Introduction

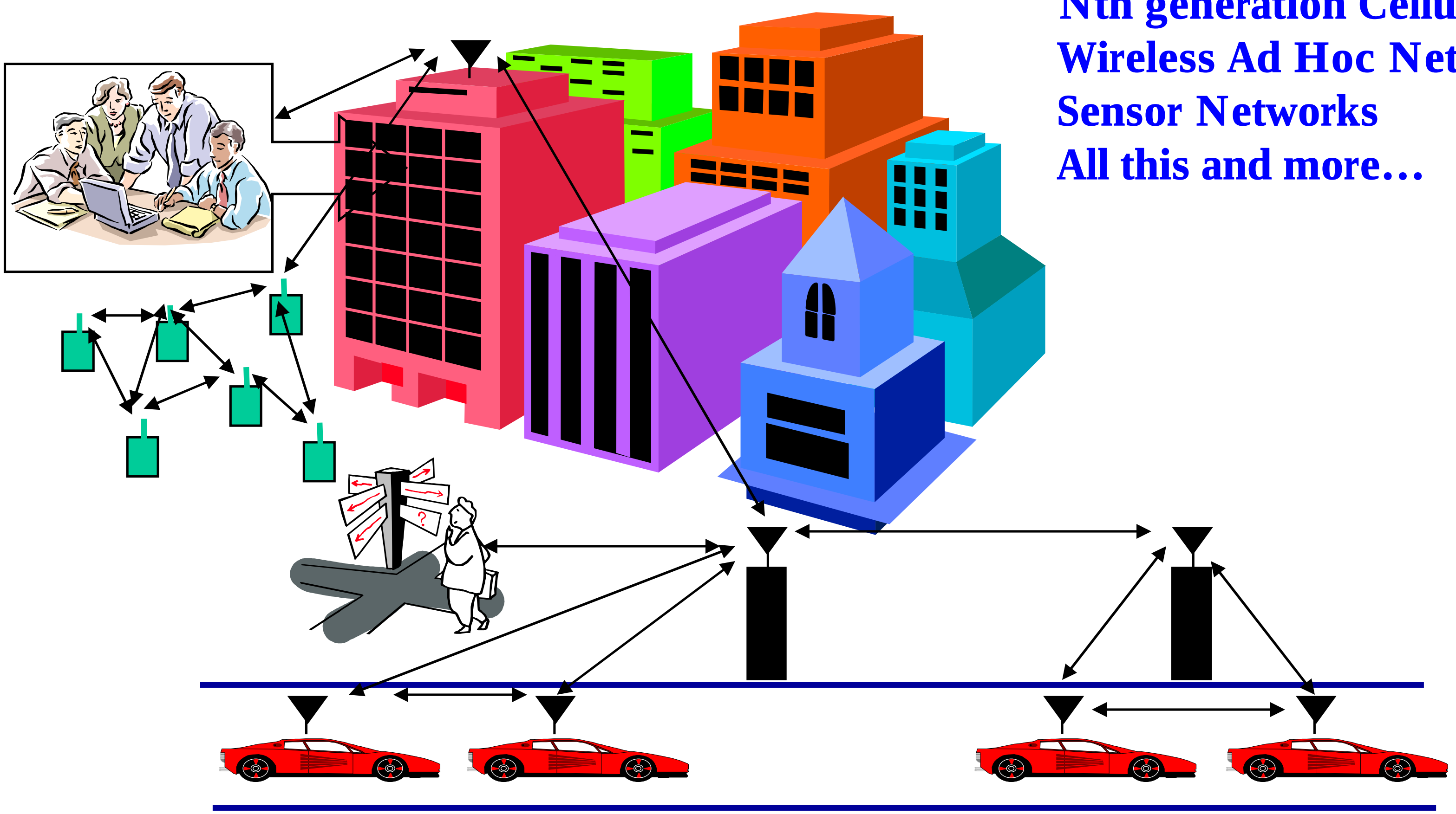
Vision and Challenges

Chengzhi Li

Future Wireless Networks

Ubiquitous Communication Among People and Devices

Wireless LANs
Nth generation Cellular Networks
Wireless Ad Hoc Networks
Sensor Networks
All this and more…



