protocols
      A. Unslotted Aloha
      B. Slotted Aloha
   2. Tree Splitting for contention resolution
   3. Carrier Sense Protocols to reduce collisions
      A. CSMA
      B. CSMA/CD
   4. Wireless LAN's
      A. Difference with bus networks
         - Hidden Nodes
         - Exposed Nodes
      B. CSMA/CA - IEEE 802.11
      C. Bluetooth and IEEE 802.16
      D. MANET Protocols
   5. Or'ed channel
      - data buses and fiber optic networks

III. A System Perspective of Network Coding and Randomly Generated Codes

   1. Wired Networks
   2. Opportunistic Reception on Wireless Networks
   3. Randomly Generated Codes

IV. Special Topologies

1. Loop Networks

   A. token passing, slotted systems and FDDI

   B. Token Bus: Loop protocols are now used in many networks that don't have physical loops

2. Linear Topologies
   - "D" Networks, Spiral networks and the Dual Bus

3. Switching Topologies

   A. Manhattan Street Network

   B. Shuffle-Exchange Networks

V. Network Analysis

1. Little's Law

2. Queueing analysis
   - Mostly M/M/1 queues

3. Priorities
   - To show that you don't get something for nothing

4. Kleinrock's approximation
   - To determine average delay in store-and-forward networks (Internet)

   A. Burke's Lemma

   B. Jackson Networks

VI. Routing

1. Introduction

2. Pre-ARPANet

   A. Tables at each node

   B. Source Routing

   C. Flooding

   D. Random Routing

   E. Hot Potato Routing

   F. Backward Learning

   G. Shortest Path Routing

3. Internet Era Protocols

   A. Adaptive Routing

      i. Bellman-Ford

   B. Hot Potato Derivatives

      i. Shortest Q + bias

      ii. Delta Routing

      iii. Deflection Routing

- C. Alternative to Adaptive Routing
  - i. Selective flooding
  - ii. Proportional Routing
    - a. Optimal Routing
  - iii. Dispersity Routing
- D. Classification Techniques

4. Current Work
   - A. MANET's
     - i. Dynamic Source Routing
     - ii. Flooding
     - iii. Dispersity Routing
     - iv. Table based - DSDV, WRP
     - v. On demand routes
     - vi. Fish-eye routing
     - vii. Geographic routing
     - viii. Robotic Routing
     - ix. Cluster-based routing
     - x. Landmark routing
     - xi. Resource discovery
     - xii. 7 degrees of separation
   - B. Sensor Networks
     - i. Weighted Trees
     - ii. Energy Efficient routing
     - iii. Directed diffusion
   - C. Intermittently Connected and Delay Tolerant Networks
     - i. Time-space routing
     - ii. Epidemic routing
     - iii. Network Coding
   - D. Oblivious Routing

VII. Flow Control

1. Fairness
2. Max-min flow control
3. Bottleneck flow control
4. Optimal Routing and Flow Control
5. Fair Queueing

6. Congestion
    - A. Effective Bandwidth
    - B. Policing
    - C. Leaky Bucket Algorithms
    - D. Traffic Shaping
    - E. TCP
7. Beeforth's Protocol
8. Deadlock Avoidance
9. MANET's

VIII. Broadcast/Multicast

1. Steiner Trees
   - best multicast topology
2. Reliable Broadcast Protocol
    - A. Mobile Reliable Broadcast Protocol (MANET)
    - B. Reliable Neighborcast Protocol (VANET)
3. Broadcasting in MANET's and VANET's
   - Reducing number of messages in unknown topologies

3. Types of Networks

3.1 Conventional Networks

3.1.1 Sharing the media

1. Orthogonal Transmission

   A. Frequency Division Multiplexing

   Each channel uses a separate frequency band

   B. Time Division Multiplexing

   Each channel uses a separate time slot in a frame that is composed of many time slots

   C. CDMA - code division multiple access

   Orthogonal or nearly orthogonal sequences of 1'a and 0's

   In most networks the three techniques for sharing the media are equivalent and are interchangeable.

