# 無線網路多媒體系統
# Wireless Multimedia System

Dr. Eric Wu
Lecture 11 Power Issues & Energy Efficient



## The Last Issue

- Power Consumption Issues
  - Standy/PowerON
  - Processing Power Consumption
  - Transmitting Power Consumption
  - Routing Power Consumptions



## Reading list for This Lecture

- Required Reading (August 2001 Communication Magazine)
  - [Bambus98] Bambus, "Power Sensitive Architecture in Wireless Network, Concepts, Issues and Design Aspects, IEEE Personal Communications Magazine, 1998
  - [Jones2001] C. E. Jones, K. M. Stvalingam, P. Agrawal, J. C. Chen, "A Survey of Energy Efficient Network Protocols for Wireless Networks", Journal of Wireless Networks 2001
  - [Gomez2001]J. Gomez, A.T. Campbell, M. Naghshineh, C. Bisdikian, "Conserving Transmission Power in Wireless Ad Hoc Networks"
  - [Chen2001]B. Chen, K. Jamieson, H. Balakrishnan, R. Morris, "Span: An Energy-Efficient Coordination Algorithm for Topology Maintenance in Ad Hoc Wireless Network"



## Power-Sensitive Network Architectures in Wireless Communications

Concepts, Issues, and Design Aspects



## Agenda

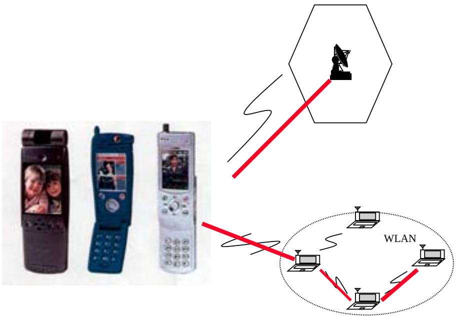
- Sensitive Power Control Wireless Network
- Energy Efficient Network Protocols for Wireless Network



## Power Control Concept and Its Practical Significance

Higher Bandwidth (150 Mega)

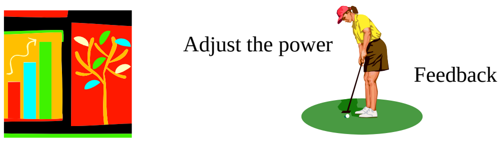
## QoS depends on Transmitter Power Control (PC)






## Related Issues

- System Point of View
  - Transmitter power minimization, network capacity maximization, optimal resource allocation
- Individual Connection Point of View
  - Online link QoS monitoring
  - Adaptation to changes due to mobility and channel impairments






## Basic Requirements for PC dynamics

- Distributed
  - Allowing autonomous execution at the node or link level
- Simple
  - Suitable for real time implementation
- Agile
  - For fast tracking of channel changes and adaptation
- Robust
  - To gracefully adapt to diverse stressful contingencies
- Scalable
  - To maintain high performance at various network scales of interest



## Research Background in PC

- Packet Radio ('80)
  - Point to Point Wireless Communication
  - Packet-Switch datagram Traffic
  - Dynamically allocate slits/codes to various communication links
  - Power Control in packet radio was mainly used for adjusting the transmission range to reach various receivers
- Cellular Networks ('90)
  - PC is used for improving spatial channel reuse and increasing network capacity
  - SIR (Signal-to-interference ratios): lowering them while congested
  - Satisfy a required SIR threshold using the least possible power



## Three Fundamental goals

- To Minimize Power Consumption and Prolog Battery Life of Mobile Nodes
- To mitigate interference and increase network capacity
- To maintain link QoS by adapting to node movements and channel impairments
- Autonomously probe: admission control, channel selection, switching, handoff



## Adaptive Power Control

- The Wireless Network as a Collection of Power-Controlled Interfering links
- Distributed Power Control: The concept of Active Link Protection
- Autonomous Online Admission Control: The Voluntary/Forced Dropped Concept
- Quick Noninvasive Channel Proving and Monitoring: The Probing Concept

## Associated Research Issues

- Online Adaptation of DPC/ALP to Congestion
- The Multi-channel Case: Channel Selection and Switching
- The Minimum-Power Routing Problem in Multi-hop Wireless Networking
- Node Mobility, Network Stretching and Reconfiguration, and Probing-Based Handoffs
- The Stochastic Basis for Power Control and Quick Online Estimation of Link Quality
- The Power Manager's Dilemma: To Transmit or Wait?
- Error-Driven Power Management
- Power-Sensitive Wireless Network Architectures?



