Cross-Layer Design for Unmanned Ground Vehicles (UGV's)

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Outline

- Layered architecture: a brief overview.
- Motivation behind cross-layer design.
- Unmanned Ground Vehicles (UGV's) as Mobile Ad hoc Networks (MANET).
- Quality of Service (QoS).
- Cross-layer integration.
- Cross-layer designs: some recent results.
- Drawbacks of cross-layer design.
- References.

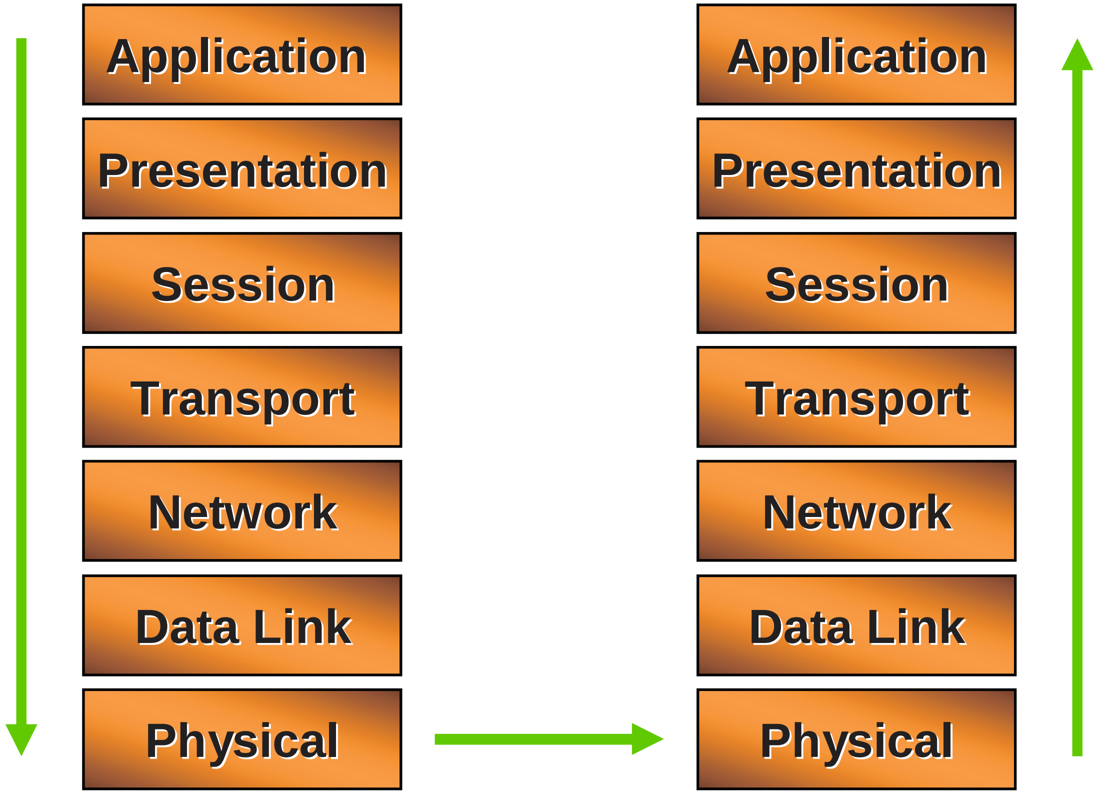
Network Layers

- The most common model for defining network layers is the Open System Interconnection (OSI) model.
  - Specified by the International Organization for Standardization (ISO).
  - Divides a communications system into seven layers.
  - Each consecutive layer creates a higher level of abstraction, which makes the design and analysis feasible.

The OSI Model

- The seven layers from bottom to top are
  - Physical Layer
  - Data Link Layer
  - Network Layer
  - Transport Layer
  - Session Layer
  - Presentation Layer
  - Application Layer

The OSI Model



Physical Layer

- Is primarily concerned with transmitting data bits (0's and 1's over a communication medium.
- Defines the rule by which data is transmitted.

Physical Layer (continued)

- Describes physical characteristics of the communication medium including
  - Signal attenuation.
  - Multipath fading.
  - Reflection and diffraction.
  - Shadowing.
  - Noise and interference.
  - Doppler spread, delay spread, angle spread.

Physical Layer (continued)

- Uses signal processing to
  - Enhance the performance of the created communication channel.
  - Adapt to changing properties of the physical medium.

Transceiver

- Converts bits into waveforms
  - Signal shaping.
  - Modulation.
- Converts waveforms into bits
  - Signal filtering.
  - Sampling and A/D conversion.
  - Channel estimation.
  - Data reconstruction.

Performance Enhancement

- Combats multipath fading.
- Makes use of structure in the physical medium to
  - Suppress interference.
  - Lower transmit power.
  - Increase data rate.

Data Link Layer

- Manages the basic transmission circuit established in Physical Layer and transforms it into a circuit that is free of transmission errors.
- Solves the problems caused by damaged, lost, or duplicated message frames so the succeeding layers are shielded from transmission errors.
  - Performs error detection, correction and retransmission.
- Defines
  - The beginning and end of each message.
  - Resolution of competing requests for the same communication link.
  - Flow control.

Data Link Layer (continued)

- The Data Link Layer is sometimes divided into two sub-layers
  - Media Access Control (MAC) layer
    - Error checking.
    - Block synchronization.
    - Govern access to the transmission medium.
  - Logical Link Control (LLC) layer
    - For interface with higher layers and perform flow and error control.

Error Protection

- Going towards Network Layer
  - Converts raw bit streams from Physical Layer into sequences of code-words which allow correction of transmission errors.
  - Groups code-words into packets suitable for Network Layer.
- Coming from Network Layer
  - Converts packet from Network Layer into sequence of code-words.
  - Produces raw bit stream suitable for Physical Layer.

Network Layer

- Performs addressing and routing.
  - These operations are common performed in conjunction with Physical Layer and Data Link Layer.
- Accepts message from Transport Layer and ensures that the packets are directed to the proper destinations.

Network Layer (continued)

- Address interpretation
  - Translates logical to physical network address.
- Routing
  - Selects optimum path.
  - Manages network congestion.
- Multiplexing
  - Breaks up packets into smaller sub-packets and sends over different paths for higher throughput.
  - Reassembles sub-packets to send over different paths.
  - Collects more packets before sending.

Transport Layer

- Also known as Host-to-Host Layer or End-to-End Layer
  - It establishes, maintains, and terminates the logical connection for the transfer of data between the end-users.
- Provides the higher layers with network-independent interface.
- Provides given quality of service regardless of network used.
- Controls flow.

Transport Layer (continued)

- Packeting
  - Divides data streams into packets.
  - Reassembles message from packets.
- Error handling.
  - Error-checking of received packets (checksum).
  - Acknowledgement of successful transmissions.
  - Automatic request of retransmission for bad packets (ARQ).
  - Error-free data delivery without losses or duplications.

Session Layer

- Responsible for initiating, maintaining, and terminating each logical session between end users.
- Responsible for managing and structuring all sessions.
- Session initiation must arrange for all the desired and required services between session participants, such as
  - Logging onto the circuit equipment.
  - Acknowledgement of successful transmissions.
  - Transferring files.
  - Using various terminal types.
  - Performing security checks.

Notes

- Some redundancy between the Session Layer and Transport Layer exists.
  - Allows to assist in the recovery from broken transport to Session connections.

Presentation Layer

- Formats the data for presentation to the user.
- Accommodates different terminals by displaying, formatting, and editing user inputs and outputs.
  - All different formats from all sources are made into a common uniform format that the rest of the OSI model can understand.
- Responsible for data compression, translation between different data formats, screen formatting, protocol conversion, character conversion and encryption.

Application Layer

- It is the end user’s access to network.
- Forms the interface to the user or a user process needing communication support.
- Deals with
  - Network management statistics.
  - Remote system initiation.
  - Termination.
  - Network monitoring.
  - Application diagnostics.

Applications Examples

- Telephony services
  - Voice.
  - Video.
- Messaging services
  - Voice mail.
  - Video mail.
  - E-mail.
  - Facsimile.
- Distributed services
  - Database
  - Tele-shopping.
  - Tele-action

Notes

- Each Layer in the OSI model has a companion layer at the receiving end.
- All layers must match in order for the network to function properly.

Advantages of OSI Model

- The implementation of services of one layer is independent of the implementation of services in any other layer.
- If a change is undertaken in one layer, it does not affect the others.
- OSI model facilitates communication among developers, manufacturers and users of a communication system.

Disadvantages of OSI Model

- The needs of a service provided by the communication system to its users are defined at the top-level.
  - The hierarchy and the overall performance of the system is however build upon the bottom-level.
  - The bottom level does not communicate directly, but through all higher layers with the top-level.
- Information is lost during this layer by layer top-down conversion of top-level service needs to low-level demands on the physical layer.

Disadvantages of OSI Model (continued)

- The techniques used to provide the services in the lower layers, like error control coding, are already fairly advanced and operate close the optimum.
  - Further improvement of those techniques is therefore difficult, and their effect on the performance of the whole system is relatively low.
- One way to overcome these drawbacks is the cross-layer design of networks.