2. Statistically Shared Networks

   A. Circuit Sharing in the telephone network

   fewer circuits than there are end users

   CCS - hundred call seconds per hour that a user requires a circuit

   Busy hour statistics

   Maximum of 36 CCS

   Each user is on continuously during the busy hour

   Before the Internet, the telephone network was designed for 6 CCS

   On the average, each user is on for 10 minutes during the busy hour

   which allows 6 times as many users as circuits

   Data access to the Internet increased the busy hour statistics to 12 CCS

   about 20 minutes per user during the busy hour

   which reduces the users who can share a circuit to 3

   High speed access to the Internet has returned the busy hour average

   Incresed use of cell phones, texting, and wireless Internet access is changing the design goals once again

   B. Message Switching

   User acquires a circuit to transmit an entire data message, instead of a call

   Example - Telegraph Network

   C. Channel sharing in Local Area Networks

   Data network

   Long intervals of inactivity between transmissions

   Examples

   Aloha

Ethernet - CSMA/CD

Packet Radio - CSMA

IEEE 802.11 - CSMA/CA

D. Packet Switching, Datagram messages

Messages are divided into smaller units, packets, to prevent users with long messages from preventing users with shorter messages from acquiring the channel

Packets follow any available path through the network

Packets may arrive out of order and may have to be resequenced

Examples - Arpanet, Internet

E. Cell Switching, Virtual Circuits

Cells are fixed size packets, and are ususally smaller than Internet packets

All of the Cells follow the same path

Cells are addressed, unlike TDM slots in a telephone network, which allows more sharing on a path

Example - ATM network
Although ATM networks have disappeared, the cell switching strategies are used in Internet routers and the quality of service mechanisms are working their way into Internet routing and flow control.

3.1.2 Networks that span different distances

- The span of a circuit determines the minimum amount of time for data to traverse a network.
- This restricts the protocols that can be used to share a channel.

1. Deep Space Networks

   Propagation time hours to years

   Delay tolerant networking techniques

2. Satellite networks networks in geosynchronous orbit

   about 250 msec delay

   reservation systems

3. Wide area networks

   about 30 msec to get across the US,

4. Metropolitan area networks

   restricted to about 30 miles

   DQDB protocol and fairness,

5. Access networks,

   Telephone network - home to central office

   same span as metropolitan area network

6. Local area networks,

   Ethernet - about 3 km - CSMA/CD

IEEE 802.11 - CSMA/CA

7. Networks in automobiles

   few 10’s of feet

   increasing number of computers, and wiring cost leads to networks rather than point-to-point wiring

   standards are being developed outside networking community,

   mostly loop systems with dedicated slots

8. Networks on back planes

   Wiring dominates the cost of most systems

   few feet - contention resolution on a bit basis

   regular network topologies to make wiring easier

   router design, MSN and S-X network

9. Networks on chips

   fraction of an inch - contention resolution in a fraction of a bit time

   use network to change how modules are used rather than designing special purpose chips

3.1.3 Dependence of networks on characterisitics of physical devices and media

1. Fiber-optics

   A. High bit rates

      at a gigabit per second a bit is about 1 ft long

      limit the access protocols that can be used

      limits type of congestion control in a wide area network

   B. Dense wavelenght division multiplexing

      reduce the number of fibers needed in a network

      change network topology and reduce reliability
      recent failures in the telephone network have cut off communications to major cities

      Wavelenght switching changes relationship between connectivity and physical proximity

   C. Low error rates

      end-to-end and message based error control rather than hop-by-hop error control

      use of TCP errors for congestion control in the Internet

      reason why TCP doesn’t work well on other media

   D. Directional taps,

   E. Limited number of taps between amplifiers

2. Radio

   A. High error rates

      reduced packet size

      hop-by-hop error control in multi-hop networks

   B. Reflections

CSMA/CA instead of CSMA/CD

3. Power lines
   - Pervasive transmission media
   - Control media for the smart grid
   A. High noise
      lower bit rates
   B. lower bit rate through transformers
      data transmission in a house or neighborhood
      monitoring in a metropolitan area network
4. Automobiles
   - Electronic control is replacing mechanical control
   A. High noise environment
   B. Critical, time sensitive applications
      firing spark plugs
      Anti-lock brakes
      safety systems for collision avoidance
5. CATV
   A. Directional taps
   B. Dominant Transmission Direction

