CSE 6345 Mobile Computer Systems

Topic 1 : Introduction

With Dr. Mohan Kumar

Introduction
- **Definitions**

Mobile host and base station

Disconnected operation

Mobility – Issues and challenges

Middleware/Infrastructure support

Internet and Internet protocols

Definitions

Wireless Computing

Access to computer networks and computing resources through a wireless media.

Definitions

Wireless Computing

Access to computer networks and computing resources through a wireless media.

Nomadic Computing

Access to computer networks and computing resources while on the move.

Definitions (Contd.)

Wireless Computing

Access to computer networks and computing resources through a wireless media.

Nomadic Computing

Access to computer networks and computing resources while on the move.

Mobile Computing

Distributed Computing + Mobility

Definitions (Contd.)

Wireless Computing

Nomadic Computing

Mobile Computing

Distributed Computing + Mobility

Pervasive Computing

Access to computer networks, and computing and information resources everywhere all the time.

Why Mobile Computing?

Small and Flexible

laptops, PDAs, cell phones, sensors

Why Mobile Computing?

Small and Flexible

laptops, PDAs, cell phones, sensors

Technological advances

CPU power

Memory

Wireless communication

Why Mobile Computing?

Small and Flexible

laptops, PDAs, cell phones, sensors

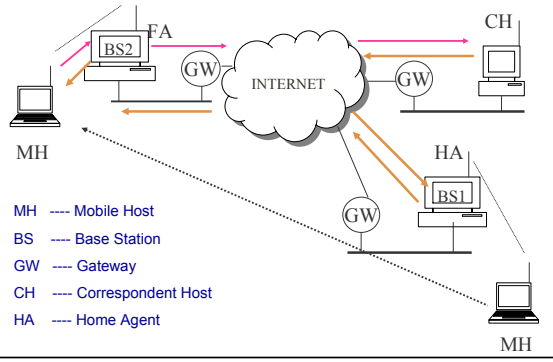
Technological advances

CPU power
Memory
Wireless communication

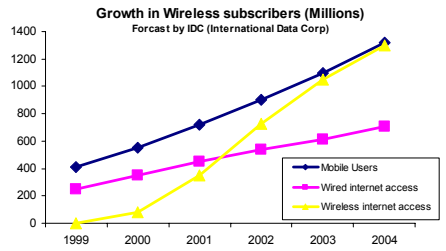
Application areas

Health
Industry control
Commerce

Mobile Environment



Growth in Mobile Users and Wireless Internet



What is a Mobile Host?

Features

Any laptop computer, handheld device equipped with wireless communication hardware

What is a Mobile Host?

Features

Any laptop computer, handheld device equipped with wireless communication hardware

Functions

similar to the functions of a personal computer

What's different about a mobile computing environment?

Mobility

location changes

What is a Base Station?

The point of contact for the MH

A gateway that connects a mobile host to the rest of the Internet

Requirements

- **Computing power, connection to wired network, wireless communication hardware**

Services

- **Infrastructure support to the MH**

What's different about a mobile computing environment?

Mobility

Disconnection

- **Disconnect**
- **Sleep**
- **Reconnect**
- **Handoff**

What's so different about a mobile computing environment?

Mobility

Disconnection

Low Bandwidth

802.11 – 11 Mbps

What's so different about a mobile computing environment?

Mobility

Disconnection

Low Bandwidth

Limited Resources on the MH

Battery, CPU, memory, cache

Issues in Mobile Systems

Network Configuration
Devices
Bandwidth and Frequency of Operation
Handoffs
QoS management
Mobility management
Location Tracking
Applications and Middleware
Security
Fault-tolerance

Challenges

Reliable wireless communications

Support for disconnected operation

Mobile applications development

Support seamless movement

Bandwidth Limited Resources Battery power

Challenges

Reliable wireless communications
Support for disconnected operation
Mobile applications development
Support seamless movement
Mobile users and applications
Transparently access files, personal data, email,

Bandwidth Limited Resources Battery power

Infrastructure support

Mobile service stations
TCP/IP
Security
Databases
Proxy services
Fault-tolerance
Location management
Caching
Prefetching

Middleware services

In mobile networking,

"computer applications are likely to involve interactions between machines without human intervention" Perkins '98.

Provide completely automatic, non-interactive reconnections

Web applications – adjust their graphical data presentations depending on available bandwidth.

Act on dynamic changes in network parameters – link bandwidth, error rate, RTT, QoS and Security requirements

Internet and Internet protocols

IP addresses and fixed network location
Transparent mobility

Internet and Internet protocols

- **IP addresses and fixed network location**
- **Transparent mobility**
- **Hourglass architecture**
  - **Narrow waist – basic network services**
  - **Wider regions – applications and communication technologies**
- **End-to-end architecture**
  - **Network – data transport**
  - **Edge - Intelligence, information processing**

Internet and Internet protocols

- **IP addresses and fixed network location**
- **Transparent mobility**
- **Hourglass architecture**
  - **Narrow waist – basic network services**
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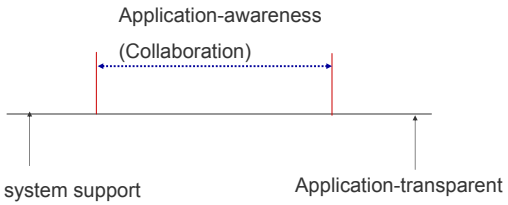
- **End-to-end architecture**
  - **Network – data transport**
  - **Best effort service**
  - **Edge - Intelligence, information processing**

Support for Disconnected operation

CODA
- **A distributed file system for networks with variable connectivity.**
- **Application transparent adaptation.**

Odyssey
- **A platform for mobile data access.**
- **Application aware adaptation – suitable for multimedia applications**

Mobile-Aware Adaptation



M. Satyanarayanan, Accessing Information on demand at any location, IEEE Personal Communications, Vol. 3, No. 1, pgs. 26-33.