An Example of a Cross-Layer Protocol

Soft-Length Symbols Protocol

Motivation

- Interference and fading inherent to the radio link limit the capacity of wireless systems
- **Goal:** To adapt the adverse radio environment efficiently and provide high speed services over wireless channels
- **Solution:** We propose a cross-layer protocol

  It operates within the data link control layer (DLC) and the physical layer

Wireless Channels

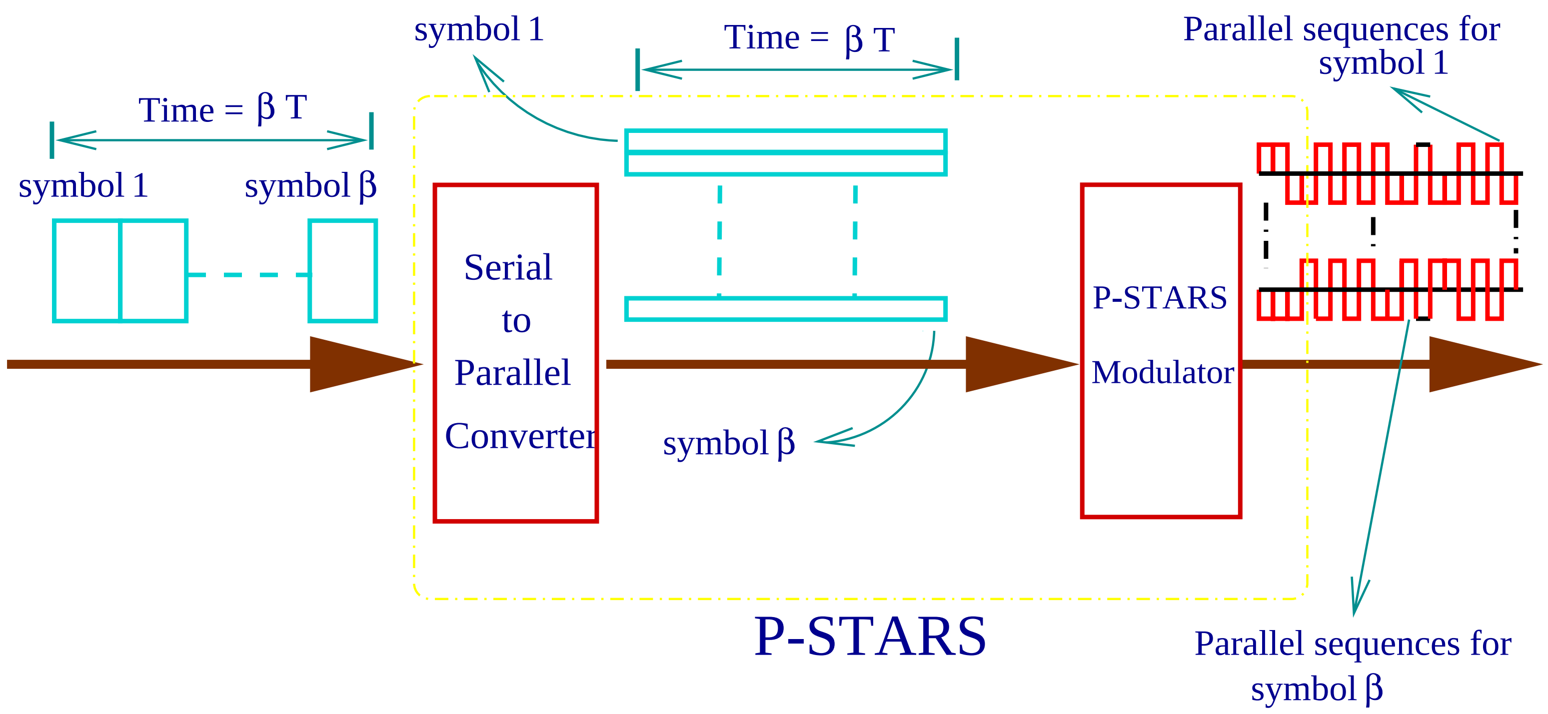
- **Problem:** Wireless channel is temporally and spatially volatile

Physical Layer

- To adapt the temporally volatile wireless channel, we transmit symbols of a user in parallel and refer to it as

  Parallel sequence transmission and reception system (P-STARS)
- P-STARS → a multicode CDMA system

System Model for P-STARS



Received Symbols in P-STARS

Comments on P-STARS

- In P-STARS, all symbols are extended over the frame
  - All symbols experience the same channel conditions in both time and frequency
  - It eliminates the need for an interleaver in the system
  - Unlike the conventional system, the receiver simultaneously receives information about all the symbols of the frame
    - We exploit this characteristics of P-STARS to design a cross-layer protocol

Comments on P-STARS (continued)

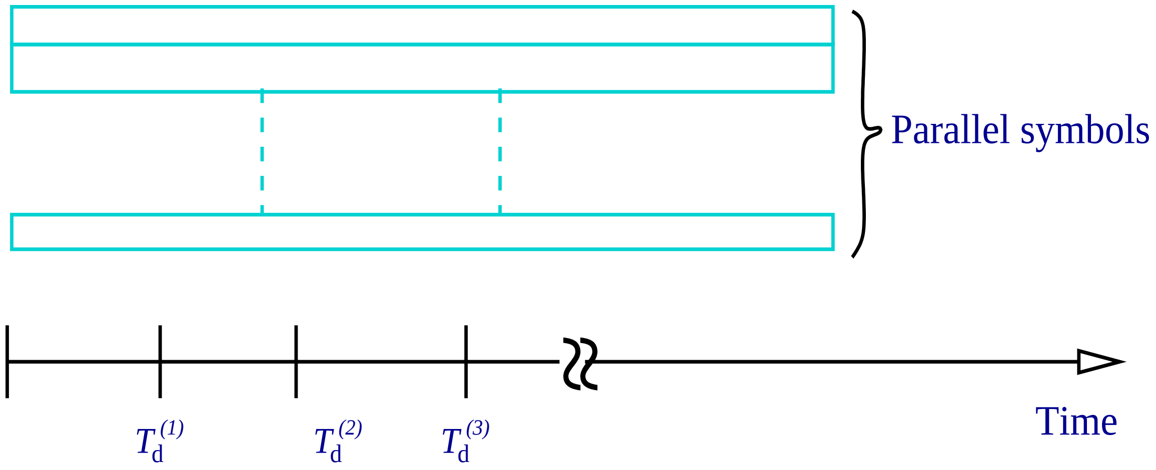
- The performance of P-STARS improves as the number of fades increases within the frame
- It is always desirable to have protocols that efficiently exploit the performance gain in the physical layer for improving the overall network performance

Comments on the Conventional System

- Information bits are first sent through a channel encoder (such as convolutional encoder) and then interleaved before transmitting them serially over the wireless channel
- At the receiving end, all the information bits are decoded together
  - Frame decision cannot be made until the whole frame is received

Soft-Length Symbols (SOLS) Protocol

- **Property of P-STARS:** The receiver can decode the symbols sequentially before receiving the entire frame due to parallel transmission



Example of SOLS Protocol

- *Step 1:* Set *n=1*
- *Step 2:* Observe the received signal over the interval $[0, T_d^{(n)}]$
- *Step 3:* Decode the information bits along with cyclic redundancy check (CRC) bits from the received signal
- *Step 4:* Check if there is an error by using CRC check

  Step 4a: If error is detected, then set *n=n+1* and Go To Step 2, otherwise, STOP

SOLS Protocol (continued)

- If the frame is detected error-free,

  the receiver sends an acknowledgement to the transmitter

  the transmitter may go into sleep mode till the next transmission time, or the transmitter may start transmitting the next available packet. This will

  - decrease the interference in the system, save the battery life and reduce the burden on power control, or
  - increase the throughput of the system