3.1.4 Networks that use existing infrastructures

1. CATV networks
   A. Tree topology -> hub and spoke topology
      easier to use CSMA/CD
   B. Dominant transmission direction
      designed to deliver TV pictures to homes
      limited number of upstream channels
      Homenets
      bidirectional transmission from hubs
2. Power lines
   A. Tree topology
      power distribution to homes
   B. Transformers
      restrict to low hertz range

3.2 Mobile, Wireless Ad hoc Networks (MANETs)

Ad hoc Network:

Construct a network from available resources:

Forward packets between wireless nodes that happen to be within communication range of one another at a particular time.

The network is self-organizing

The network is not dependent on an existing infrastructure

Evolution to Femto cells in 4G cellular networks
Insuffcient bandwidth for data application
Randomly, instead of planned, distributed of basestations
Basestations may be truned on or off occassionally.

MANET

The nodes are mobile

Topology of the network and the route between nodes is continuously changing

The location of the destinations changes

Applications

1. Rapid deployment in military applications
   - MANET's are important in military applications because the communications infrastruture may be destroyed, or may not be available to an invading army.
   - Packet radio was first used in military networks in the 1970's [4, 5, 6, 7] and interest was renewed in the 1990's [8, 9, 10, 11, 12]
     In that period of time
     - — Processing and memory became smaller and less expensive making it possible to perform more complicated operations
     - — Wireless devices became pervasive. radios went from one radio for a group of soldiers to the equivalent of individual cell phones.
     - — Digital information became more important in warfare
2. Restore communications after a catastrophy
   - Use existing infrastructure in unconventional ways
     - Normally, wireless LAN's are used to collect data and transmit the data on a wired network
     - If the wired network fails, the data can be removed by the LAN, and ad hoc interconnections with other LAN's can be used to carry the data to a part of the wired network that is still operating.
   - Examples
     - On 9/11 a main telephone switching center on West Street and the fiber trunks under Broadway were destroyed, disabling communications in the Wall Stree area for several days
     - In all of the NYC blackouts the telephone network became overloaded, which resulted in a loss of communications

- Following Katrina communications in New Orleans was lost for more than two weeks
- Earthquakes in San Francisco have cut the fiber-optic cables, which are routed over the Bay Bridge.
- The Baltimore tunnel fire cut the phone lines to Washington DC

3. Try new services without investing in infrastructure
   - If the application is successful, and the number of customers increases, we can introduce infrastructure, lines or basestations, to make the service use the bandwidth more efficiently
   - Example: Transmit traffic reports between cars on a highway
4. Supplementing congested cell phone networks
   - Decrease the probability of dropping calls in busy regions in a cellular telephony network
   - In lightly loaded networks, the transmission power of cellular units is sufficient to reach the base station.
     The units in a cell interfere with the other units in the cell, and units in adjacent cells and must use orthogonal transmission techniques, FDM, CDMA, to transmit simultaneously on different channels.
   - In a heavily loaded network, there aren't a sufficient number of orthogonal channels.
     If a new user moves into the cell from an adjacent cell, a call must be dropped.
     If a user trys to place a call, that user receives a trunk busy signal
   - If users decrease their transmission power, the number of channels available for simultaneous transmission increases.
     If the power from a user interferes with users up to a distance r, and the area of the network is A_{net}, the number of times that a channel can be used in the network is $\frac{A_{net}}{2\pi r^2}$.
     The number of channels is proportional to $\frac{1}{r^2}$.
   - When users decrease their transmit power, the distance that they travel toward the destination decreases, and the number of times that the packet must be forwarded increases.
     If the distance to the destination is d, and the users travels r each time it is transmitted, the users must use approximately $\frac{d}{r}$ channels to reach the destination.
     The progress toward the destination depends on the number of users in the transmission region, and decreases when the number of users decreases.
   - For uniformly distributed source and destination locations, the number of simultaneous users is inversely proportional to the transmission radius.
   - When all users must reach the same base station, and there are K channels, then there are only K simultaneous users, regardless of how small they make their transmission radii.
   - In order to realize the gain of multi-hop the users in a congested cell must direct their traffic toward the base station in an uncongested cell, and must be forwarded more times.
   - Alternatively, the number of base stations can be increased using mobile base stations called COWS (Cells on Wheels). COWS are currently used for political or sporting events to increase cell phone traffic, but can also be rolled into regions with expected congestion - such as the exit from the Lincoln Tunnel at rush hour.