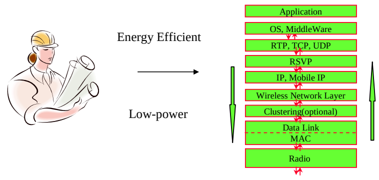
## A Survey of Energy Efficient Network Protocols for Wireless Networks

*Wireless Network 2001*



## Abstract

- As wireless networks become an integral component of the modern communication infrastructure, energy efficiency will be an important design consideration due to the limited battery life of mobile terminals.
- This paper presents a comprehensive summary of recent work addressing energy efficient and low-power design within all layers of the wireless network protocol stack.






## Introduction

- Wireless devices have maximum utility when they can be used "anywhere at anytime". One of the greatest limitations to that goal, however, is finite power supplies.
- Studies show that the significant consumers of power in a typical laptop are the microprocessor (CPU), liquid crystal display (LCD), hard disk, system memory (DRAM), keyboard/mouse, CDROM drive, floppy drive, I/O subsystem, and the wireless network interface card [55,62].
- A typical example from a Toshiba 410 CDT mobile computer demonstrates that nearly 36% of power consumed is by the display,21% by the CPU/ memory, 18% by the wireless interface, and 18% by the hard drive.



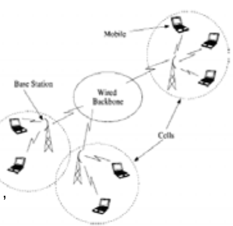
## Introduction(cont.)

- Consequently, energy conservation has been largely considered in the hardware design of the mobile terminal [10] and in components such as CPU,disks, displays, etc.
- Significant additional power savings may result by incorporating low-power strategies into the design of network protocols used for data communication.



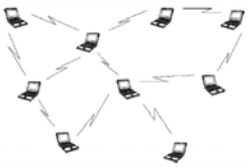
## Background

- Infrastructure wireless network architecture:
  - Wireless networks often extend, rather than replace, wired networks
  - A hierarchy of wide area and local area wired networks is used as the backbone network.
  - BS are responsible for coordinating access to one or more transmission channel(s) for mobiles located within the coverage cell.
  - Transmission channels may be FDMA , TDMA ,CDMA



## Background(cont.)

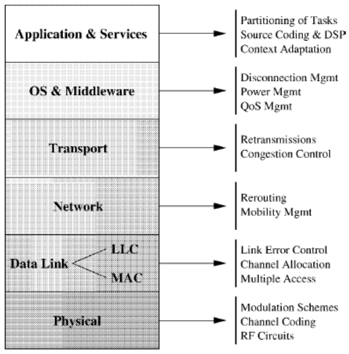
- Ad hoc wireless network architecture:
  - are multihop wireless networks in which a set of mobiles cooperatively maintain network connectivity . This on-demand network architecture is completely un-tethered from physical wires.
  - characterized by dynamic, unpre-dictable, random, multi-hop topo-logies with typically no infrastructure
  - **IETF working group MANET (Mobile Ad hoc Networks).**





## Background(cont.)

- Protocol layers






## Protocol layers -background

- Physical
  - The physical layer consists of radio frequency (RF) circuits, modulation, and channel coding systems. From an energy efficient perspective, considerable attention has already been given to the design of this layer [10].
- Data link
  - The data link layer is responsible for establishing a reliable and secure logical link over the unreliable wireless link. The data link layer is thus responsible for wireless link error control, security (encryption/ decryption),mapping network layer packets into frames, and packet retransmission.
  - A sublayer of the data link layer, the media access control (MAC) protocol layer is responsible for allocating the time-frequency or code space among mobiles sharing wireless channels in a region.