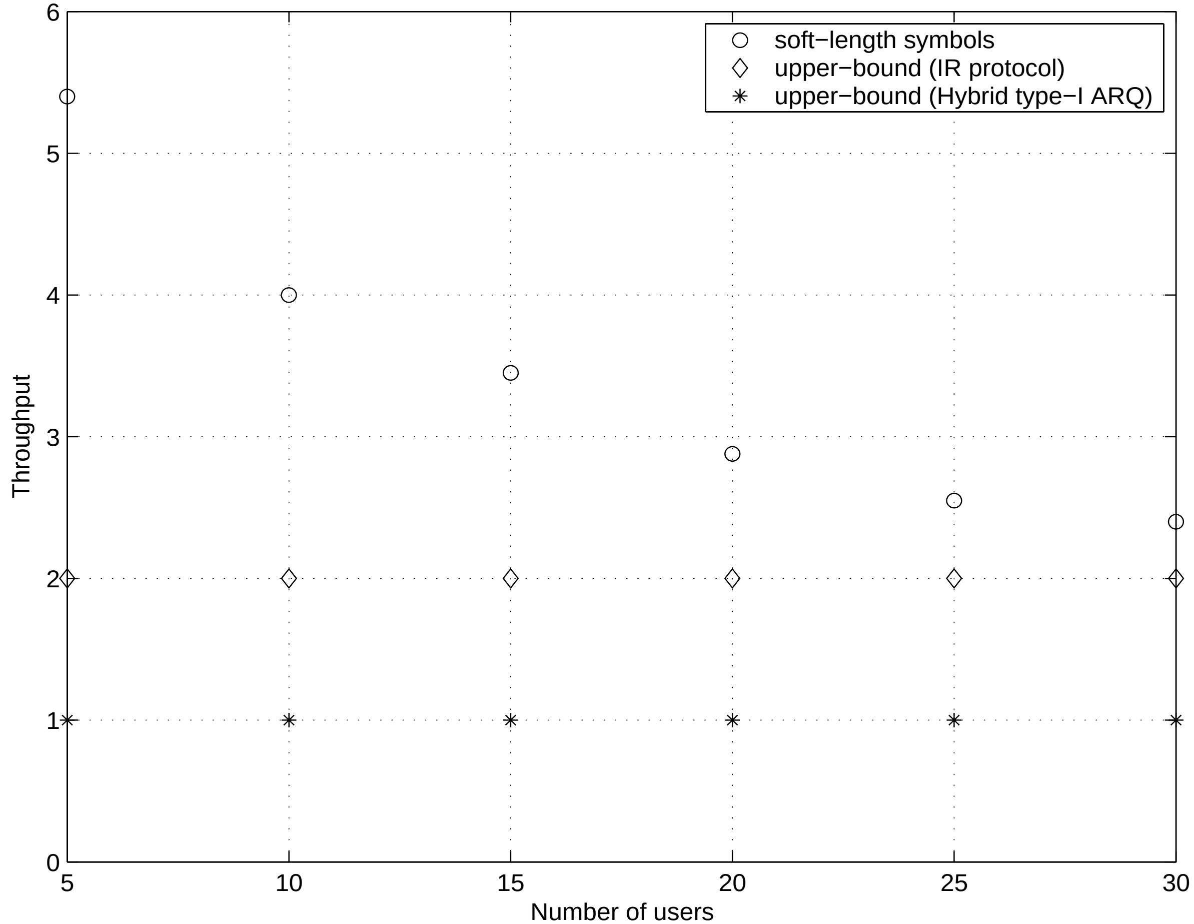
Comments on SOLS

- Symbol length will depend on the instantaneous channel and interference conditions
- The capacity of P-STARS will be optimized by minimizing the symbol duration

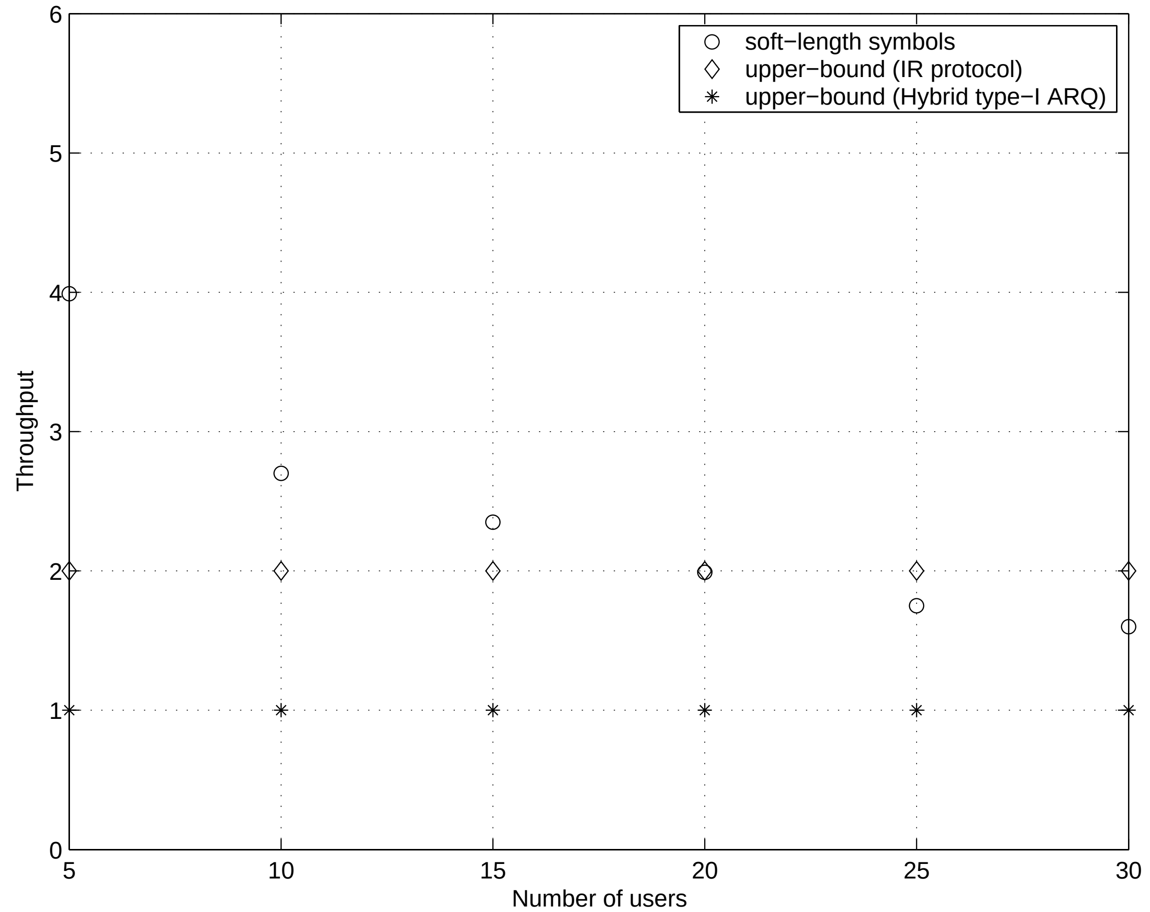
Numerical Results

- Single circular cell system with power control
- Bits are first CRC encoded and passed through a convolutional encoder of rate 1/2
- Processing gain = 64
- Rayleigh fading channels and number of paths = 1 – 3
- SNR = 10 dB
- Desired performance metric
    - Throughput – for variable rate (e.g. data) users
    - Frame Error Rate (FER) – for constant rate (e.g. voice) user
- Performance comparison
    - Upper bound of Increment Redundancy (IR) protocol
    - Upper bound of hybrid Type-I ARQ protocol