Application-Transparent Adaptation

Applications work with no modifications
- Hide differences between static and mobile environments
- File system proxy, e.g., Coda
- Web Proxy, e.g. WebExpress

Application-aware adaptation

React to mobile resource changes
- **Client-based application adaptation**
- **Client-server application adaptation**
- **Proxy-based application application adaptation**

Summary

Case for Mobile computing
Mobility – issues and challenges
Infrastructure for mobile computing

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Topic 2 : Mobile and Wireless Networks

With Dr. Mohan Kumar

Lesson 2

Topics to be covered in this lesson on Wireless Networks

- **Wireless Network Limitations and Functions**
- **MAC Protocols for Wireless Networks**
- **Types of Wireless Networks**

Mobile and Wireless Networks

What are mobile networks?

What are wireless networks?

Wireless Networks

Limited channel capacity

Wireless Networks

- Limited channel capacity
- Higher noise and interference

Wireless Networks

- Limited channel capacity
- Higher noise and interference
- Frequency allocation restrictions

Wireless Networks

- Limited channel capacity
- Higher noise and interference
- Frequency allocation restrictions
- Information is transmitted through free space

Mobile Network functions

- Maintaining communication despite mobility

Mobile Network functions

- Maintaining communication with mobility
- Keeping track of locations

Wireless network functions

Provide wireless interfaces to users

Wireless network functions

Provide wireless interfaces to users

Bandwidth allocations and error control

MAC protocols

FDMA

MAC protocols

FDMA

TDMA

MAC protocols

- FDMA
- TDMA
- CDMA

MAC protocols

- FDMA
- TDMA
- CDMA
- GSM

Emerging Mobile and Wireless Networks

- Wireless LANs
- Wireless Loops
- Satellites
- Wireless ATM
- Cellular/PCS

Wireless LANs

- For small areas such as a building, hallway, park or office

Wireless LAN standards

IEEE 802.11

- **1 Mbps**
  - **is being enhanced to 11 Mbps**

Wireless LAN standards

IEEE 802.11

- **1 Mbps**
- **Physical media can be infrared or spread spectrum**
- **Prioritized access to the medium**

Wireless LAN standards

IEEE 802.11

- **1 Mbps**
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Wireless LAN standards

IEEE 802.11

- **1 Mbps**
- **Physical media can be infrared or spread spectrum**
- **Prioritized access to the medium**
- **Battery conservation for inactive or idle wireless users**

Wireless LAN standards

IEEE 802.11(Contd..)

Many universities and companies use 802.11 WLAN

Wireless LAN standards

HIPERLAN

23.5 Mbps

Physical media is spread spectrum

Wireless LAN standards

HIPERLAN

23.5 Mbps

Wireless LAN standards

HIPERLAN

23.5 Mbps

Physical media is spread spectrum

Prioritized access to the medium

Wireless LAN standards

HIPERLAN

- **23.5 Mbps**
- **Physical media is spread spectrum**
- **Prioritized access to the medium**
- **HIPERLAN2 provide different levels of quality of service to the applications**

Wireless Networks

Wireless local loops
- LMDS

Wireless Networks

Wireless local loops

Satellites

Satellites

Iridium

- **A LEO system which uses 66 satellites to provide mobile communications.**

Wireless ATM

ATM cell transmitted over wireless channels.

Wireless ATM

Advantages:

- **Seamless interconnection with backbone ATM networks**
- **Support for QoS in wireless networks**

Wireless ATM

Advantages

- **Seamless interconnection with backbone ATM networks**

Wireless ATM

Advantages:

- **Seamless interconnection with backbone ATM networks**
- **Support for QOS of wireless and mobile users**
- **Suitability of small packets over wireless channels.**

Wireless ATM

Challenges

- **Maintaining end-to-end ATM connections as the user moves**

Wireless ATM

Challenges

- **Maintaining end-to-end ATM connections as the user moves**
  - Connection re-routing needs to be performed
- **Support for quality of service**

Wireless ATM

Challenges

- **Maintaining end-to-end ATM connections as the user moves**
  - Connection re-routing needs to be performed

Wireless ATM

Challenges

- **Present lack of standards**
- **Cost and complexity in implementation**
- **Amount of overheads**

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Mobile Computer Systems

Topic 3 : Mobile IP

With Dr. Mohan Kumar

Mobile IP

Internet Access
- **Access to information**
- **IP connectivity**
- **PDAs, cellular phones etc.**

Mobile IP

Internet Access
- **Access to information**
- **IP connectivity**
- **PDAs, cellular phones etc.**

Mobile computing – future
- **No disruption of services when user changes point of attachment**
- **Automatic, transparent and instantaneous**

IP and Mobile IP

IP:

Packets are routed to their destinations according to IP addresses
- **IP addresses are associated with a fixed network location**

Mobile IP:
- **Packets may be destined to mobile nodes**

  Providing services to mobile nodes transparently is the challenge.

Mobile IP

Convenience of seamless roaming and effective application transparency to the users

Mobility transparent to applications as well as higher level protocols such as TCP

Protocol Stack

Networking Layers	Standard Protocols
Applications	HTTP,NFS,SNMP,Telnet, FTP
Transport	TCP, UDP,RTP
Network	IP, ICMP,IGMP,IPSec, Mobile IP
Data Link	IEEE 802.*, PPP
Physical	Network adapter

ICMP: Internet Control Message protocol; IGMP : Internet group management Protocol; IPSec : Internet protocol security

Protocol Stack

Networking Layers	Standard Protocols
Applications	HTTP,NFS,SNMP,Telnet, FTP Designed for traditional networks
Transport	TCP, UDP,RTP
Network	IP, ICMP,IGMP,IPSec, Mobile IP
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Protocol Stack

Networking Layers	Standard Protocols
Applications	HTTP,NFS,SNMP,Telnet, FTP
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Protocol Stack

Networking Layers	Standard Protocols
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Physical	Network adapter

Mobile IP terminology

Care-of-address

An IP address at the mobile node's current point of attachment to the Internet, when it is not connected to the home network.

Mobile node's topologically significant address

Mobile IP terminology

Home address

The IP address assigned to the mobile node, making it logically appear attached to its home network

Static address used to identify TCP connections

Mobile IP terminology

Home Agent

Is an entity on the home network that effectively causes the mobile node to be reachable at its home address even when the mobile node is not attached to its home network.