QoS Provisioning in Wireless Networks

Quality of Service (QoS)

- Data rate R
- Delay tolerable $D_{\max}$
- Packet loss probability P_{loss}

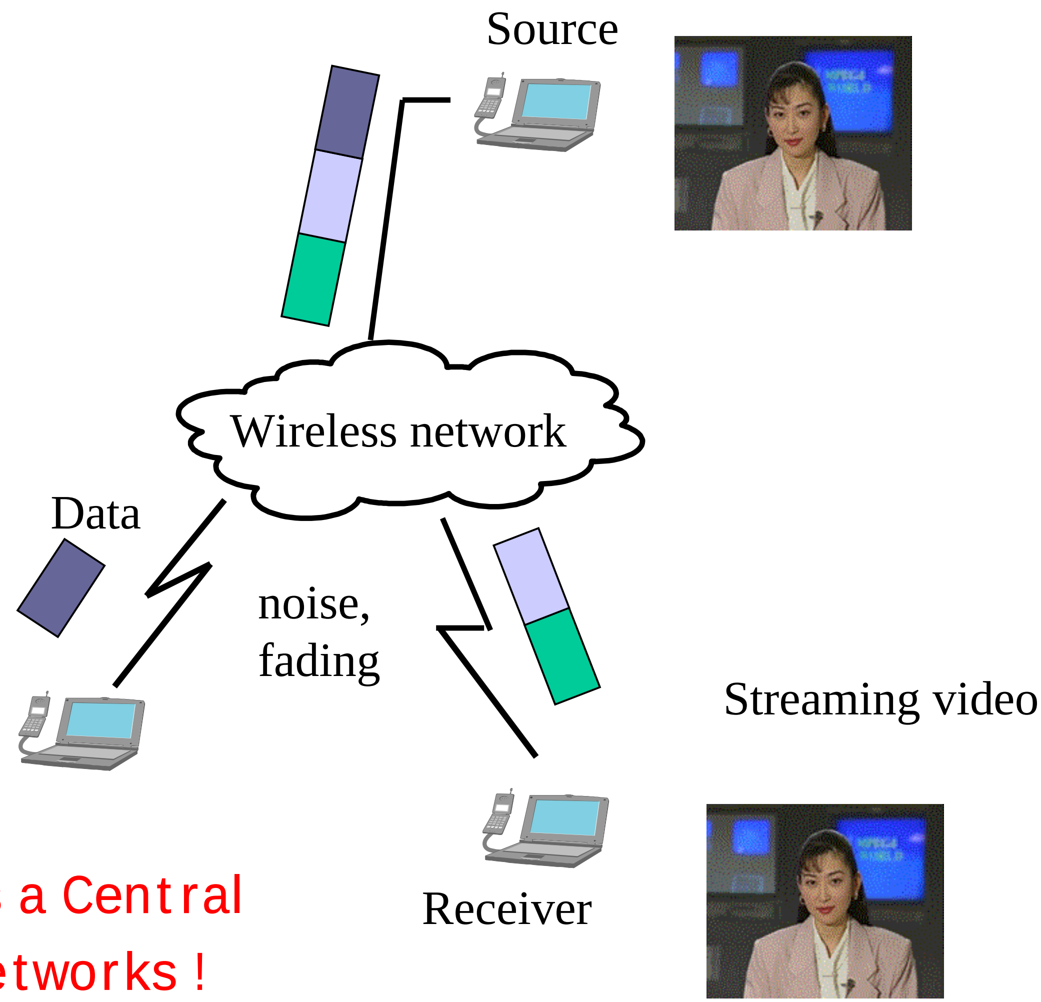
$$P_{loss} = \text{Prob}\{D(t) \geq D_{\max}\}$$

Do we need QoS?

Can we provide QoS?