## Protocol layers -background

- Network
  - The network layer is responsible for routing packets, establishing the network service type (connectionless versus connection-oriented), and transferring packets between the transport and link layers. In a mobile environment this layer has the added responsibility of rerouting packets and mobility management.
- Transport
  - The transport layer is responsible for providing efficient and reliable data transport between network end-points independent of the physical network(s) in use**.**
- OS/Middleware
  - The operating system and middleware layer handles disconnection, adaptivity support, and power and quality of service (QoS) management within wireless devices. This is in addition to the conventional tasks such as process scheduling and file system management.



## Protocol layers -background

- Application
  - The application and services layer deals with :
    - partitioning of tasks between fixed and mobile hosts,
    - audio/video source coding/encoding,
    - digital signal processing,
    - context adaptation in a mobile environment.
  - Services provided at this layer are varied and application specific.



## Physical layer -background

- In the past, Research addresses two different perspectives of the energy problem:
  - (i) an increase in battery capacity, and
  - (ii) a decrease in the amount of energy consumed at the wireless terminal.
- Low-power design at the hardware layer uses different techniques including variable clock speed CPUs [22], flash memory [41], and disk spindown [17].
- One way to achieve this for future wireless networks is to design the higher layers of the protocol stack with energy efficiency as an important goal**.**

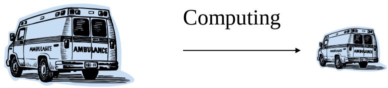
## Sources of power consumption

- The sources of power consumption, with regard to network operations, can be classified into two types:
  - communication related ,and
  - computation related.
- Communication involves usage of the transceiver at the source, intermediate (in the case of ad hoc networks), and destination nodes.
  - A typical mobile radio may exist in three modes: transmit, receive, and standby.
  - Proxim RangeLAN2 2.4 GHz 1.6 Mbps PCMCIA card requires 1.5 W in transmit, 0.75 W in receive, and 0.01 W in standby mode.
  - Lucent's 15dBm 2.4 GHz 2 Mbps Wavelan PCMCIA card is 1.82 W in transmit mode, 1.80 W in receive mode, and 0.18 W in standby mode.



## Sources of power consumption(cont.)

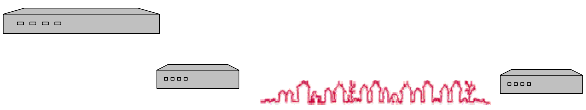
- The computation considered in this paper is chiefly concerned with protocol processing aspects. It mainly involves usage of the CPU and main memory and, to a very small extent, the disk or other components. Also, data compression techniques, which reduce packet length (and hence energy usage), may result in increased power consumption due to increased computation.
- There exists a potential tradeoff between computation and communication costs.






## General conservation guidelines and mechanisms

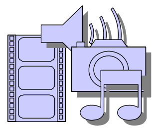
- Collisions should be eliminated as much as possible within the MAC layer since they result in retransmissions.
  - Retransmissions cannot be completely avoided in a wireless network due to the high error-rates.
  - it may not be possible to fully eliminate collisions in a wireless mobile network**.**
  - using a small packet size for registration and bandwidth request may reduce energy consumption. e.g., EC-MAC protocol [53]





## General conservation guidelines and mechanisms

- In a typical broadcast environment, the receiver remains on at all times which results in significant power consumption.
  - This is the default mechanism used in the IEEE 802.11wireless protocol in which the receiver is expected to keep track of channel status through constant monitoring.
  - One solution is to broadcast a schedule that contains data transmission starting times for each mobile as in [53]. This enables the mobiles to switch to standby mode until the receive start time.
  - Another solution is to turn off the transceiver whenever the node determines that it will not be receiving data for a period of time. e.g.,PAMAS protocol[51]





## General conservation guidelines and mechanisms

- Furthermore, significant time and power is spent by the mobile radio in switching from transmit to receive modes, and vice versa.
  - A protocol that allocates permission on a slot-by-slot basis suffers substantial overhead.
  - this turnaround is a crucial factor in the performance of a protocol**.**
  - If possible, the mobile should be allocated contiguous slots for transmission or reception to reduce turnaround, resulting in lower power consumption.
  - The scheduling algorithms studied in [13] consider contiguous allocation and aggregate packet requests.
  - Thus, computation of the transmission schedule ought to be relegated to the base station, which in turn broadcasts the schedule to each mobile.
  - The scheduling algorithm at the base station may consider the node's battery power level in addition to the connection priority.