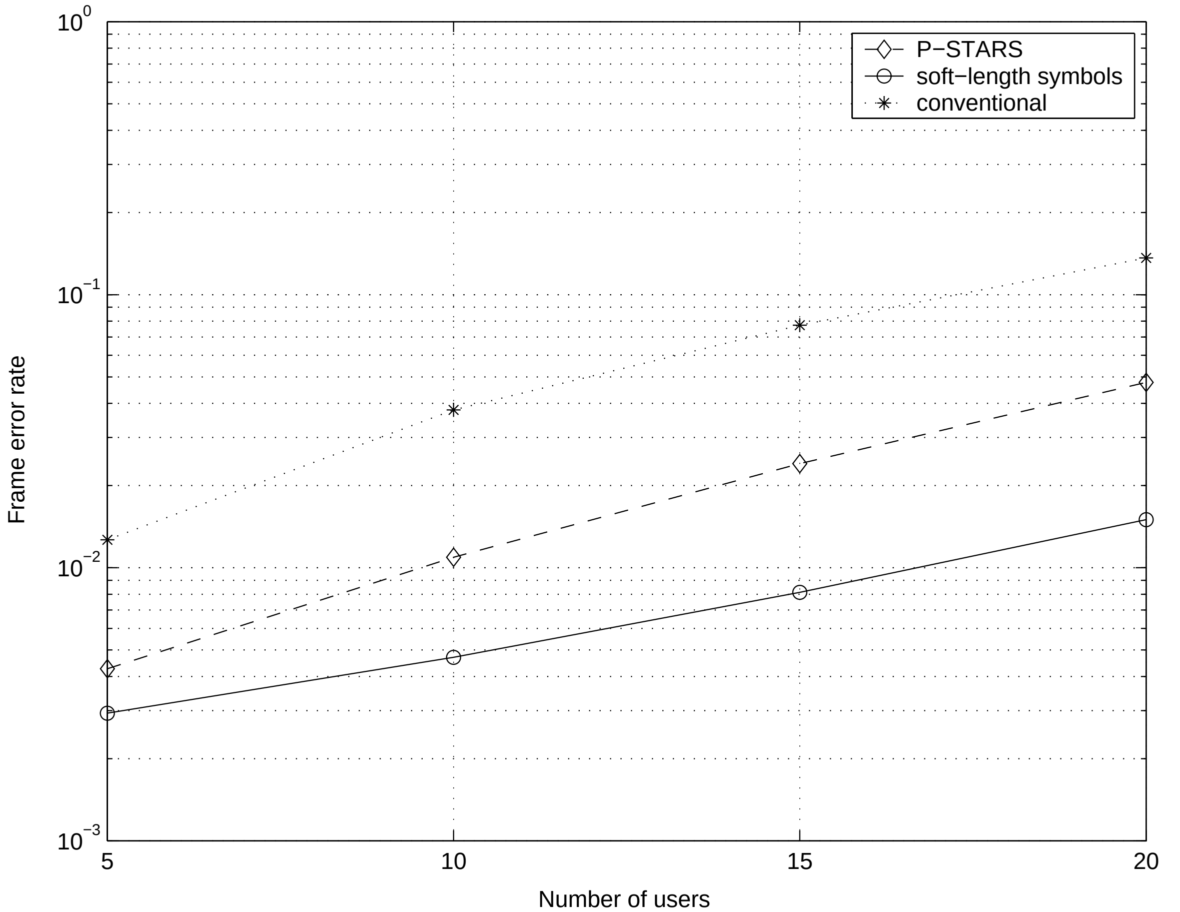
Variable Rate Users with Six Fades



Variable Rate Users with One Fade



Constant Rate Users with Six Fades



Conclusions

- P-STARS is a fade resistant wireless system that transmits symbols of a user simultaneously
- P-STARS allows us to decode all the symbols in a frame even before receiving the entire frame → SOLS protocol
  - SOLS protocols optimizes the capacity of P-STARS by minimizing the symbol duration
  - SOLS protocol is capable of outperforming the conventional ARQ protocols for variable rate users
  - SOLS can be used with the users who do not utilize ARQ protocol in the conventional system, such as voice users

What is Cross-Layer

- A layer is allowed to communicate with more than just its direct neighbors.
- A layer still provides services to the next higher layer
  - The implementation of these services is done with the needs of even higher layers in mind.
- Cross-layer design approach has the advantage of bringing new degrees of freedom to the optimization process in different layers.
  - Additional degrees of freedom can be used to increase the performance of the whole communication system.

Why Cross Layer

- Design incompatibilities exist between the internet and wireless communications systems.
  - Internet is constructed on the basis of wired communication networks having high reliability and high communication capacity.
  - A cellular system has an unreliable link due to
    - Various kinds of interference and noise.
    - Multipath fading.
    - Low communication capacity because of limited resource of frequency spectrum.
- A new architecture is needed to support wireless internet access scenario.

Why Cross Layer (continued)

- The seven-layer ISO-OSI hierarchy protocol stack is the basis of design and implementation of the Internet.
  - Protocols are designed independently for different layers.
    - Simplifies the implementation of protocols within the same layer.
- Applying this hierarchy protocol stack to the wireless Internet scenario without any modification is not fully appropriate due to two major characteristics of wireless communications
  - Mobility.
  - Wireless access.

Solving Mobility and Wireless Access Problem

- Mobility problem is solved by the mobile Internet Protocol (IP) proposed to modify the IP.
- To solve the wireless access problem following protocols are considered for lower layers of the protocol stack.
  - Radio link protocol (RLP).
  - Wireless medium access control (MAC) protocol.
  - Wireless physical equipment.

Why Cross Layer

- The above efforts cannot thoroughly solve the incompatibility between the Internet and wireless systems.
- **Example**
  - Optimization of Transmission Control Protocol (TCP) and RLP independently in the corresponding layers may not lead to the optimization of the overall system.
  - For designing a wireless MAC protocol, it is more efficient if the traffic characteristics are known in MAC layer.
  - Implementation of power control due to different QoS requirements, knowledge of traffic types are required even in the Physical Layer.

TCP

- TCP is a connection oriented data transport protocol used by many end user applications.
- TCP has been designed under the assumption
  - All losses are caused almost exclusively by network congestion.
- The packet loss is implicitly identified at the TCP either
  - By the absence of acknowledgement (ACK) within a round-trip timeout (RTO) interval or
  - By the arrival of several duplicate cumulative ACKs.

TCP

- Upon loss detection, TCP initiates the congestion avoidance mechanisms that include
  - Rate reduction.
  - Multiplicative increase of the retransmission timeout.

Why Cross Layer

- Network congestion assumption of TCP does not hold for mobile networks.
- The packet loss in wireless systems are often caused by link losses due to
  - Severe fading conditions or
  - Intermittent connectivity due to handoffs.
- Error control methods are implemented in the lower-level wireless network protocols
  - FEC coding is implemented in Physical Layer.
  - A NAK-based (negative ACK) ARQ scheme is used in RLP.

Why Cross Layer

- If TCP and RLP operate independently, their interaction causes performance degradation because
  - Slow frame loss recovery of RLP leads to increased timeout of TCP.
  - Successive TCP packet losses lead to TCP retransmission timer back-offs and large RTO values.
  - When TCP packets are transmitted at widely varying intervals (e.g. telnet sessions), the RLP retransmission timer advances even slower, and the RLP cannot invoke frame loss recovery quickly enough.
- **Solution:** Coordination between TCP and RLP.

Why Cross Layer

- Traffic on future wireless networks is expected to be a mix of
  - Real-time traffic such as voice, multimedia teleconferencing and games.
  - Data-traffic such as WWW browsing, messaging and file transfers.
- All of these applications will require
  - Widely varying and very diverse quality of service (QoS) guarantees for different types of offered traffic.

Why Cross Layer

- Heterogeneous nature of network and traffic
  - Requires a coordinated adaptation from multiple layers.
  - The QoS adaptation even requires all layers' participation.
    - A single colocated layer for various adaptation tasks would be too complex and heavy.
- **Solution:** A cooperation of multiple layers' adaptation leads to a simpler and more flexible approach.

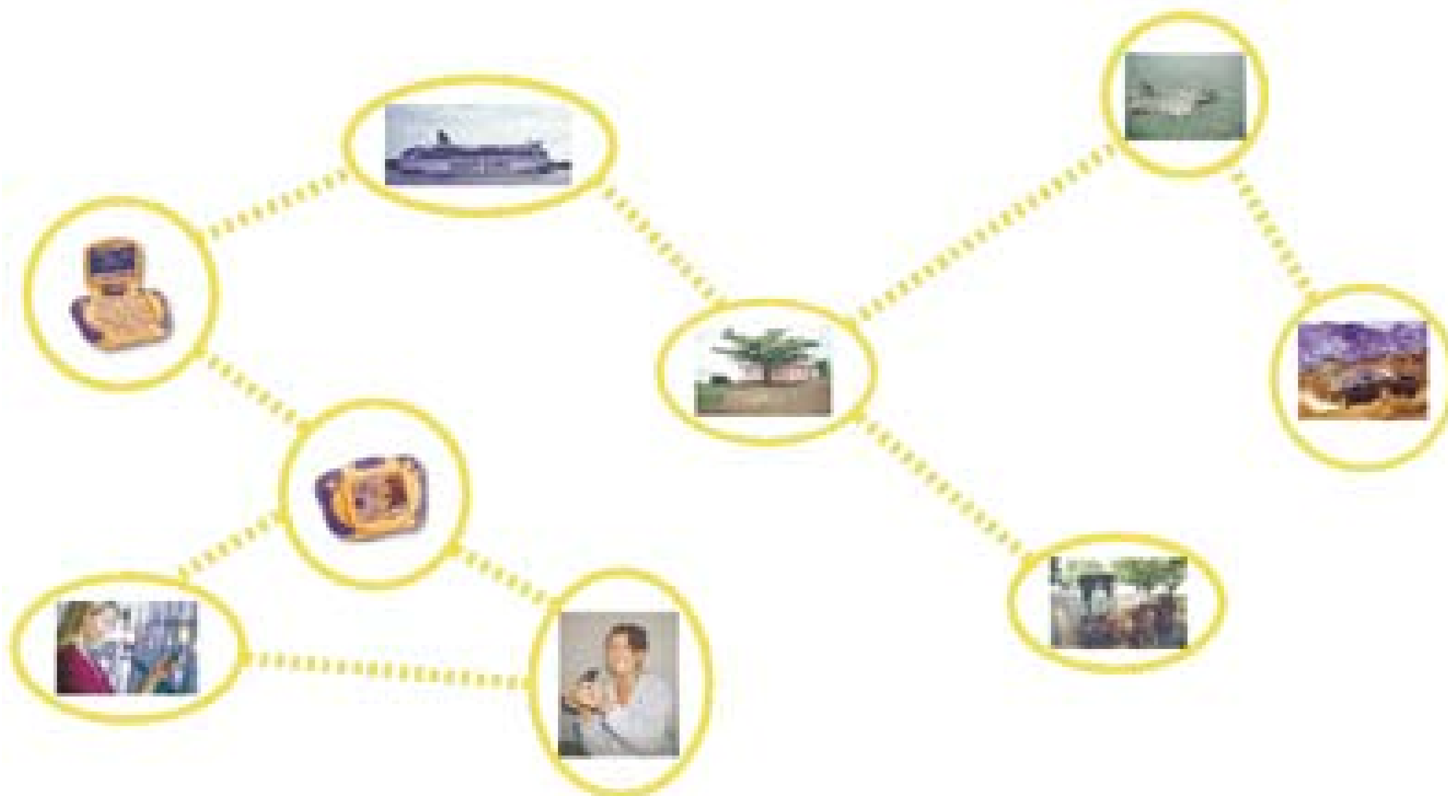
Why Cross Layer

- Scarce radio resource and limited power necessitate the optimization of network performance.
  - Strict layering structure is sub-optimal and thus the required optimization is hardly achievable.
  - **Example:** Error correction schemes are provided in both Data Link Layer and Transport Layer.
    - In wireless systems, these schemes have to be invoked much more frequently to combat the errors due to unreliable channels.
- **Solution:** A coordination of Data Link Layer and Transport Layer.