How to Provide QoS still is a Central Problem for Wireless Networks !

Why it is so difficult?



Three Fundamental Challenges

- Broadcast Nature of RF Communications
- Dynamic Environment
- Poor Local Resources

Broadcast Nature of RF Communications

- Limited transmission range
- Hidden & Exposed terminal problems
- Limited Data Rate
  - IEEE 802.11a/g ~54 mbps
  - IEEE 802.11b ~ 11 mbps
  - July 20, 2004, AT&T announced 3G service
    - 320 kbps download speed for cellphone or labtop
    - only 4 cities (Francisco, Seattle, Detroit, and Phoenix)
- Uncertainty of performance
  - Variance of bit error
  - Variance of latency
  - Variance of capacity

Dynamic Environment

- Node Mobility è Dynamic system
  - Network topology changes
  - Network performance changes (error rate, latency, cost, connectivity ...)
  - Available resources change
  - Application changes
    - Loss of bandwidth triggers change from color to B&W
- Bursty traffic è Dynamic workload

Poor local resources due to portability

- CPU
- Memory
- limited battery life time

All these challenges are instinct and every problem in QoS provisioning is related to one or more challenges

Several Years Ago

- People in Communications Field
  - ignored the bursty nature of real traffic sources and the role of delay in networking
  - many algorithms such as AMC were designed independently of traffic nature and application service requirements

- People in Networking Field
  - ignored the fundamental role of radio channel in wireless communications
  - many routing protocols and MAC protocols were designed independent of the radio channel condition