New problems

1. Resource Discovery:
   Finding destinations or servers

2. Adapting to changes in the network topology:
   New classes of routing and flow control mechanisms

3.3 Sensor networks

Describe Smart Dust [13]

Changes in the Communication Model

1. Severe Energy Constraints
   - Small devices with small batteries
   - Limited transmission distance

     limited radio power
2. Limited transmission bandwidth
   - Wireless network with simple radios
3. Data Collection Network
   - Many sources to a small number of destinations, instead of point-to-point communications
   - Data funnels, rather than data being more uniformly distributed over the network
   - Some parts of the network, especially those near the destination, are much more congested than others
4. All of the data sources transmit an impulse of data
   - The transmissions are triggered by an external physical event, rather than being independent of one another

     Example: All earth quake detection messages happen at nearly the same time

     The Poisson arrival model used in most communications systems is inappropriate
   - Random access protocols will perform poorly - scheduled transmissions
5. Data compression in the network
   - The physical event has a limited spacial bandwidth

     Sensors that are near each other make similar measurements

     The lower the spacial bandwidth, the greater the distance over which measurements are the same.

     Example: The temperature in a building fire changes over smaller distances than the vibration in an earthquake.
   - We can reduce the amount of data transmitted by performing data compression on nearby measurements
   - These networks process the data in the network to reduce the bandwidth needed and the transmission energy expended.

     All previous networks preserved data integrity
   - Routing can be used to make greater compression possible

3.4 Intelligent Transportation Systems and Vehicular Networks

VANET: Vehicle Ad hoc NETwork

Objectives:

1. Increase Safety
   - Reduce accidents, near air collisions, bridge failures
2. Conserve Fuel
   - Reduce traffic jams, unnecessary stops at traffic lights,
3. Reduce the need for new infrastructure, Roads, Airports, Trains By increasing the capacity of existing facilities
4. Improve public transportation
   - More convenient ways to use subways and buses
5. Link driving, trains, parking spots

Applications:

I. Automobiles:
   A. Sensors -> Communications -> Coordination (Cyber-Physical Systems)
      1. Platooning:
         a. Sensors: Warning, car in front
         b. Communications: Share sensors, Distributed Anti-lock Brakes
         c. Coordination: Platoons, Convoys
      2. Highway merges and lane changes
         a. Sensors: Cars in blind spot
         b. Communications: 2 cars headed for the same spot
         c. Coordination: Signal Intent, Obtain Permission
      3. 4 way stop problem
         a. Sensors: Cars waiting for a light
         b. Communications: Schedule for cars approaching intersection
         c. Coordination: Schedule convoys of cars so that none stop
   B. Communications between cars and with infrastructure
      1. Traffic Light Control
         a. Lights with Sensors
            - **Now**: Sensor detects a waiting car and changes the light. Car stops,
            - **Communications:** Traffic light is informed before car arrive. Light on crossing road turns yellow before car arrives, so that a car doesn't have to stop
         b. Timed traffic lights