Whenever the mobile node is not attached to the home network, home agent gets all the packets that are destined for the mobile node and delivers them to the mobile node's current point of attachment.

Mobile IP terminology

Foreign agent

A mobility agent on the foreign network that assists the mobile node in receiving datagrams delivered to the care-of-address.

Working of Mobile IP

In order to maintain higher layer transparency, as the mobile node moves, the IP address should remain the same.

Mobile IP achieves this by using two IP addresses, home address and the care-of-address.

Mobile IP terminology

Encapsulation/Tunneling

The process of inserting original IP packets inside another IP packet.

Working of Mobile IP

Mobile IP is composed of three mechanisms

Discovering the care-of-address

Registering with the care-of-address

Tunneling to the care-of-address

Discovering the care-of-address

Through agent advertisements

Home agent and foreign agent broadcast agent advertisements at regular intervals

Mobile node may also broadcast or multicast a request for a care-of-address

Registering care-of-address

Mobile node registers its care-of-address with the home agent (HA)

Foreign agent (FA) sends a registration request to the home agent with the care-of address information

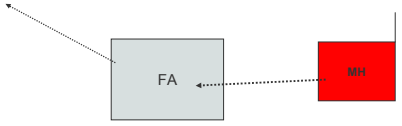
The HA adds the necessary information to the routing table, approves the request and sends a registration reply back to the mobile node.

The FA stores the mobile node's home address, home agent's address, MAC number and port number

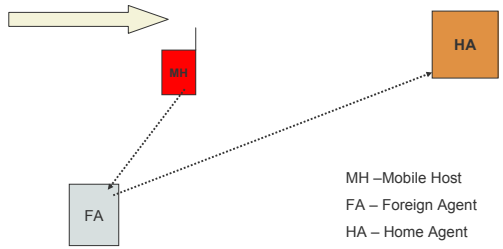
Registering care-of-address

Mobile node registers its care-of-address with the home agent (HA)

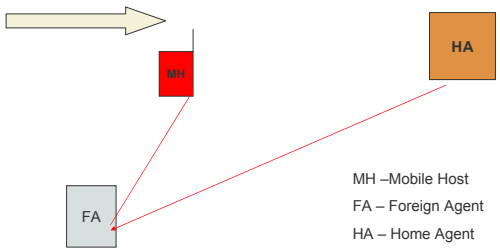
Foreign agent (FA) sends a registration request to the home agent with the care-of address information



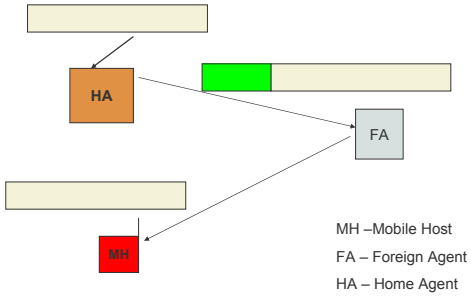
Registering care-of-address



Registering care-of-address (Contd.)



Tunneling to the care-of-address



Tunneling to the care-of-address

When the HA receives a datagram addressed to the mobile node, it inserts a new IP header (tunnel header) to that datagram in front of the original IP header.

The tunnel header has mobile node's care-of-address in the destination address field and home agent's address in the source address field.

Problems facing Mobile IP

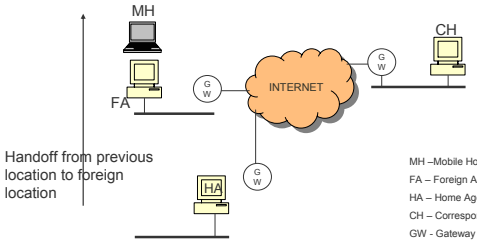
Handoff Management

Triangular routing

Ingress filtering

Many border routers discard packets, if the source address is not one from within the network. Mobile nodes use home address as the source address, which presents the difficulty.

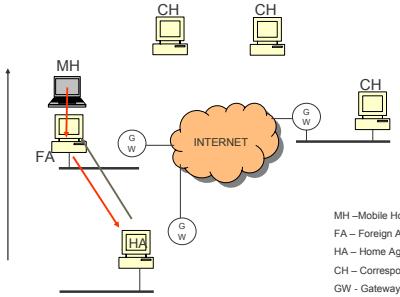
Mobile IP (Overview)



Handoff from previous location to foreign location

MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

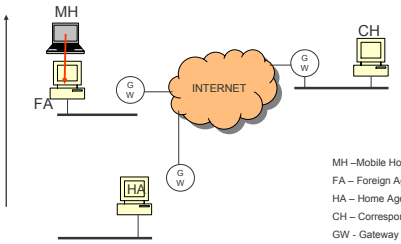
Mobile IP (Overview)



MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

FA registers with HA and HA acknowledges

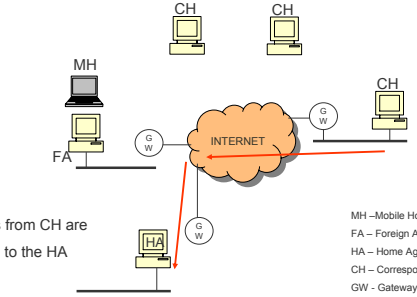
Mobile IP (Overview)



MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

MH registers with FA

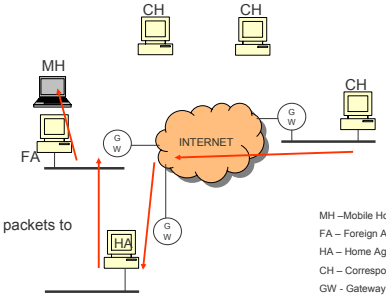
Mobile IP (Overview)