Now researchers try to bridge the gap between two fields

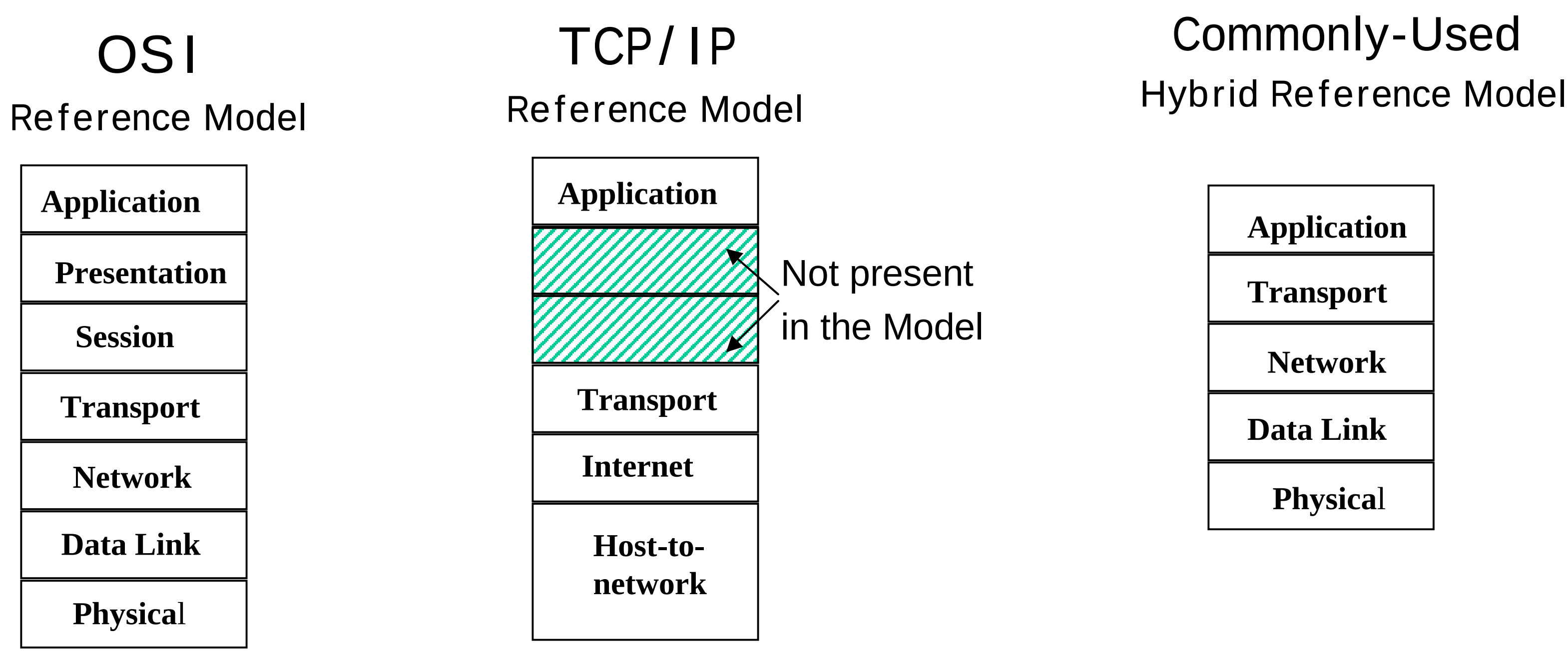
Current Research Trend

- Try to push the state of the art in design of protocols, algorithms, and architecture of wireless networks to the limit to improve the performance of wireless networks from several disciplines
  - communication/information theory
  - networking
  - optimization, etc.

- QoS provisioning in wireless networks must encompasses issues at all layers (Application, Transport, Network, Link, and Physical layers)

- Cross-layer adaptability is the key to QoS provisioning

Layered Protocol Architecture



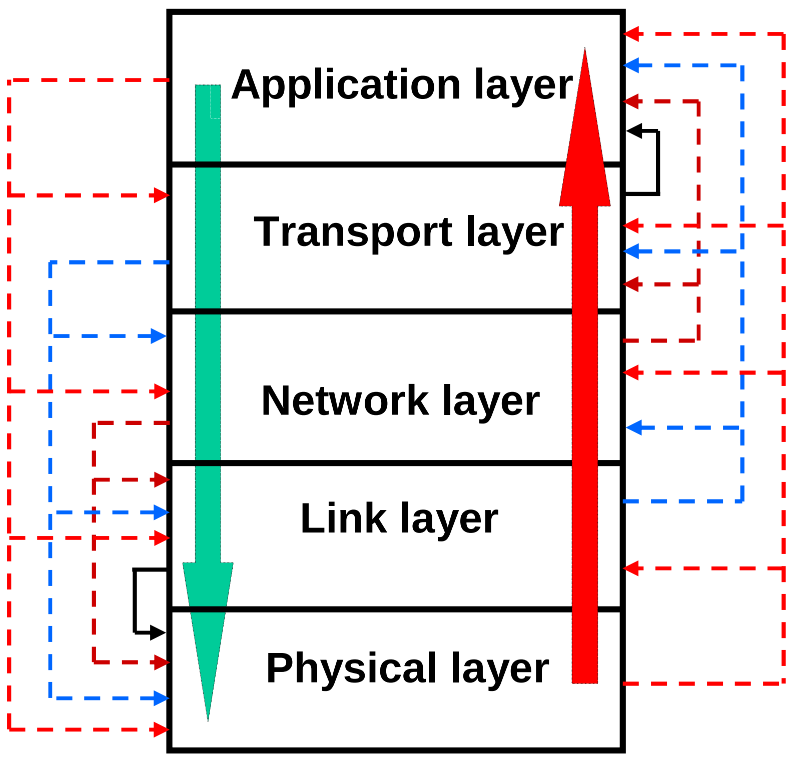
- Networks are organized as a series of layers, each one built upon the one below it.
  - Main reason: reduce complexity (divide & conquer approach)
    - Split the network into smaller modules with different functionalities
    - Each layer is designed and operated independently, offer certain services to the higher layers, shielding those layers from the details of how the services are implemented
    - Static interfaces between layers independent of the individual network constraints, applications, and protocol mechanism

Overview Layered Design

- Advantages of layered design
  - Simplicity
  - Easy to standardize
  - Flexibility to deploy new protocols and upgrade
- Any disadvantage?
  - Inflexible & suboptimal
  - Layered architecture forces networks to operate under the worst conditions in sub-optimal mode, rather than adapting to changing conditions in optimal mode
- Underlying assumptions:
  - Relative static networking environment
  - Reliable/stable link capacity
  - ……
- These assumptions are not suitable for wireless networks
  - Channel quality dynamically changes
  - Network topology dynamically changes
  - ……

Pure Layered Design is not Suitable for QoS Provisioning over Wireless Networks!