Why Cross Layer

- Integrated design approach of emerging short-range networks, such as Mobile Ad hoc Network (MANET) and Personal Area Network.
  - The end-to-end communication mostly takes place in several point-to-point level communications.
- In traditional network
  - Data Link Layer is for point-to-point communications, while Transport Layer is for end-to-end communications across various links.
- Cross-layer design helps avoid duplicate efforts from each related layer.

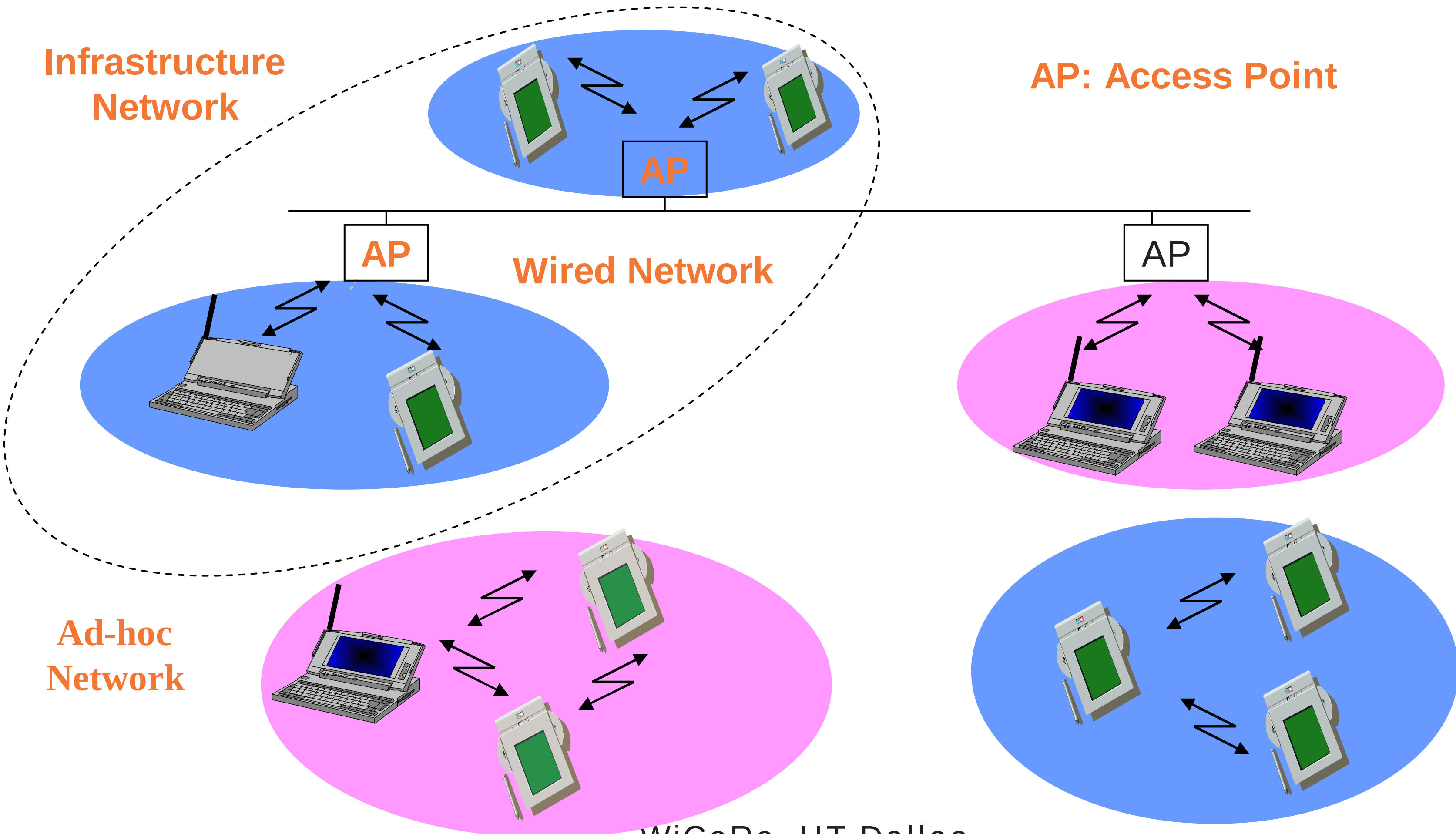
MANET



MANET

- MANET are networks with the following characteristics.
  - Rapidly deployable.
  - Non-reliance on pre-existing infrastructure.
  - Continuously changing set of nodes.
  - Self-adaptive to the connectivity and propagation pattern.
  - Adaptive to the traffic and mobility patterns.

Infrastructure Network *vs* Ad hoc Network



MANET

- MANET is different from infrastructure network in the following sense
  - No fixed infrastructure.
  - Multi-hop routing.
  - Peer-to-peer operation.
  - Each node acts as a router.
  - Usually temporary.
- Advantages
  - Can be rapidly deployed and reconfigured.
  - Highly robust due to their distributed nature.

Unmanned Ground Vehicles (UGV's)

- Perform scout/reconnaissance missions prior to main body movement.
- Breach and/or clear hazardous areas.
- Facilitate communication of main body by serving as relay stations.

UGV as MANET

- Several UGV's and/or manned vehicles can collaborate to form MANET.
- Occupy key terrain with optimal transmission characteristics.
- Move to successive locations as main body movement progresses.
- Provide robust and reliable information connectivity to main body elements.

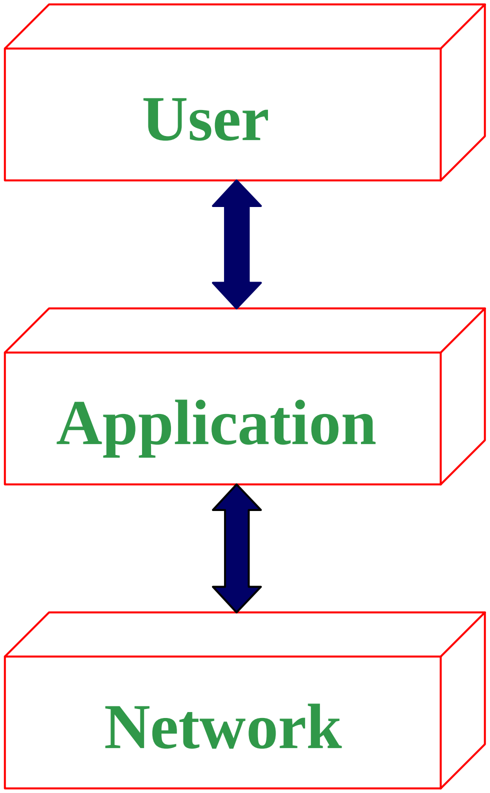
Undesirable Scenarios

- Communications channel might become saturated due to
  - Peak loading.
  - Time varying channel quality.
- Key decision makers might fail to get key information about
  - Position, number and type of equipment.
  - Intensity of contact.
- Commands of key decision makers might get delayed for several minutes.
  - Permission to fire, withdraw and maneuver.

Facts and Requirements

- It is critical to provide robust, reliable and on time information between maneuver elements with time varying channel capacity.
- Delayed and/or lost critical information has significant impact in terms of costly damage and casualties.
- **Requirements:** Quality of Service (QoS) support.

QoS: A Layered View



Application-layer QoS

- How well user expectations are qualitatively satisfied.
  - Clear voice.
  - Jitter-free video, etc.
- Depends on following parameters
  - Arrival pattern: depends on type of bit rate.
  - Sensitivity to delivery delays.
- Application level QoS implementation
  - End-to-end protocols (RTP/RTCP).
  - Application-specific representations and encodings (FEC, interleaving).

Arrival Pattern

Rate Type	Descriptions
Stream	Predictable delivery at a relatively constant bit rate (CBR) – e.g. audio.
Burst	Unpredictable delivery of data at a variable bit rate (VBR) – e.g. MPEG which move data in bulk.

Delay Tolerance

Delay Tolerance	Delivery Type	Description
High	Asynchronous	No constraints on delivery time. Example: E-mail.
	Synchronous	Data is time-sensitive, but flexible. Example: FTP
	Interactive	Quite sensitive to delay. Example: Remote logon, Web access.
Low	Mission-critical	Data delivery delay disable functionality Example: Military applications.