Packets from CH are Routed to the HA

MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

Mobile IP

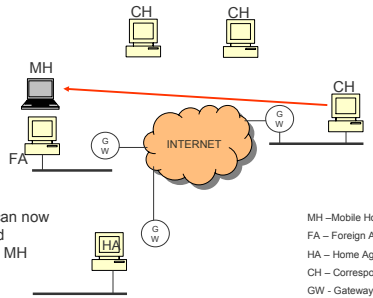


HA redirects packets to MH

This is triangular routing

MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

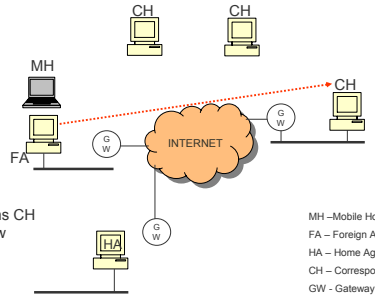
Mobile IP



Packets can now be Routed directly to MH

MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

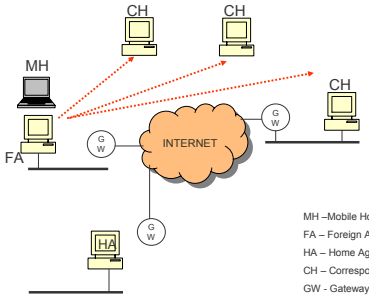
Mobile IP



FA informs CH about new location

MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

Mobile IP



MH –Mobile Host
FA – Foreign Agent
HA – Home Agent
CH – Correspondent Host
GW - Gateway

Mobile IP

Problems
Solutions
Research challenges

Triangle Routing

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Mobile Computer Systems

Topic 4 :TCP Enhancements

With Dr. Mohan Kumar

TCP/IP

Wired Networks
- **De-facto standard**
- **Reliable transport protocol**
- **Error recovery mechanisms**
  - **Congestion control**
- **Significant drop in packet losses**

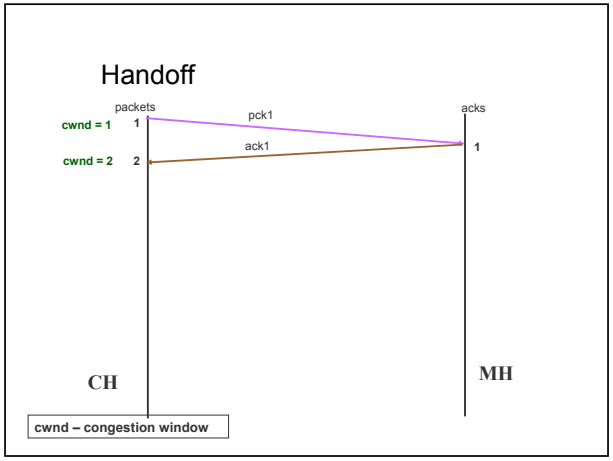
TCP/IP and Wireless Networks

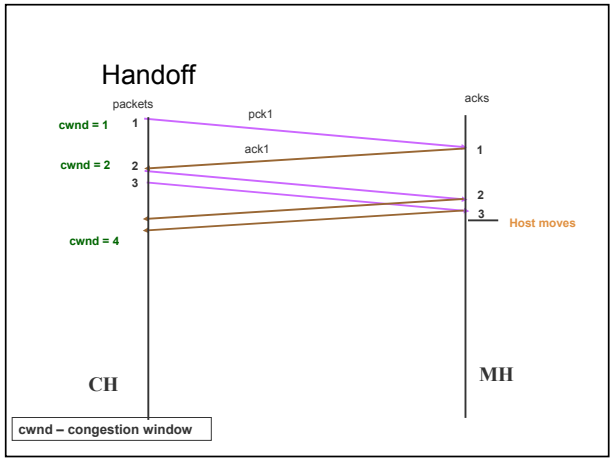
TCP/IP was designed for Wired Networks

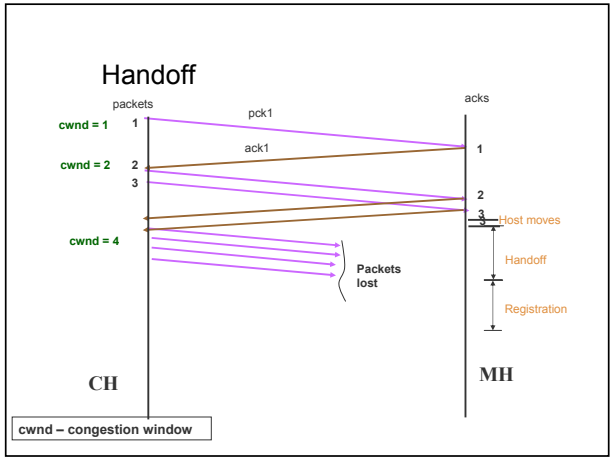
Wireless networks are prone to errors and packet losses

Handoff

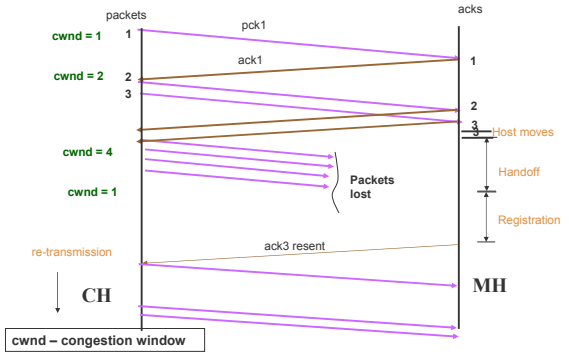
- Congestion







Handoff



Improving TCP

Link layer approach

Split connection

New protocols

TCP/IP Optimisations

TCP and wireless

Detection of errors

Adaptive retransmission

Energy saving capability and

Reliable congestion detection

Link Layer Approach

Aware of wireless network conditions

Feedback from link layer to TCP

Snoop protocol

Snoop Protocol

IP layer modified

Snoop module resides at a BS

- **Monitors TCP headers of data and acks**
- **Detects lost packets**
- **Performs re-transmissions**

Snoop Protocol

Limitations

- **Short timeouts**
- **Large RTT -- >Poor performance**

Improving TCP

Link layer approach

Split connection

New protocols

TCP/IP Optimisations

Split Connection

- **Split into Two connections**
- **Wired and wireless**
- Indirect TCP

Indirect TCP

Two-part end-to-end connection
- **Wired and wireless**

Mobile support Router
- **Center point between the wired and wireless networks**
- **MSR sends acks**

Indirect TCP

Limitations
- **No TCP end-to-end semantics**
- **Packet buffering at MSRs**
  - overhead
- **Not scalable**

Improving TCP

Link layer approach

Split connection

New protocols
- WAP – Wireless Access Protocol

TCP/IP Optimisations

Wireless Application Protocol (WAP)

Application communication protocol designed for mobile devices to access services and information on the Internet

Enables creation of web applications for mobile devices

WAP forum founded in 1997 by Ericsson, Motorola, Nokia and Unwired Planet, and publishes the WAP specifications

WAP (Contd.)