Big Picture for Cross-Layer Design



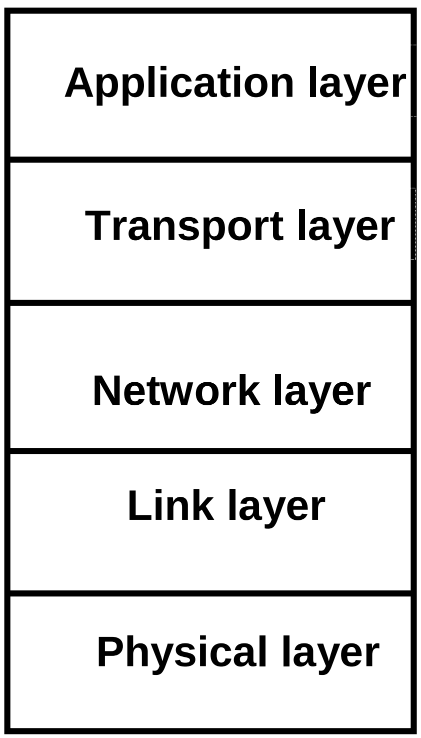
- Motivation for cross-layer design
  - Service provisioning in a highly dynamic environment
  - Unavoidable direct coupling between physical layer and higher layers
  - fully exploit the limited resources to enhance QoS provisioning by using adaptive protocols & algorithms at multiple layers
- Common misconception:
  - Layered architecture must be completely eliminated
  - All layers must be integrated and jointly optimized
- General methodology
  - Maintain the layered architecture
  - Capture important information which influence other layers
  - Exchange the information between layers
  - Implement adaptive protocols & algorithms at each layer to optimize the performance

Caution Needs to be Taken

- Cross-layer design advantages:
  - Adaptability at each layer based on information exchange between layers can exploits the interactions between layers to deal with dynamic environment
  - Limited resources can be fully utilized to improve performance
- Cross-layer design disadvantages
  - Hard to characterize the interactions between protocols at different layers
  - Joint optimization across layers may lead to complex algorithms

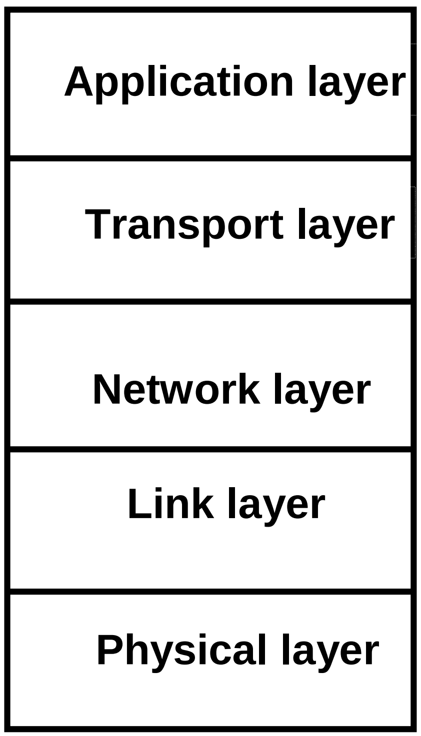
Note: Understanding and exploiting the interactions between different layers is the core of the cross-layer design