Network Layer QoS

- **Bandwidth** – the rate at which an application's traffic must be carried by the network.
- **Latency** – the delay that an application can tolerate in delivering a packet of data.
- **Jitter** – maximum variation in delay = maximum delay – minimum delay.
- **Loss** – the percentage of lost data.

QoS Constraints

- **Time constraints**
  - Delay, jitter.
- **Space constraints**
  - System buffer.
- **Frequency constraints**
  - Network/system bandwidth.
- **Reliability constraints**
  - Error rate.

Traffic Behavior and QoS Requirements

- **Applications:** simple mail transfer protocol (SMTP), file transfer protocol (FTP), remote terminal (Telnet)**.**
- **Traffic behavior:** small or batch file transfers.
- **QoS requirements:** very tolerant of delay, low bandwidth requirement.

Traffic Behavior and QoS Requirements

- **Applications:** HTML web browsing.
- **Traffic behavior:** series of small bursty transfer.
- **QoS requirements:** tolerant of moderate delay, various bandwidth requirements.

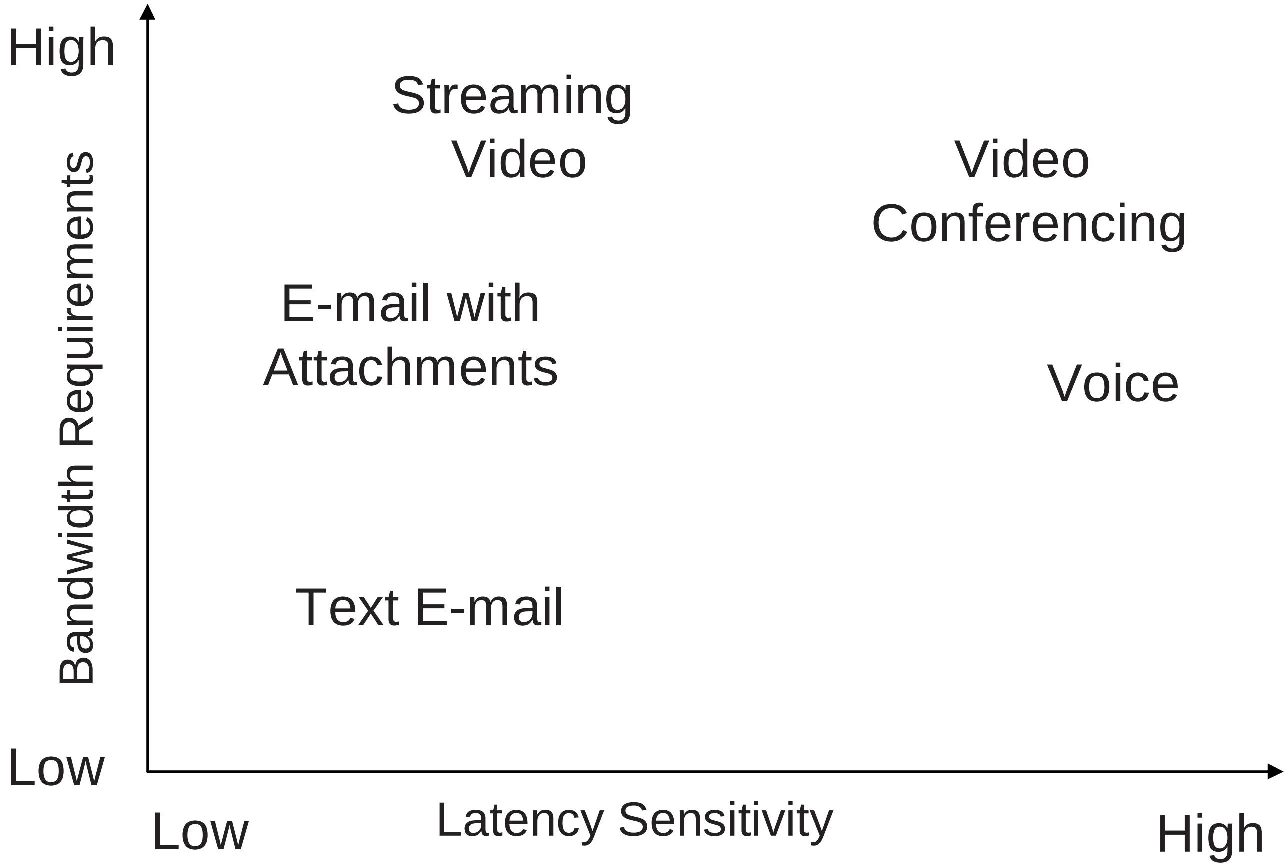
Traffic Behavior and QoS Requirements

- **Applications:** IP-based voice (VoIP), real audio.
- **Traffic behavior:** constant or variable bit rate.
- **QoS requirements:** very sensitive to delay/jitter, low bandwidth requirement.

Traffic Behavior and QoS Requirements

- **Applications:** video conferencing.
- **Traffic behavior:** variable bit rate.
- **QoS requirements:** very sensitive to delay/jitter, high or variable bandwidth requirement.

Different Applications and Network Requirements



QoS Provisioning

- Two basic types of QoS provisioning
  - Integrated services
  - Differentiated services

Integrated Services (IS)

- IS for a flow of packets is defined on two levels.
  - First, a number of general categories of service is provided.
  - Second, within each category, the service for a particular flow is specified by the values of certain parameters.
  - Together, these values are referred to as traffic specification (TSpec)
- Three categories of service are defined
  - Guaranteed.
  - Controlled load.
  - Best effort.

IS Process

- An application can request a reservation for a flow for a guaranteed or controlled load QoS.
- If the reservation is accepted, the TSpec is the part of the contract between data flow and service.
- As long as the flow's data traffic is described accurately by the TSpec, the requested QoS is provided.
- Packets, that are not part of a reserved flow are by default given a best-effort delivery service.

Guaranteed Service

- Provides assured data rate.
- There is a specified upper bound on total delay (queuing delay + propagation delay) through the network.
- There are no queuing losses: no packets are lost due to buffer overflow.

Controlled Load

- Does not provide assured data rate.
- No specified upper bound on queuing delay through network.
- A very high percentage of transmitted packets is successfully delivered (i.e. almost no queuing loss).

Differentiated Services

- Provides a simple and coarse method of classifying services of various applications and differentiates between them.
- Two types of service classification
  - Expedited forwarding.
  - Assured forwarding.

Expedited Forwarding

- Minimizes delay and jitter.
- Provides the highest level of aggregate quality of service.
- Any traffic that exceeds the traffic profile (defined by the local policy) is discarded.

Assured Forwarding

- Excess traffic is not delivered with as high probability as the traffic within profile.
  - It may be demoted but not necessarily dropped.

Characteristics of MANET

- Shared medium instead of point-to-point link
  - Interference from neighboring nodes.
- Low bandwidth capacity
  - 2 Mbps – 11 Mbps wireless node instead of gigabit router.
- Node mobility
  - Frequent (inevitable) QoS breaks which require recovery.

QoS Provision in MANET

- Prominent QoS requirements in MANET
  - **Route stability:** dynamic topology, interference.
- Hard to provide QoS without considering
  - Shared wireless medium.
  - Dynamic topology.
- **One possible solution:** cross-layer integration.

Cross-Layer Integration

- QoS aware routing
  - Ad hoc QoS On-demand Routing (AQOR) with feedback from MAC.
- QoS aware MAC
  - QoS traffic scheduling over unreliable medium.
  - Network status feedback.

Motivation

- MAC understands the environment better than the Network Layer.
  - Channel information.
  - Connectivity information.
- Current IEEE 802.11 Distributed Coordination Function (DCF) is designed for the best-effort traffic.
  - No differentiation between different priority flows.
  - QoS flows left unprotected in the shared medium.

Tasks of QoS Aware MAC

- Guarantees the service committed at Network Layer.
  - Assures the availability of reserved bandwidth over the shared medium.
  - Provides prioritized wireless medium access for different flows.
- Cooperates with routing protocol.
- Maximizes channel utilization, minimizes delay.

MAC Layer Choices

- Scheduled access.
  - CDMA/TDMA, IEEE 802.11 Point Coordination Function (PCF).
  - Collision-free.
  - Centralized.
- Random access.
  - IEEE 802.11 IEEE 802.11 Distributed Coordination Function (DCF).
  - Distributed.
  - Better mobility support.