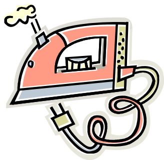



## General conservation guidelines and mechanisms

- At the link layer, transmissions may be avoided when channel conditions are poor, as studied in [69]. Also, error control schemes that combine ARQ and FEC mechanisms may be used to conserve power.
- Energy efficient routing protocols may be achieved by establishing routes that ensure that all nodes equally deplete their battery power, as studied in [11,68]. This helps balance the amount of traffic carried by each node.
- Another method is to take advantage of the broadcast nature of the network for broadcast and multicast traffic as in [52,66].
- In [49], the topology of the network is controlled by varying the transmit power of the nodes, and the topology is generated to satisfy certain network properties.

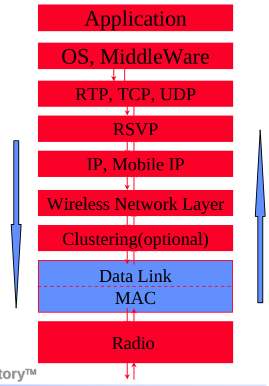
## General conservation guidelines and mechanisms

- At the OS level, the common factor to all the different techniques proposed is suspension of a specific sub-unit such as disk, memory, display, etc. based upon detection of prolonged inactivity.





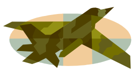
## Power Consumptions






## MAC sub-layer

- The MAC layer is a sublayer of the data link layer which is responsible for providing reliability to upper layers for the point-to-point connections established by the physical layer.
- The MAC sublayer interfaces with the physical layer and is represented by protocols that define how the shared wireless channels are to be allocated among a number of mobiles.
- Three specific MAC protocols:
  - IEEE 802.11 [23]
  - EC-MAC[53] (Energy Conserving-MAC protocol)
  - PAMAS [51] ( Power Aware Multi-Access protocol)





## IEEE 802.11 standard

- The IEEE 802.11 [23] standard recommends the following technique for power conservation.
  - A mobile that wishes to conserve power may switch to sleep mode and inform the base station of this decision.
  - The base station buffers packets received from the network that are destined for the sleeping mobile.
  - The base station periodically transmits a beacon that contains information about such buffered packets.
  - When the mobile wakes up, it listens for this beacon, and responds to the base station which then forwards the packets.
- Presented in [16] is a load-sharing method for saving energy in an IEEE 802.11 network. Simulation results indicate total power savings of 5–15%.



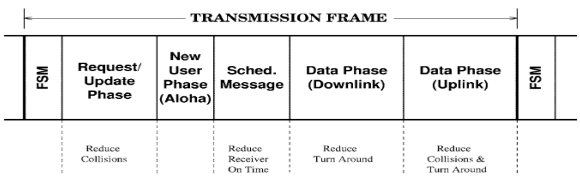
## IEEE 802.11 standard(cont.)

- The energy cost is studied in terms of fixed cost per packet which reflects MAC operation and incremental cost that depends on packet size.
- The results show that both point-to-point and broadcast traffic transmission incur the same incremental costs, but point-to-point transmission incurs higher fixed costs because of the MAC coordination (CTS and ACK)
- These experiments are a valuable source of information and represent an important step in expanding the knowledge of energy efficient protocol development.



## EC-MAC protocol

- The EC-MAC protocol [12,53] was developed with the issue of energy efficiency as a primary design goal.
- The EC-MAC protocol is defined for an infrastructure network with a single base station serving mobiles in its coverage area.
- Transmission in EC-MAC is organized by the base station into frames as shown in following, and each slot equals the basic unit of wireless data transmission.



## EC-MAC protocol (cont.)

- the base station transmits the FSM which contains synchronization information and the uplink transmission order for the subsequent reservation phase.
- During the request/update phase, each registered mobile transmits new connection requests and status of established queues according to the transmission order received in the FSM. In this phase, collisions are avoided by having the BS send the explicit order of reservation transmission.
- New mobiles that have entered the cell coverage area register with the base station during the new-user phase.
  - Here, collisions are not easily avoided and hence this may be operated using a variant of Aloha.
  - This phase also provides time for the BS to compute the data phase transmission schedule.