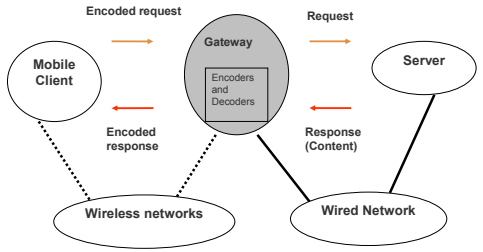
It is inherited from the Internet standards
- **TCP/IP, HTTP and HTML**

Uses Wireless Markup Language (WML)
- **HTML optimized for mobile devices**

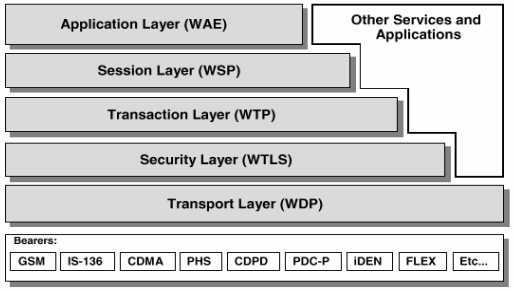
A protocol designed for micro browsers
- **A micro browser is a software that makes minimal demands on hardware, memory and CPU and can display information using WML**

Defined as an XML 1.0 application

How WAP works



WAP Architecture



Improving TCP

Link layer approach

Split connection

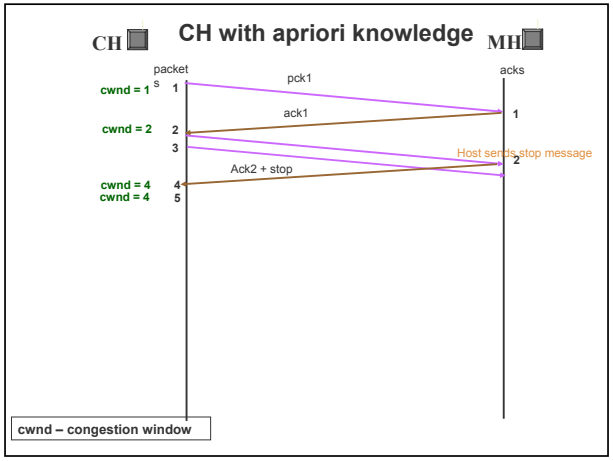
New protocols

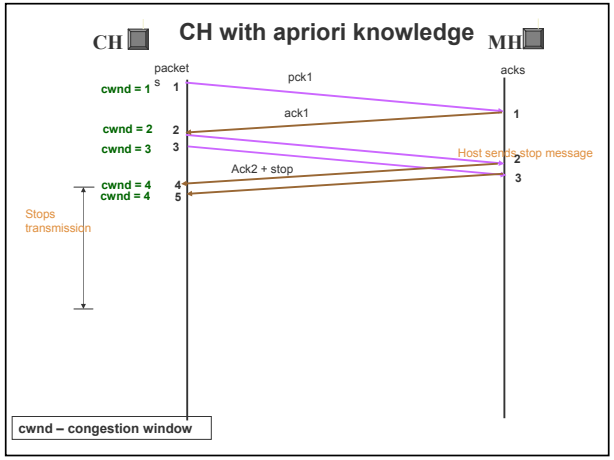
TCP/IP Optimisations

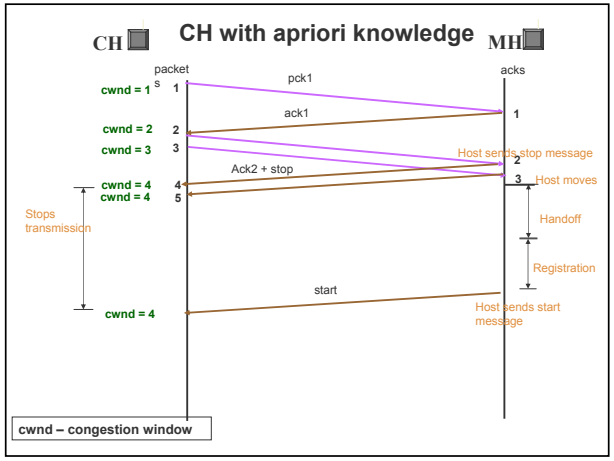
TCP/IP Optimizations

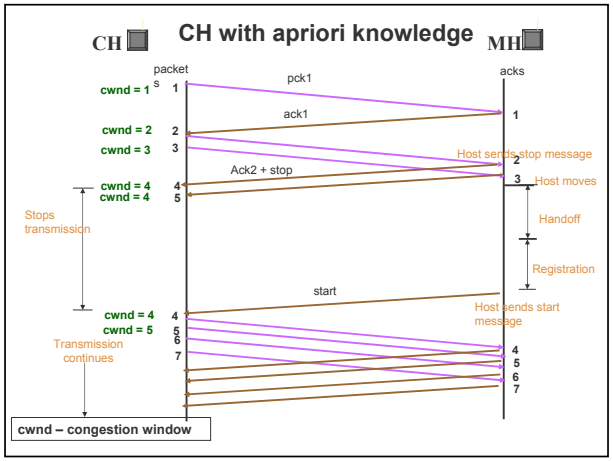
CH gets apriori knowledge that MH is going to move

- **Prevents CH to going into congestion control during the handoff**
- **CH notified by the MH prior to its moving**
- **Once the handoff and registration is successful, CH notified by MH to start transmission again.**
- **CH resumes transmission with the original window size**









Cellular IP

Protocol for local mobility

Suitable for hosts with high mobility

Uses distributed caches for location management and routing purposes

TCP/IP Optimizations (Contd.)