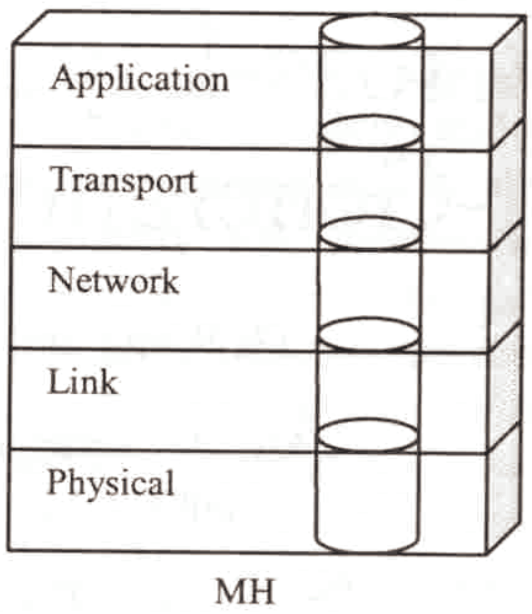
Interlayer Signaling Pipe (ISP)

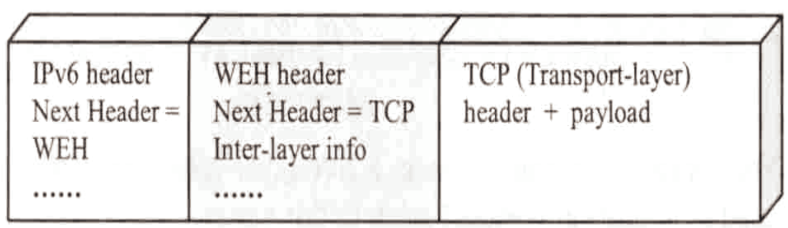
- A new protocol stack for wireless internet access scenario.
- Solves incompatibility between the Internet and wireless systems.
- Can be used to support a TCP-RLP coordination mechanism.

ISP Architecture

- ISP system architecture includes
  - Remote host (RH) as a server.
  - Wired Internet as backbone.
  - Internet access point (IAP) as a wireless router.
  - Radio access point (RAP) as a base station.
  - Mobile host (MH) as a client.
- The first (last) hop of the peer-to-peer connection in the transport layer between a MH and RH is over a wireless link between the MH and the RAP covering the MH.

Concept Model of ISP





Note: For presentation convenience a five-layer model is used

ISP

- The necessary cross-layer information is stored in Wireless Extension Header (WEH) of an IPv6 packet.
  - WEH is indexed by the next header field in the IP packet header.
- Only those routers supporting wireless access and the corresponding RH and MH communicating with each other can read out the content of WEH.
  - Other routers ignore it during the transmission.

ISP (continued)

- The IAP reads the WEH and gets the information (from either the MH or the RH) for
  - Routing
  - Radio link protocol
  - Medium access control
  - Physical layer transmission control.

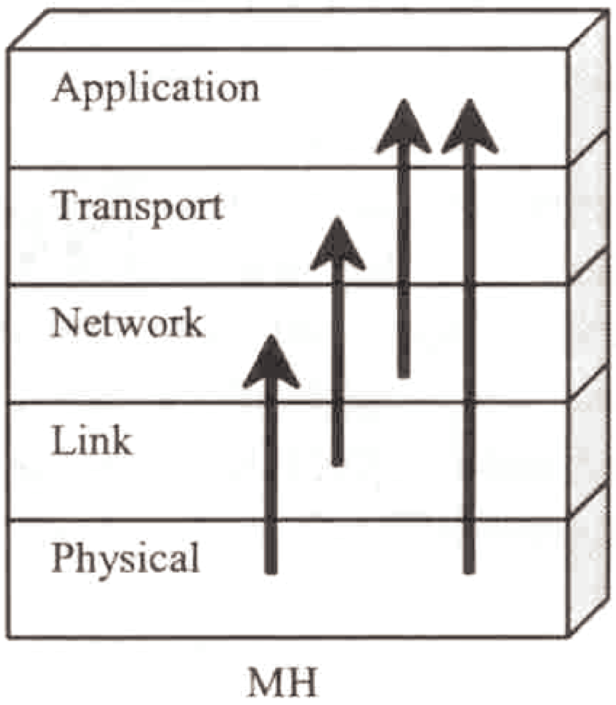
Drawbacks of ISP

- An IP packet normally can only be processed layer by layer.
    - **Low flexibility:** It is not easy for higher layers to access to the IP-level header.
- **High propagation latency:** The conceptual bottom-to-top "pipe" seems excessive in most cases.

Selected Holes (SH)

- Uses the widely deployed signaling protocol named Internet Control Message Protocol (ICMP).
- Punches selected holes in the protocol stack and propagates information across layers by using ICMP messages.
- In this scheme, desired information is
  - abstracted to parameters.
  - measured by corresponding layers whenever convenient.
- A new ICPM message is generated only when a parameter is changed beyond the thresholds.

Concept Model of SH



Note: For presentation convenience a five-layer model is used

Advantages of Using ICMP Messages

- ICMP messages are generic, efficient and they already exist.
- As opposed to exposing everything about the device layer to the higher layers, it provides a controlled way of exposing selective information.

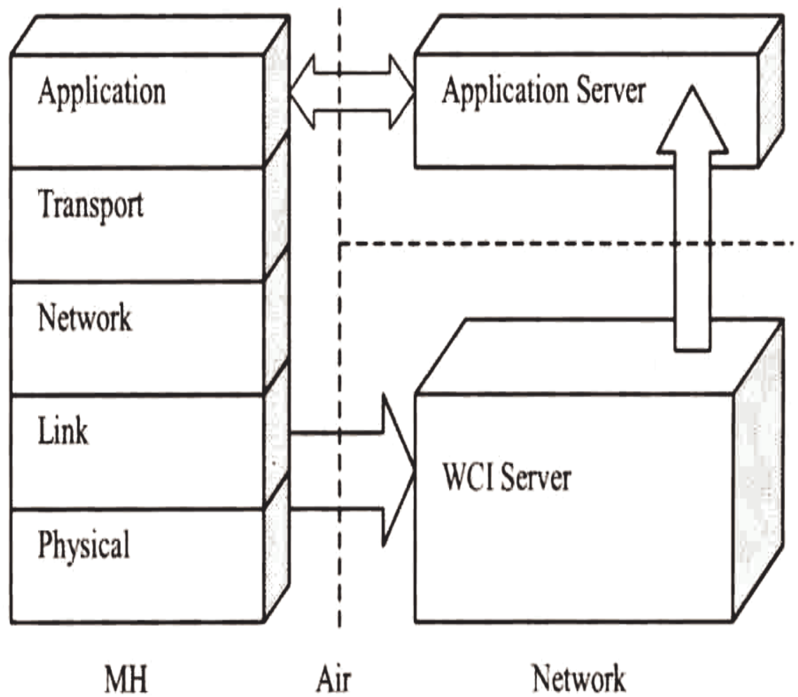
Pros and Cons of Selected Holes

- Since the cross-layer communications are carried out through selected “holes” not a general “pipe”, this method is more flexible and efficient.
- This method is more matured since it has been implemented on Linux operating system with Application Program Interfaces (API) developed.
- **Drawback:** An ICMP message is always encapsulated in an IP packet
    - Indicates the message has to pass by Network Layer even if the signaling is only desired between Link Layer and Application Layer.

Network Service (NS)

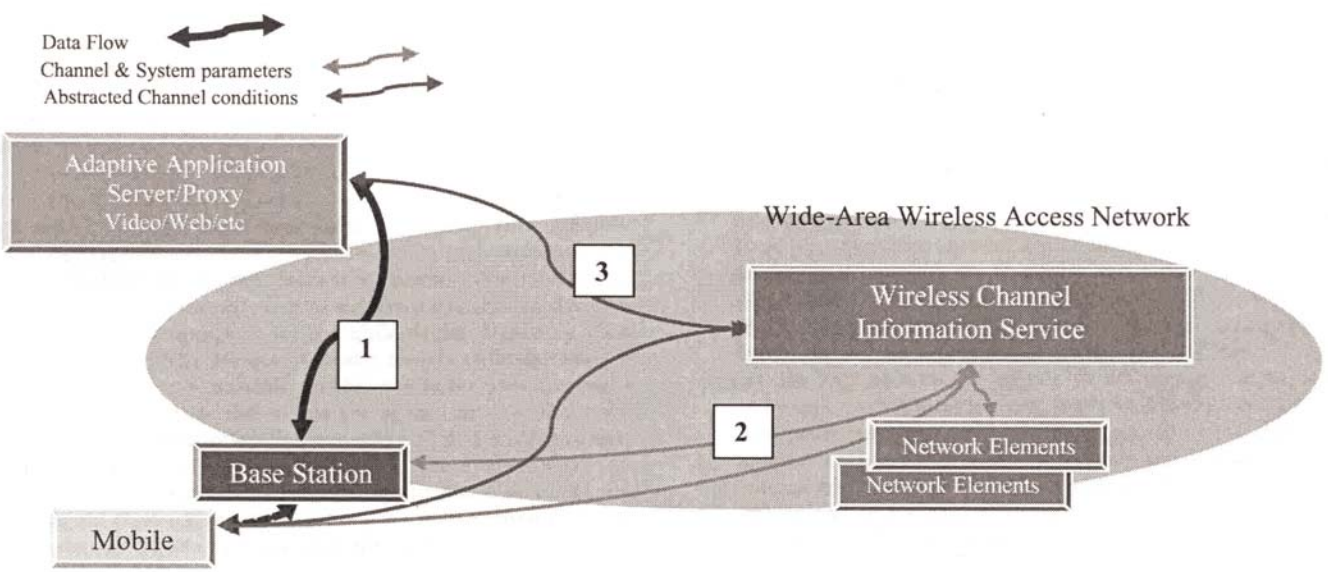
- A specific access network service called Wireless Channel Information (WCI) is introduced.
- **Motivation:** To overcome the lack of efficient access to wireless channel conditions.
- Put much of this burden on WCI service so that
  - Applications and operating systems (OS) do not have to access and process physical and link layer parameters that are often specific to wireless interface technologies.