## EC-MAC protocol (cont.)

- The base station broadcasts a schedule message that contains the slot permissions for the subsequent data phase.
- Downlink transmission from the base station to the mobile is scheduled considering the QoS requirements.
- Likewise, the uplink slots are allocated using a suitable scheduling algorithm.

- Energy consumption is reduced in EC-MAC because of the use of a centralized scheduler.
  - Therefore, collisions over the wireless channel are avoided and this reduces the number of retransmissions.
  - Additionally, mobile receivers are not required to monitor the transmission channel as a result of communication schedules**.**



## EC-MAC protocol (cont.)

- The frames may be designed to be fixed or variable length.
- Fixed length frames are desirable from the energy efficiency perspective, since a mobile that goes to sleep mode will know when to wake up to receive the FSM.
- However,variable length frames are better for meeting the demands of bursty traffic.
- The EC-MAC studies used fixed length frames.



## PAMAS protocol

- the PAMAS (Power Aware Multi-Access) protocol [51] was designed for the ad hoc network, with energy efficiency as the primary design goal.
  - modifies the MACA protocol described in [29] by providing separate channels for RTS/CTS control packets and data packets.
  - a mobile with a packet to transmit sends a RTS message over the control channel, and awaits the CTS reply message from the receiving mobile.
  - The mobile enters a backoff state if no CTS arrives.
  - However, if a CTS is received, then the mobile transmits the packet over the data channel.
  - The receiving mobile transmits a “busy tone” over the control channel enabling users tuned to the control channel to determine that the data channel is busy.



## PAMAS protocol (cont.)

- Power conservation is achieved by requiring mobiles that are not able to receive and send packets to turn off the wireless interface.
  - The idea is that a data transmission between two mobiles need not be overheard by all the neighbors of the transmitter.
  - A mobile should power itself off when:
    - (i) it has no packets to transmit and a neighbor begins transmitting a packet not destined for it
    - (ii) it does have packets to transmit but at least one neighbor-pair is communicating.
  - Each mobile determines the length of time that it should be powered off through the use of a *probe* protocol, the details of which are available in [51].
  - The results from simulation and analysis show that between 10% and 70% power savings can be achieved for fully connected topologies.

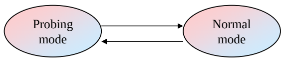


## LLC sub-layer

- The two most common techniques used for error control are ARQ and FEC.
- Both ARQ and FEC error control methods waste network bandwidth and consume power resources due to retransmission of data packets and greater overhead necessary in error correction.
- A balance needs to be maintained within this layer between competing measures for enhancing throughput, reliability, security, and energy efficiency.
- Recent research has addressed low-power error control and several energy efficient link layer protocols have been proposed.
  - Adaptive error control with ARQ
  - Adaptive error control with ARQ/FEC combination
  - Adaptive power control and coding scheme

## Adaptive error control with ARQ

- The following guidelines in developing a protocol should be considered in order to maximize the energy efficiency of the protocol.
  - Avoid persistence in retransmitting data.
  - Trade off number of retransmission attempts for probability of successful transmission.
  - Inhibit transmission when channel conditions are poor.
- The conclusion reached is that although throughput is not necessarily maximized, the energy efficiency of a protocol may be maximized by decreasing the number of transmission attempts and/or transmission power in the wireless environment.




$$\frac{\text{Energy}}{\text{Packet No}}$$



## Adaptive error control with ARQ/FEC combination

- The authors[32] describe an error control architecture for the wireless link in which each packet stream maintains its own time-adaptive customized error control scheme based on certain set up parameters and a channel model estimated at run-time.
- The idea behind this protocol is that there exists no energy efficient "one-size-fits-all" error control scheme for all traffic types and channel conditions.
- Therefore, error control schemes should be customized to traffic requirement sand channel conditions in order to obtain more optimal energy savings for each wireless connection.