FA smooth handoff

- **Avoids the loss of packets addressed to old foreign agent**
- **Make old FA forward packets to the new FA**
- **Send binding updated to the old FA through the new FA**
- **Such forwarding can be done for pre-specified amount of time (registration lifetime)**

Cellular IP (Contd.)

Key characteristics

- **Fully Distributed**
- **Nodes are unaware of the network topology**
- **No centralized databases or single points of failure**
- **Handoff process is simple, smooth, transparent and automatic**
- **Can accommodate large number of users by separating idle and active hosts**
- **Easy global migration**

Cellular IP (Contd.)

Distributed Cache

Paging Cache
For idle host information

Routing Cache
For active host information

Cellular IP (Contd.)

Routing

Packets addressed to a mobile host are routed to its current base station on a hop-by-hop basis.

Mappings **are information elements that map mobile host identifiers to node ports**

Mappings **are created in the routing caches by control packets transmitted by the mobile host towards the gateway router. By monitoring these packets, nodes on the network create a hop-by-hop reverse path for the mobile host.**

Cellular IP (Contd.)

Difference from IP

Simple and low cost implementation of Internet host mobility

Requires no new packet formats

Requires no address space allocation beyond what is present in IP

Cellular IP (Contd.)

Paging

Process of keeping track of mobile hosts in idle state and promoting to active state upon receiving data

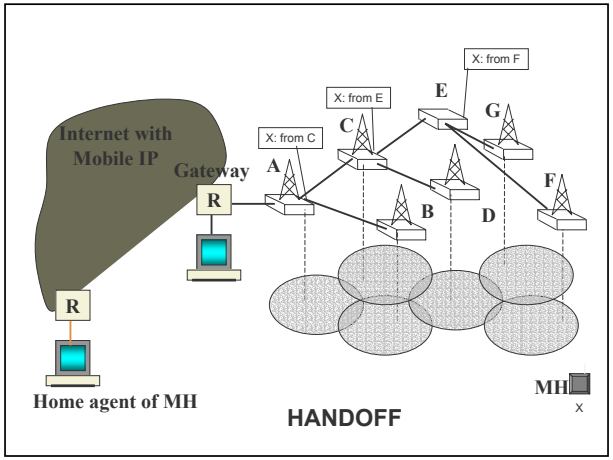
Idle mobile hosts periodically generate paging update messages

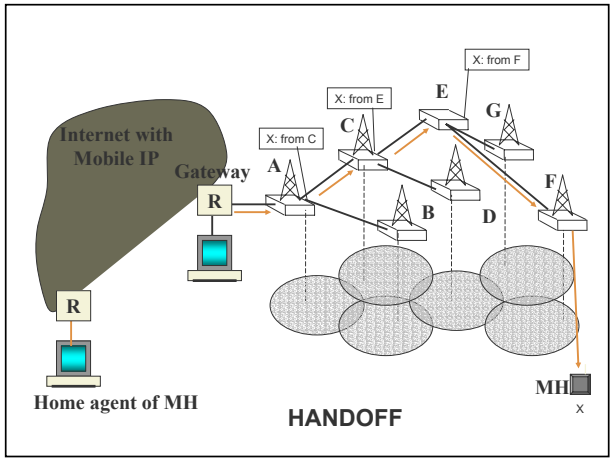
Nodes monitor passing paging update packets and updates the paging cache

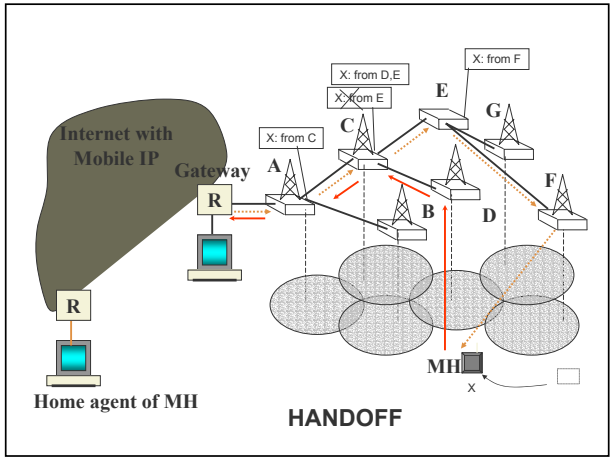
Cellular IP (Contd.)

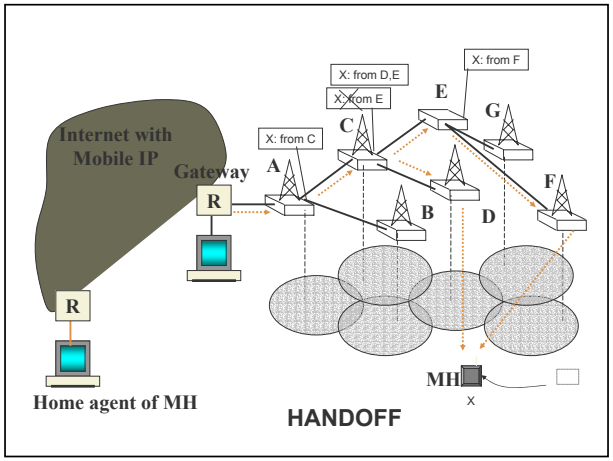
Handoffs

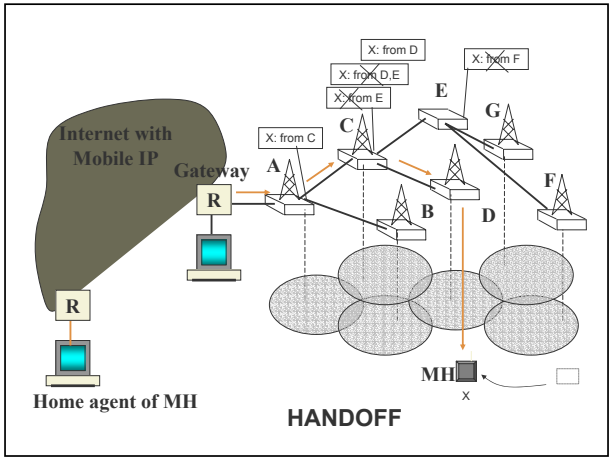
- **Migration during an ongoing data transfer**
- **Handoffs in cellular IP are always initiated by the mobile host**
- **As the host approaches a new base station, it redirects its data packets from the old to the new base station.**
- **First of these packets create the new mappings for the host.**









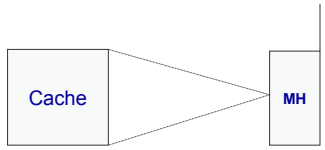


CSE 6345 Mobile Computer Systems

Topic 5 : Caching in Mobile computers

With Dr. Mohan Kumar

Cache



Cache and mobile computing

Cache and mobile computing

What, when and how long?