- **Now:** Coordinated lights in direction of rush hour traffic, so that cars traveling at the *normal* speed never have to stop
- **Communications:** Inform light when cars will arrive. Account for reducing speed for buses and cars parking

c. Future:

i. Coordinate nearby lights to minimize stopping

ii. Deflection routing for cars to avoid busy intersections

iii. 4-way stop problem

2. Early Warning for cars entering a region

a. Construction, Debris in roadway, Breakdowns, Accidents, Icy or slippery roadways

b. Problems: Detection and spreading information
- ad hoc vrs. Infrastructure networks
- controlled broadcast distribution of messages

3. Route Planning

a. GPS Maps with Information from Police, Traffic reports, Progress of other participating automobiles

b. Problems: Recommending routes based on fraction of cars participating

4. Extend route planning to train arrivals and parking availability

a. Sensors and reservation devices in commuter parking, determine availability and pre-pay for commuter parking

— Parking spot availability being implemented in San Francisco

b. Cost and time for train vrs. driving

II. Planes
Air Traffic Control

- Combine distributed control with current centralized control
- Communications between airplanes is regulated

1. 3-D safe positioning

- Direct communications with nearby airplanes
- Decrease safe separation in holding patterns

2. Reduce number of near air collisions

- Similar to Platooning on Highways

3. Communications between planes and other vehicles sharing a runway

- Increase Frequency of Take-offs and Landings
  - Increase capacity of airports
  - Eliminate the need for a 4th NYC airport
- Prevent Runway Incursions
- Decrease load on air traffic controllers

III. Trains
A simplified version of the highway problem - Except:

- Longer stopping distances
- Communications and processing can be standardized and all trains forced to use the same procedures

1. Decrease minimum safe separation of trains
   - Increase passenger throughput by increasing the number of commuter trains during the rush hour

2. Making mass transit more convenient
   - Each subway car can be the engine and can be operated separatly.
     — Trains are a convoy are a convoy of cars, rather than connected together.
     — Cars switch tracks independently, and can skip stations or head for different destinations
   - Operate subways like paratransit buses
     — On demand to destinations.
     — Fewer changes, Fewer stops
   - Passengers have communicating smart cards that tell the trains where they want to go, and tell the passengers which cars to board