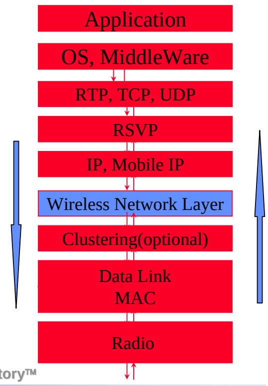


## Adaptive power control and coding scheme

- A dynamic power control and coding protocol for optimizing throughput, channel quality, and battery life is studied in [2,44].
  - This distributed algorithm, in which each mobile determines its own operating point with respect to power and error control parameters,
  - maintains the goal of minimizing power utilization and maximizing capacity in terms of the number of simultaneous connections.
  - Power control, as defined by the authors, is the technique of controlling the transmit power so as to affect receiver power, and ultimately the carrier-to-interference ratio (CIR).
- Simulation results indicate that the proposed dynamic power control and coding protocol supports better quality channels as compared to schemes that use fixed codes;
- therefore power-control alone does not perform as well as an adaptive power-control/FEC protocol.



## Power Consumptions






## Network layer

- The main functions of the network layer are routing packets and congestion control.
- we present energy efficient routing algorithms developed for wireless ad hoc networks.
- Typical routing algorithms for ad hoc networks consider two different approaches:
  - Use frequent topology updates resulting in improved routing, but increased update messages consume precious bandwidth.
  - Use infrequent topology updates resulting in decreased update messages, but inefficient routing and occasionally missed packets results.
- Typical metrics used to evaluate ad hoc routing protocols are shortest-hop, shortest-delay, and locality stability (Wooet al. [68]).



## Example Ad Hoc Topology

Frequent Update <-> Efficient Routing

Shortest Hop Routing <-> Energy

Multiple Hop <-> Delay

Coordinating Active Node <-> Reliability

## Network layer(cont.)

- Unicast traffic :
  - is defined as traffic in which packets are destined for a single receiver.
    - In [68], routing of unicast traffic is addressed with respect to battery power consumption.
    - The authors' research focuses on designing protocols to reduce energy consumption and to increase the life of each mobile, increasing network life as well.
    - To achieve this, five different metrics are defined from which to study the performance of power-aware routing protocols.
- Broadcast traffic:
  - is defined as traffic in which packets are destined for all mobiles in the system,is considered.



## Unicast traffic

- Five different metrics :
  - Energy consumed per packet.
    - If energy consumed per packet is minimized then the total energy consumed is also minimized.
  - Time to network partition.
    - Routes between the two partitions must go through one of the "critical" mobiles; therefore a routing algorithm should divide the work among these mobiles in such a way that the mobiles drain their power at equal rates.
  - Variance in power levels across mobiles.
    - all mobiles are equal and no one mobile is penalized or privileged over any other.



## Unicast traffic (cont.)

- Cost per packet.
  - Routes should be created such that mobiles with depleted energy reserves do not lie on many routes.
- Maximum mobile cost.
  - attempts to minimize the cost experienced by a mobile when routing a packet through it.

- In order to conserve energy, the goal is to minimize all the metrics except for the second which should be maximized.
- As a result, a shortest-hop routing protocol may no longer be applicable; rather, a shortest-cost routing protocol with respect to the five energy efficiency metrics would be pertinent.



## Unicast traffic (cont.)

- A new power-cost metric incorporating both a mobile's lifetime and distance based power metrics is proposed,
- using the newly defined metric, three power-aware localized routing algorithms are developed: power, cost, and power-cost.
  - The power algorithm attempts to minimize the total amount of power utilized when transmitting a packet,
  - The cost algorithm avoids mobiles that maintain low battery reserves in order to extend the network lifetime.
  - The power-cost routing algorithm is a combination of the two algorithms**.**



## Broadcast traffic

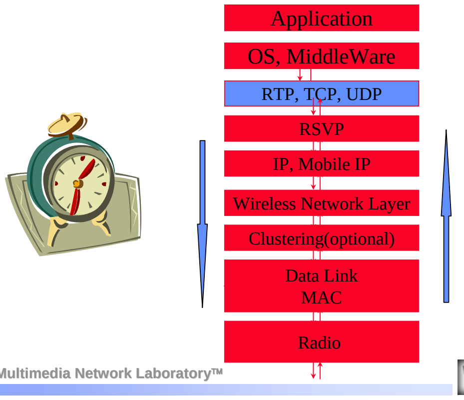
- **The key idea in conserving energy is to allow each mobile's radio to turn off after receiving a packet if its neighbors have already received a copy of the packet. [52]**
- **In order to increase mobile and network life, any broadcast algorithm used in the wireless environment should focus on conserving energy and sharing the cost of routing among all mobiles in the system.**
- **results indicate that savings in energy consumption of 20% or better are possible using the power aware broadcast algorithm, with greater savings in larger networks and networks with increased traffic loads.**