Concept Model of NS



Note: For presentation convenience a five-layer model is used

WCI Service Process



WCI Server

- Collects raw physical and link layer parameters related to wireless channel conditions
- Processes the raw data to produce clearly defined meaningful parameters such as
  - Available bandwidth without error
  - IP packet error rate at a given packet size
  - Latency
  - Link condition
  - Hand-off, etc.
- Provides them to adaptive mobile applications to aid them in their adaptation decision making.

Advantages of Using NS

- Rich information is already available on wireless channel conditions for both the uplink and downlink inside wide-area wireless access networks.
  - Channel conditions can be accurately and efficiently estimated.
- No radio resource is wasted for communicating channel conditions at application layer.

Advantages of Using NS

- A WCI service can be implemented once by wireless network operators that support a large number of mobile clients.
  - Enables the immediate use of adaptive applications for many mobile applications without modifications on client-side applications or OS.
- By providing a standard way to access WCI services
  - Adaptive applications and/or OS support for them do not need to be custom-written specifically for different wireless network technologies.

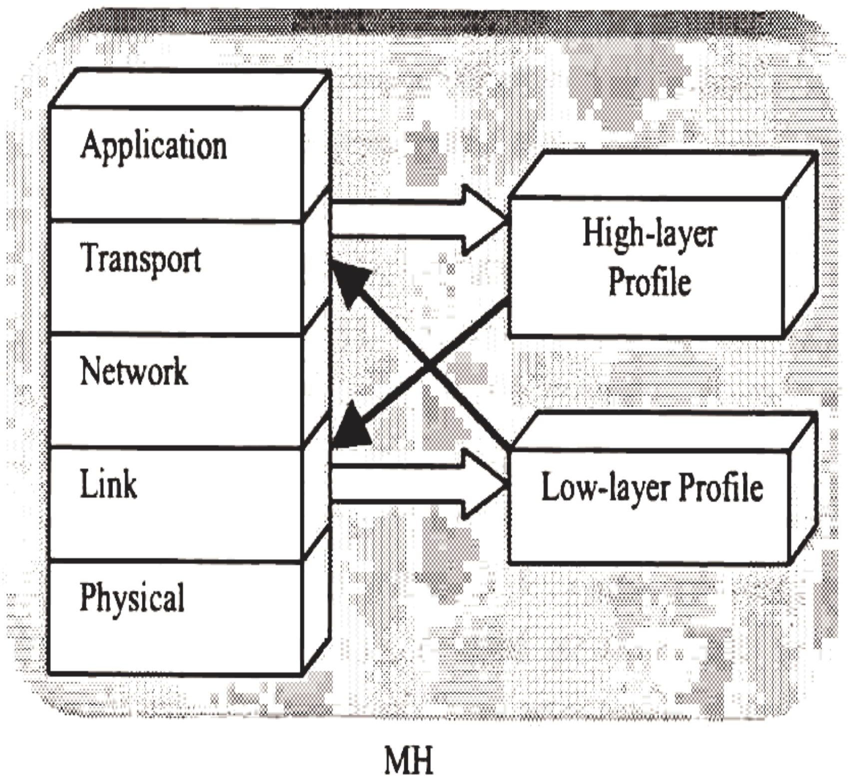
Drawback of NS

- Any intensive use of this method would introduce considerable signaling overhead and delay over a radio access network.

Local Profiles (LP)

- Local profiles are used to store periodically updating information for a mobile host in an ad hoc network.
- Cross-layer information is abstracted from each necessary layer respectively and stored in separate profiles with the mobile host.
- Other interested layers can then select the profiles to fetch the desired information.

Concept Model of LP



Note: For presentation convenience a five-layer model is used

LP

- **Advantage:** More flexible since profile formats can be tailored to specific applications, and then the interested layers/applications can access the desired information directly.
- **Drawback:** Due to high latency, this method is not suitable for time-stringent tasks.

Drawbacks of Previous Methods

- The signaling propagation path across the protocol stack are not efficient.
  - The layer-by-layer propagation approach just follows the data propagation mode.
    - The intermediate layers have to be involved even if only the source layer and destination layer are targeted => causes unnecessary processing overhead and propagation latency.

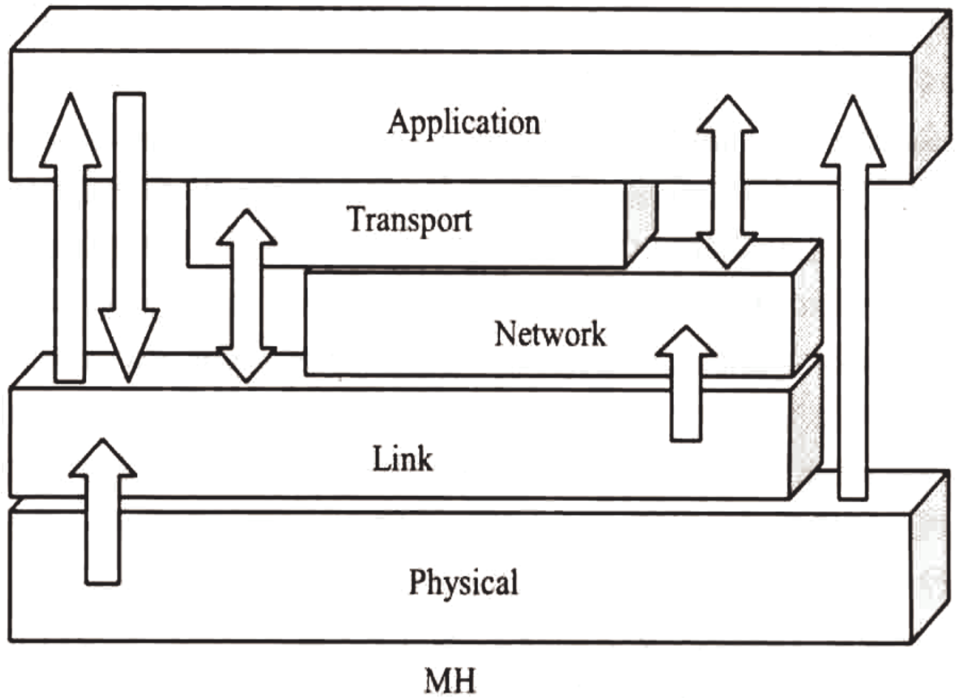
Drawbacks of Previous Methods

- The signaling message formats are
  - either not flexible enough for active signaling in both upward and downward directions
  - or not optimized for different signaling inside and outside the mobile handset respectively.
- The desired message formats should be scaleable enough for rich signaling more than cross-layer hints and notifications.

An Improved Method

- Cross LAyer Signaling Shortcuts (CLASS) has been proposed to overcome the drawbacks of previously mentioned methods.
- Distinct features of CLASS
  - Direct signaling between non-neighboring layers.
  - Light-weighted internal message format.
  - Standardized external message format.

Concept Model of CLASS



Note: For presentation convenience a five-layer model is used

Features of CLASS

- **Direct signaling between non-neighboring layers:** Breaks the layer ordering constraints while keeping the layering structure.
  - Cross-layer messages propagate through local out-of-bound signaling shortcuts.
  - **Example:** Direct communications between Application Layer and Network Layer without turning to the otherwise middleman, Transport Layer.

Features of CLASS

- **Light-weighted internal message format:** For internal signaling, it is not necessary to use standardized protocols, which are normally heavy-loaded.
- For internal signaling, CLASS requires only three fields
  - Destination Address: includes destination layer and destination protocols or applications.
  - Event Type: indicates a parameter.
  - Event Contents: the value of the parameter.

Internal Message Size

- For CLASS the whole message is only 4 bytes.
  - Destination Address: 1 byte.
  - Event Type: 1 byte.
  - Event Contents: 2 bytes.
- For the method that uses ICMP messages, the internal message size is 30 bytes (7.5 times bigger than that of CLASS).
  - IP header: 20 bytes.
  - ICMP header : 8 bytes.
  - Checksum field: 2 bytes.

Features of CLASS

- Standardized external message format
  - ICMP can be used for general messages.
  - TCP/IP headers can be used for short notifications.

Drawbacks of Cross-layer Design

- The interaction between different layers can affect not only the layers concerned but also other parts of the system.
- Cross-layer design often causes several adaptation loops which are parts of different protocols to interact with each other
  - If a parameter is controlled and used by two different adaptation loops, they can conflict with each other.

Issues of Cross-layer Design

- Implementation of several cross-layer interactions gives rise to the following questions.
  - Will the resulting system have longevity.
  - Will there be a need to update the whole system for every modification?
  - Will this lead to a higher per-unit cost, which eventually is regarded by the end user as a lower performance?

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