Cache consistency issues?

Cache and mobile computing

What, when and how long?

Cache and mobile computing

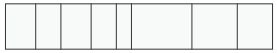
What, when and how long?

Cache consistency issues

When and how to invalidate cached items?

Items to be cached : General

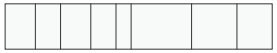
Access probabilities



Cached items in an MH

Items to be cached : General

Access probabilities
Data access patterns
Update rates

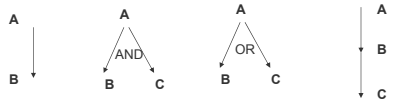


Cached items in an MH

Items to be cached : General

Access probabilities
Data access patterns

Cached items in an MH



Items to be Cached : Mobile hosts

Communication/access costs

Items to be Cached : Mobile hosts

Communication/access costs

Mobility pattern of the client

Items to be Cached : Mobile hosts

Communication/access costs

Mobility pattern of the client

Connectivity characteristics and

- **Disconnection pattern – sleep and wakeup modes**
- **Available bandwidth**

Caching strategies

Periodic broadcast of invalidations (Barbara and Imilienski)

- **The server broadcasts aggregated invalidation reports every L time units**

Caching strategies

Periodic broadcast of invalidations (Barbara and Imilienski)

Maintain a directory of cached items and multicast

Caching strategies

An MSS maintains a directory for every MH associated with it.

Caching strategies

An MSS maintains a directory for every MH associated with it.

MH tells MSS when it copies or updates an item in its cache

Caching strategies

An MSS maintains a directory for every MH associated with it.

MH tells MSS when it copies or updates an object in its cache

Data update anywhere in the network – invalidation is sent out to all MSSs

Caching strategies

An MSS maintains a directory for every MH associated with it.

MH tells MSS when it copies or updates an object in its cache

Data update anywhere in the network – invalidation is sent out to all MSSs

MSS nearest to the MH communicates the invalidation to the MH

- **if MH is awake (immediate)**
- **when MH wakes up and queries**

Cache strategies (continued).

When MH is roaming, its directory entry is copied to the nearest MSS

Cache strategies (continued).

Directory size is proportional to the number of MHs

MH migration?
Cost of directory movement migration?

Cache strategies (continued).

Directory size is proportional to the number of MHs

Strategies …(Contd.)

Local caches updated at MHs using I reports.

Flush cache if MH disconnected for k number of reports

Queries answered after receiving I reports

Cache consistency Management

Reference: "Strategy to Manage Cache Consistency in a Disconnected Distributed Environment" by A. Kahol et.al.

Caching Strategies

Analysis of static and dynamic data allocation schemes

Reduce the cost of communication between SC and MC
- **SC - Stationary Computer, MC – Mobile Computer**

Two cost models
- **Connection (time) – based**
- **Message – based**

Reference: "Minimization of Communication Cost Through Caching in Mobile Environments" by A. P. Sistla, O. Wolfson, and Y. Huang.

"Minimization of Communication Cost through Caching in Mobile Environments" (Sistla et.al)

Assume online database
- **A web page or a file**

Data item – **x**

Data Access and Updates

If **x** is accessed frequently and updated infrequently
- **Allocate copy of x to MC**
- **All updates of x are transmitted from SC to MC**
- **No cost involved in reading**

Data Access and Updates

If **x** is accessed frequently and updated infrequently

- **Allocate copy of x to MC**
- **All updates of x are transmitted from SC to MC**
- **No cost involved in reading**

If **x** is accessed infrequently and updated frequently

- **Copy of x is not allocated to MC**
- **Access to x is on demand from the MC only**

Static and Dynamic Allocation

Static

- **Allocation scheme does not change – it is fixed**

- **Can be expensive if the reads outnumber the writes and it is a one copy scheme or if the writes outnumber the reads and it is a two copies scheme.**

- **ST_1 and ST_2**

Static and Dynamic Allocation (Contd.)

Dynamic

- **Allocation scheme changes based on the access sequence.**

- **Check after k requests**
  - If *one copy* scheme and if number of reads is greater than the number of writes then switch to *two copies* scheme.
  - If *two copies* scheme and if number of writes greater than number of reads then switch to *one copy* scheme.

- **SW_K**

The Model

Reads are issued at the MC and writes are issued at the SC

- **Reads by MC – Cost is one**
- **Writes by SC – Cost is zero**

Schedule a sequence of requests.

- **r, r, r, w, w, r, w, r, w, r, w, w, r, r**

Concurrency control mechanism is used to serialize the concurrent requests.

Two Cost Models

Connection

- **One copy**
  - Cost of read(MC) = 1
  - Cost of write(SC) = 0
- **Two copies**
  - Cost of read(MC) = 0
  - Cost of write(SC) = 1

Total cost of schedule (Ψ)

- **Cost(Ψ) = cost of (r, r, w, w, r, …..)**

Two Cost Models (Contd.)