## Broadcast traffic(cont.)

- **In [18], a simulation based comparison of energy consumption for two ad hoc routing protocols –DSR and AODV:**
  - The analysis considers the cost for sending and receiving traffic, for dropped packets, and for routing overhead packets.
  - The observations indicate that energy spent on receiving and discarding packets can be significant.
  - For DSR, results show that the cost of source routing headers was not very high, but operating the receiver in promiscuous mode for caching and route response purposes resulted in high power consumption.
  - Results also indicate that since AODV generates broadcast traffic more often, the energy cost is high given that broadcast traffic consumes more energy.

# Power Consumptions





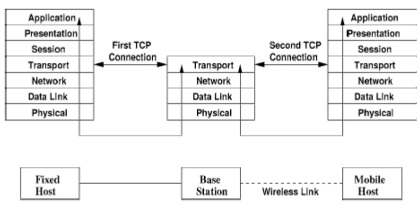

# Transport layer

- Recently, various schemes have been proposed to alleviate the effects of non congestion-related losses on TCP performance over networks with wireless links.
- These schemes, which attempt to reduce retransmissions, are classified into three basic groups:
  - (i) split connection protocols,
  - (ii) link layer protocols,
  - (iii) end-to-end protocols.



# Transport layer(cont.)

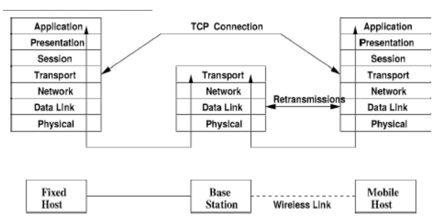
- split connection protocols:
  - completely hide the wireless link from the wired network by terminating the TCP connections at the base station






# Transport layer(cont.)

- link layer protocols:
  - which attempts to hide link related losses from the TCP source by using a combination of local retransmissions and forward error correction over the wireless link.






# Transport layer(cont.)

- end-to-end protocols:
  - include modified versions of TCP that are more sensitive to the wireless environment.
  - require that a TCP source handle losses through the use of such mechanisms as selective acknowledgements and explicit loss notification (ELN).
  - Selective Ack. allow the TCP source to recover from multiple packet losses,
  - ELN mechanisms aid the TCP source in distinguishing between congestion and other forms of loss.



# Transport layer(cont.)

- Energy consumption analysis of TCP
  - the performance of a particular protocol is largely dependent upon various factors such as mobility handling, amount of overhead costs incurred, frequency and handling of disconnections , etc.
  - Therefore, performance and energy conservation may range widely for these protocols depending upon both internal algorithm and external environmental factors.
- **Simulation [60] results show that no single TCP version is most appropriate within wired/wireless heterogenous networks, and that the key to balancing energy and throughput performance is through the error control mechanism.**
  - Using these results, the authors propose a modified version of TCP, referred to as TCP Probing.

## Transport layer(cont.)

- In TCP-Probing, data transmission is suspended and a probe cycle is initiated when a data segment is delayed or lost, rather than immediately invoking congestion control.
- A probe cycle consists of an exchange of probe segments between sender and receiver.
- Probe segments are implemented as extensions to the TCP header and carry no payload.
- The TCP sender monitors the network through the probe cycle which terminates when two consecutive round-trip-times (RTT) are successfully measured.
- The sender invokes standard TCP congestion control if persistent error conditions are detected.
- if monitored conditions indicate transient random error, then the sender resumes transmission according to available network bandwidth.