Physical Layer



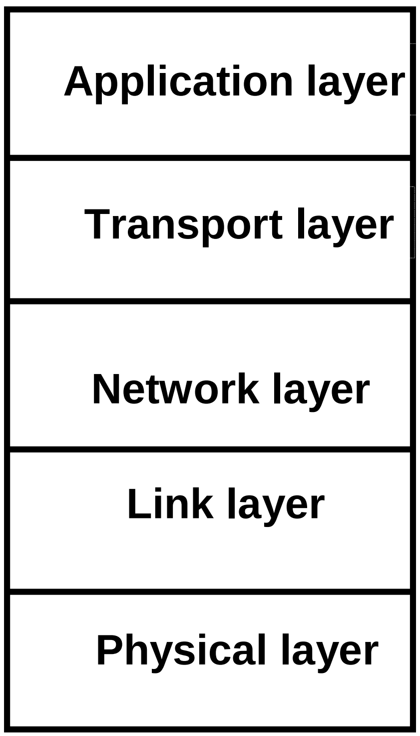
- Main function:
  - transmits raw bits over a communication channel
- Main goal:
  - achieve channel bit rate that closes to fundamental limits
- Main techniques:
  - multiple antennas
  - modulation and channel coding
  - symbol rate
  - power control, ……
- Main metrics:
  - BER, SNR, transmitter power level
  - spectral efficiency (data rate/channel bandwidth)
- QoS issues:
  - minimize BER, energy consumption
  - maximize spectral efficiency
- Cross-layer issues:
  - How to create models to translate actual channel characteristics such as bit error rate, signal-to-noise ratio, modulation, coding rate and symbol rate into useful info at upper layers?
  - How to adapt the transmission scheme not only to underlying channel conditions but also to the traffic characteristics and QoS requirements through variation of the transmitted power level, symbol rate, modulation and coding scheme, and ……
    - QoS-aware adaptive modulation and channel coding, power control
    - ……

Data Link Layer



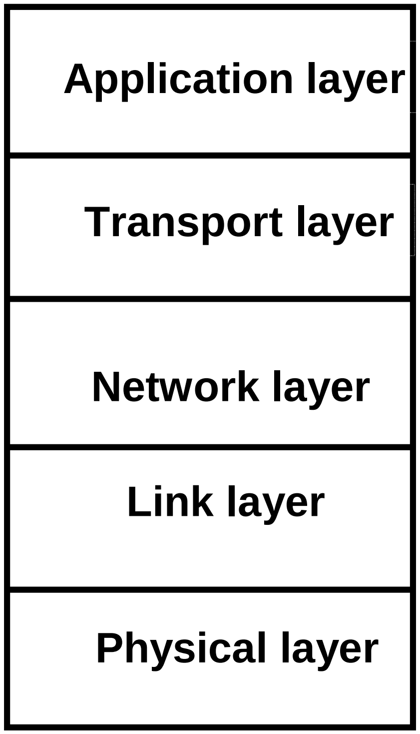
- Main functions:
  - Achieve reliable and efficient communication between two adjacent nodes
- Main Techniques:
  - Error control: automatic repeat request (ARQ)
    - Stop-and-wait & Go-back-n & Selected-repeat
  - Medium Access Control
    - Divide the spectrum into different channels
    - Assign different channels to different users
    - Allow multiple users to share a common channel
      - Centralized MAC
      - Distributed (random) Mac
      - CSMA/CA - RTS/CTS/DATA/ACK (IEEE 802.11 DCF)
- QoS issues:
  - service differentiation, fairness, delay and throughput guarantees
- Cross-layer issues:
  - Adaptive MAC and scheduling algorithm design based on underlying channel conditions and traffic characteristics and QoS requirements
  - Minimize the energy consumption and maximize spectral efficiency and meet QoS requirements through transmitted power control and directional antennas
  - ……