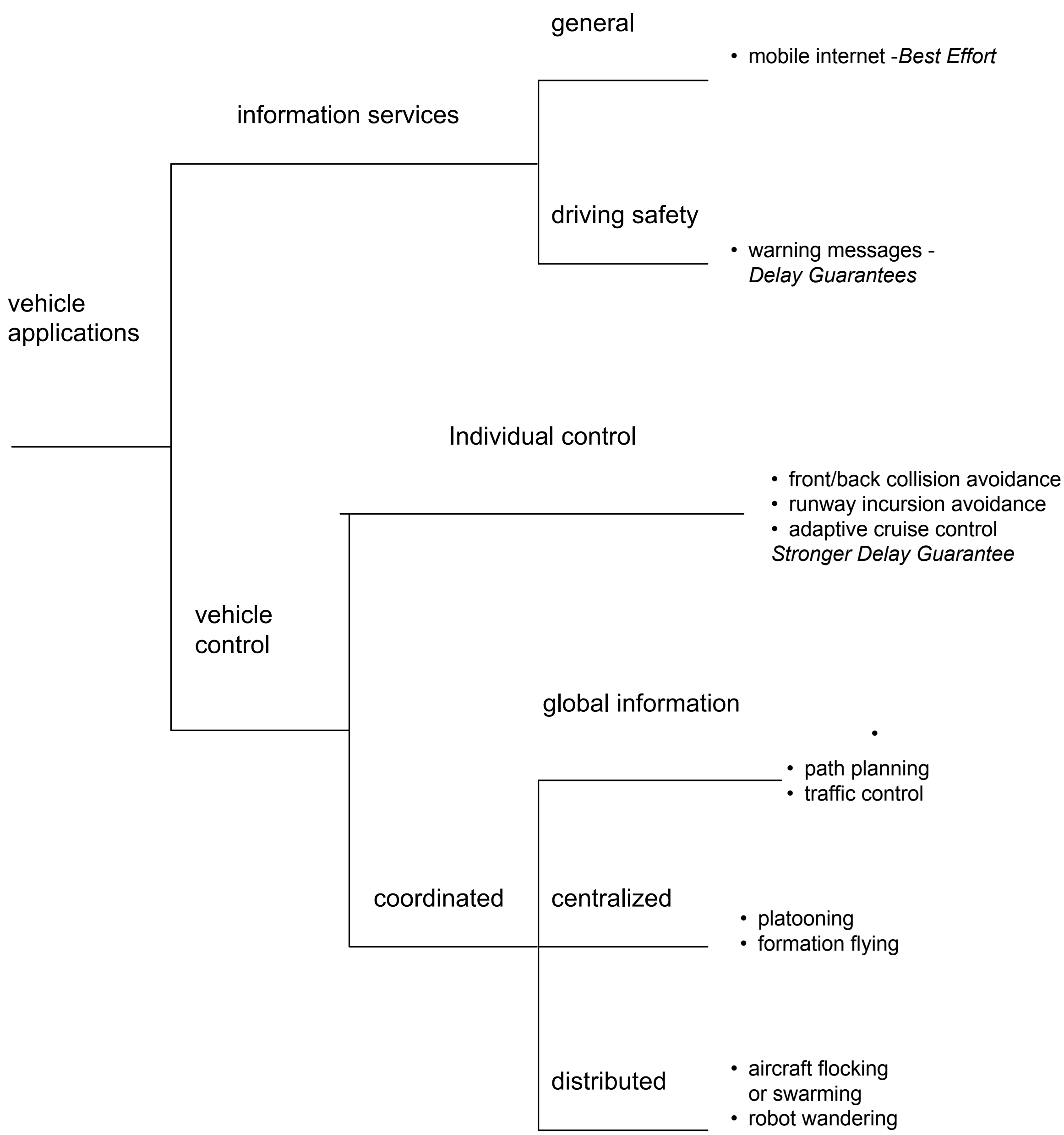
IV. Infrastructure - Roadways, Bridges

1. Collect traffic data
   - Long term planning to increase infrastructure
   - Daily use - redistribute lanes and one-way streets to accommodate traffic
     - Some NYC bridges use more lanes in the direction of rush hour traffic
     - With communications we can operate the lanes based on actual, rather than expected, traffic, and reflect accidents or short term construction on the roadways
   - Balance evacuation with re-entry of buses and emergency responders during disasters
     - during hurricane Katrina the highways around New Orleans operated in one direction, leaving the city. As a result, buses could not return to the city to evacuate more people.
   - Congestion pricing - decrease the cost of public transportation as well as increase the cost of using a roadway to encourage more use of public transportation. The increased cost of using the roadways should be used to subsidize public transportation. mix

2. Infrastructure: Sensor networks to monitor the state of bridges, tunnels
   - Wireless network, collect large amount of data

3. Pavement: Sensing and Communications to:
   - Find pot holes and schedule maintenance
   - Detect debris on the roadway and schedule its removal
   - Detect icy or slippery conditions and dispatch road crews.

Vehicular communications applications have diferent communications requirements



New work

1. Neighborcast model of communications
   - Communicate with nearby vehicles rather than specific vehicles
   - Communications between nearby traffic lights for timing coordination
2. Distributed processing:
   - Too much information to send to central location.
   - It would take too long to assemble all information
   - Entire problem is too large to consider at once
3. Information propagation out of neighborhood
   - Rolling traffic jams
   - Affecting the timing of nearby traffic lights affects timing of other traffic lights that are near them.
4. Self-organizing systems
   - Groups of cars that travel together and cooperate
   - Groups of cars stopped at traffic lights form the equivalent of convoys
5. Application of formal methods in protocols to vehicle control protocols
   - Failures in the operation of computer controlled braking systems have resulted in loss of life and major vehicle recalls
   - Probabilistic protocol verification to determine likelihood that control procedure will give an unexpected or dangerous result when different combinations of failures occur [14].