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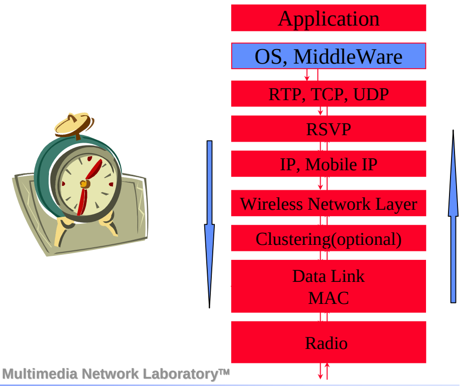
## Power Consumptions

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## OS/middleware

- The main function of an operating system is to manage access to physical resources like CPU, memory, and disk space from the applications running on the host.
- To reduce power dissipation, CPUs used in the design of portable devices can be operated at lower speeds by scaling down the supply voltage [10].
  - To maintain the same throughput, the reduction in circuit speed can be compensated by architectural techniques like pipelining and parallelism.
  - These techniques increase throughput resulting in an energy efficient system operating at a lower voltage but with the same throughput.
  - The operating system is active in relating scheduling and delay to speed changes.

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## OS/middleware(cont.)

- Another technique of power management at this layer is predictive shutdown [10].
  - This method exploits the event driven nature of computing in that sporadic computation activity is triggered by external events and separated by periods of inactivity.
  - A straightforward means of reducing average energy consumption is to shut down the system during periods of inactivity.
  - However, preserving the latency and throughput of applications requires intelligent activity-based predictive shutdown strategies.
- The study [31] considers DRAM chips that support different power modes: active, standby, nap and power down.
- Trace-driven and execution-driven simulations show that improvement of 6% to 55% in the Energy × Delay metric

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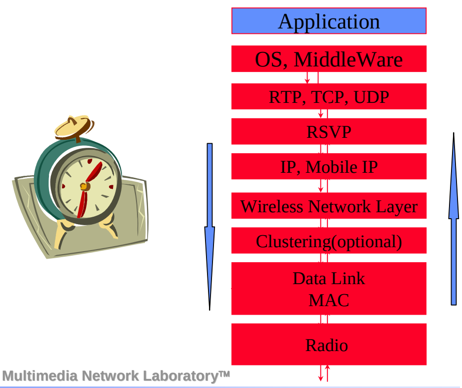
## Power Consumptions

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## Application layer

- Energy efficiency at the application layer is becoming an important area of research as is indicated by industry.
  - APIs such as Advanced Configuration and Power Interface [27] and power management analysis tools such as Power Monitor [26] are being developed to assist software developers in creating programs that are more power conserving.
  - Another power management tool developed at Carnegie Mellon University is PowerScope [20].
    - PowerScope maps energy consumption to program structure, producing a profile of energy usage by process and procedure.
    - The authors report a 46% reduction in energy consumption of an adaptive video playing application by taking advantage of the information provided by PowerScope.

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## Application layer(cont.)

- Load partitioning:
  - Challenged by power and bandwidth constraints, applications may be selectively partitioned between the mobile and base station [43,65].
  - Thus, most of the power intensive computations of an application are executed at the base station, and the mobile host plays the role of an intelligent terminal for displaying and acquiring multimedia data [43].



## Application layer(cont.)

- Proxies:
  - Proxies are middleware that automatically adapt the applications to changes in battery power and bandwidth.
  - A simple example of proxy usage during multimedia transmissions in a low-power or low bandwidth environment is to suppress video and permit only audio streams.
  - Another example is to direct a file to be printed at the nearest printer when the host is mobile.
  - Proxies are either on the mobile or base station side of the wireless link.



## Application layer(cont.)

- Databases:
  - Energy efficiency in database design by minimizing power consumed per transaction through embedded indexing has been addressed in [24].
    - By embedding the directory in the form of an index, the mobile only needs to become active when data of interest is being broadcast
    - When a mobile needs a piece of information an initial probe is made into the broadcast channel.
    - The goal of the authors is to provide methods to combine index information together with data on the single broadcast channel in order to minimize access time.



## Application layer(cont.)

- Video processing:
  - Multimedia processing and transmission require considerable battery power as well as network bandwidth.
  - This is especially true for video processing and transmission.
  - However, reducing the effective bit rate of video transmissions allows lightweight video encoding and decoding techniques to be utilized thereby reducing power consumption.
  - Several studies have shown that transmission accounts for more than a third of the energy consumption in video processing and exchange in a portable device.
    - The reduction in the number of bits can be achieved in one of two ways:
      - reducing the number of bits in the compressed video stream generated by the video encoder, and
      - discarding selected packets at the wireless network interface card (WNIC).