Network Layer



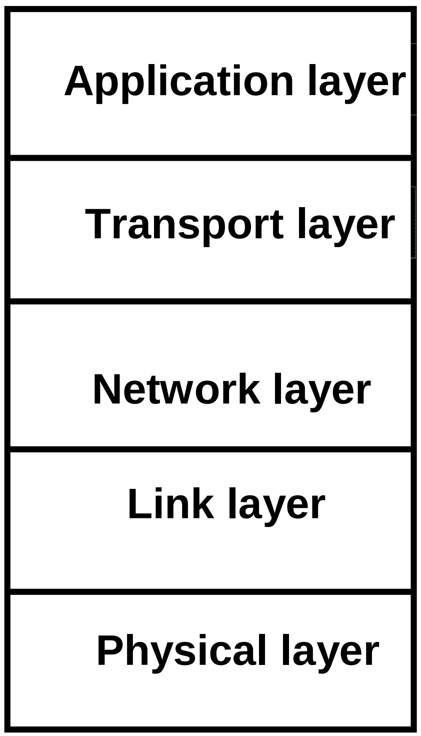
- Main function:
  - route packets from source to destination
  - maintain network connectivity
  - controls the network operation
- Main Techniques:
  - routing
  - admission control
  - resource reservation
  - traffic engineering
- Main metrics:
  - Connectivity
  - delay
  - data rate
  - network resource utilization
- QoS issues:
  - routing efficiency, network connectivity and capacity, QoS provisioning
- Cross-layer issues:
  - Cross-layer adaptability for service differentiation
  - Physical + MAC + Network routing for minimizing engergy consumption, QoS
  - Multi-path routing + channel coding + limited ARQ for QoS
  - ……

Transport Layer



- Main function:
  - provide cost-effective end-to-end data transportation
- Main protocols:
  - TCP - connection oriented service: modeled as the telephone system: establish connection, use it and then close it. Acts like a tube; order of packets is preserved
  - UTP – connectionless service: modeled after the postal system. Each packet carries the full destination address and it is routed independently. Packets may arrive out of order
- Main metric for TCP: throughput
- QoS issue:
  - Reliable data transportation over wireless links/ad-hoc networks
- Cross-layer issues:
  - Cross-layer reliable transport protocol to minimize the impact of mobility and channel error on the performance
  - ……

Application Layer



- Main applications:
  - Distributed control, multimedia conferencing, Internet access, ……
- QoS issues:
  - How application adapts to the underlying network capabilities?
    - Adaptive video compression algorithm
      - Under poor wireless network conditions
        - » High compression rate -> poor image quality ->lower source data rate -> but satisfy performance requirements
      - Under good wireless network conditions
        - » Low compress rate->high image quality->high source data rate
- Cross-layer issues:
  - How to adapt to the underlying networking conditions to deliver the highest possible application quality
  - ……

Key Issues in Cross-Layer Design

- What information should be exchanged between layers?
- How should the information be used by adaptation protocols at particular layer?
- How to create models to translate actual channel characteristics such as bit error rate, signal-to-noise ratio, modulation and coding scheme, and symbol rate into useful models at upper layers?
- How to quantify tradeoffs of performance versus complexity and scalability?
- Would the advantage of cross-layer design lead to new network architecture?

Several Active Research Groups for Cross-Layer Design

- Wireless system lab in Stanford University (Prof. A. Goldsmith)
  - Cross-layer design of ad-hoc wireless networks for real-time media
- Research group in U. of Minnesota (Prof. G. B. Giannakis)
- Research group in U. T. Austin (Prof. T. S. Rappaport)
- Research group in U. of Maryland (Prof. A. Ephremides)
- Italian National Research Coucil (CNR) IIT Institute, Pisa, Italy (Dr. Marco Conti)

Several Professors with NSF Career Awards for Cross-Layer Design

- Prof. T. Javidi in U. of Washington
  - Cross-layer integrated protocol design for broadband wireless data networks: A microeconomic approach
- Prof. R. Kravets in UIUC
  - Pulsar: A cross-layer approach to energy conservation in mobile ad-hoc networks
- Prof. J. Zhang in Arizona State University
  - Efficient resource management and multi-access protocols for bursty traffic over wireless networks: A cross-layer design approach
- Prof. S. Krishnamurthy in U. of Cal. Riverside
  - Cross-layer architectures for power adaptive and smart antenna equipped mobile ad-hoc networks