3.5 Intermitently Connected and Delay Tolerant Networks [15]

Opportunistic transmission: Communications channels are not always available. When a channel becomes available, use it to forward all of the data that has been acquired.

Applications

- Zebra-net: Monitor location of zebra using radio collars. When new zebra are encountered, transfer own information, and information that has been received from other zebra to the new zebra. Eventually a zebra gets close to a collection station and the information from all of the zebra is received.
- Deep Space communications: A deep space probe may not have sufficient energy to send a large amount of data to the Earth. Use satellites in different orbits around the Sun or planets to forward data toward the Earth. Plan the orbits to reduce the time or number of satellites needed for the data to reach the Earth. The data may take years to reach the Earth.
- Sensor nets with wake and sleep periods to conserve battery power: Plan sleep periods to minimize communications delay and survive failures,
- Military ad-hoc networks: Opportunistic data forwarding when aircraft fly over a battle field.

REFERENCES

[1] D. Bertsekas, R. G. Gallager, **Data Networks**, Prentice-Hall Inc, 1992.

[2] A. Leon-Garcia, I. Widjaja "Communication Networks: Fundamental Concepts and Key Architectures," McGraw-Hill, 2000.

[3] A. S. Tanenbaum, Computer Networks, 4th edition, Prentice-Hall 2002

[4] L. Kleinrock, F. A. Tobagi, "Packet Switching in Radio Channels: Part I-Carrier Sense Multiple-Access Modes and Their Throughput-Delay Characteristics," IEEE Trans. on Commun., vol. COM-23, no.12, Dec. 1975, pp 1400-1416.

[5] L. Kleinrock, M. O. Scholl, "Packet Switching in Radio Channels: New Conflict-Free Multiple Access Schemes," IEEE Trans on Commun, vol. COM-28, no. 7, July 1980, pp. 1015-1020.

[6] J. Burchfiel, R. Tomlinson, M. Beeler, "Functions and structure of a packet radio station," AFIPS, vol. 44, pp. 245-251, 1975.

[7] B. M. Leiner, D. L. Nielson, F. Tobagi, "Issues in Packet radio Network Design," Proc. IEEE, vol. 75, No. 1, pp. 6-20, Jan. 1987

[8] I. Chlamtac, A. Farago, "A new approach to the design and analysis of peer-to-peer mobile networks," Wireless Networks, 1999, v5, n3, pp 149-156.

[9] E. M. Royer, C. K. Toh, "A review of current routing protocols for ad hoc mobile wireless networks," IEEE Personal Comm. Mag, Apr. 1999, v6, n2, pp 46-55.

[10] J. P. Hubaux, T. Gross, J. Y. Le Boudec, M. Vetterli, "Toward self-organized mobile ad hoc networks: the terminodes project," IEEE Commun. Mag. , Vol. 39 No. 1 , Jan. 2001, pp 118 -124.

[11] C. Elliott, B. Heile, "Self-organizing, self-healing wireless networks," IEEE Aerospace Conf. 2000, Vol. 1, pp 149 -156.

[12] Z. Haas, M. Gerla, D. B. Johnson, C. E. Perkins, M. B. Pursley, M. Steenstrup, "Guest editorial: Wireless ad hoc networks," IEE JSAC, vol. 17, no. 8 , Aug. 1999, pp. 1329 -1332.

[13] J. M. Kahn, R. H. Katz, K. S. J. Pister, "Next Century Challenges: Mobile Networking for "Smart Dust", 5th ACM/IEEE conf. on Mobile computing and networking, August 15 - 19, 1999, Seattle, WA, USA, pp. 270-8.

[14] Bohyun Kim, N. F. Maxemchuk, "A Safe Driver Assisted Merge Protocol," IEEE Systems Conference (SysCon) 2012, 19-22 Mar. 2012, Vancouver, BC, Canada, pp. 1-4.

[15] Z. Zheng, "Routing in Intermittently Connected Mobile Ad Hoc Networks: Overview and Challanges," IEEE Communications Surveys and Tutorials, March, 2006.