Message

- **Data message cost = 1**
- **Control message cost = ω**
  - $0 \leq \omega \leq 1$
- **One copy**
  - Cost of read = $1 + \omega$
  - A read request and a response with the data
  - Cost of write = 0
- **Two copies**
  - Cost of read = 0

Writes in two copies scheme

If write is transmitted to the MC and

- **MC does not deallocate its copy**
  - Cost = 1
- **MC deallocates its copy**
  - Cost = $1+ \omega$

If the write is not propagated to the MC, but

- **Copy of MC is deallocated**
  - Cost = ω

Sliding-window Algorithms

If *one copy* and if # r > # w …

- **SC maintains the window of requests**

If *two copies* and if # w > # r …

- **MC maintains the window of requests**

SW_1 is the classic write-invalidate protocol

CSE 6345
Mobile Computer Systems

Topic 6 :Integrated Caching for Mobile Computers

With Dr. Mohan Kumar

Organization

Prefetching

Broadcasting

Integration
- **Push and Pull**

Demand fetch and cache

Demand fetch
- **Remote data is fetched only when it is requested**

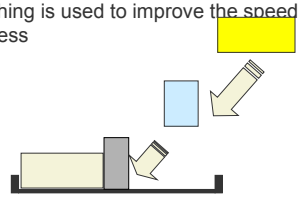
Traditional cache
- **Repeatedly accessible remote data are retained in the local cache**

Cached data items

Prefetch

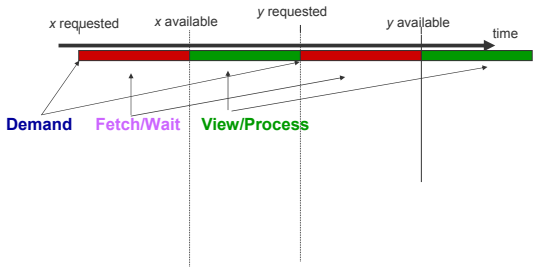
In prefetching, remote data is fetched in anticipation of a future success

Prefetching is used to improve the speed of information success

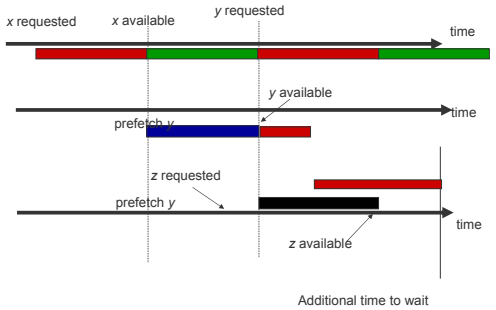


Cached and prefetched data items

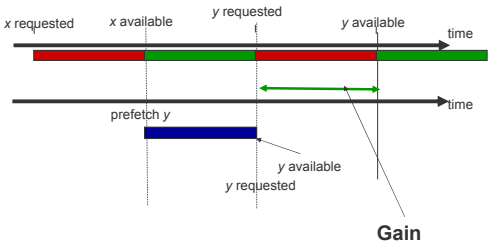
Demand Fetch



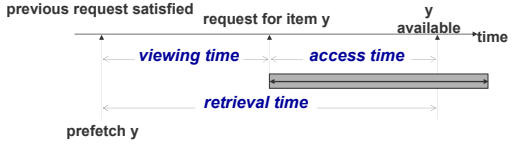
The Risk



Prefetch



Analysis of prefetch



Performance of Prefetch

$$G = E[t \mid noprefetch] - E[t \mid prefetch]$$

G = Access improvement
E(t | ..) = Expected time

Performance of Prefetch

G = Access improvement
E(t | ..) = Expected time

C =retrieval cost

p_i = access probability of item *i*

r_i = retrieval time of item *i*

F = list4911 Tf 7T2e0n0.9534 =of Pref34 =st

Prefetch multiple items

n = number of items

N = < 1,2 ,….., n> list of all items

C = list of items in the cache

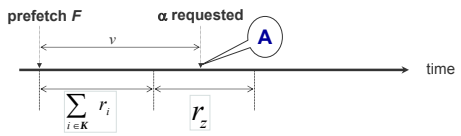
K = list of items prefetched before the end of viewing time

r_i = retrieval time of item I

$P_I = P_r(\alpha = i)$ where α is the item be accessed next

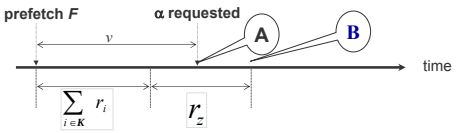
Maximize G

Access improvement for prefetch



A. **If $\alpha \in K$, access time is zero**

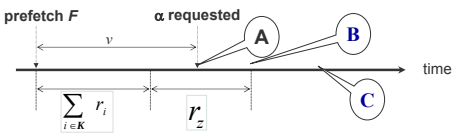
Access improvement for prefetch



A. **If $\alpha \in K$, access time is zero**

B. **If $\alpha = z$, access time equals the time to complete the prefetch**

Access improvement for prefetch



A. **If $\alpha \in K$, access time is zero**

B. **If $\alpha = z$, access time equals the time to complete the prefetch**

C. **If $\alpha \notin F$, access time equals the time to complete the prefetch, plus the time to retrieve the item actually requested.**

Access Improvement

$$G^{\circ}(\mathbf{F}) = E(T^{\circ}_{(\text{no prefetch})}) - E(T^{\circ}_{(\text{prefetch } \mathbf{F})})$$

Access Improvement

$$G^{\circ}(\mathbf{F}) = E(T^{\circ}_{(\text{no prefetch})}) - E(T^{\circ}_{(\text{prefetch } \mathbf{F})})$$

$$\sum_{i \in \mathbf{N}} P_i r_i$$

Access Improvement

$$G^{\circ}(\mathbf{F}) = E(T^{\circ}_{(\text{no prefetch})}) - E(T^{\circ}_{(\text{prefetch } \mathbf{F})})$$

$$\sum_{i \in \mathbf{N}} P_i r_i \qquad \sum_{i \in \mathbf{N}} P_i T^{\circ}_{(\text{prefetch } \mathbf{F}, \alpha = i)}$$

Access Improvement

$$G^{\circ}(\mathbf{F}) = E(T^{\circ}_{(\text{no prefetch})}) - E(T^{\circ}_{(\text{prefetch } \mathbf{F})})$$

$$\sum_{i \in \mathbf{N}} P_i r_i \qquad \sum_{i \in \mathbf{N}} P_i T^{\circ}_{(\text{prefetch } \mathbf{F}, \alpha = i)}$$

Let $\boldsymbol{F} = \boldsymbol{K} \cdot \langle z \rangle$ where $\boldsymbol{K} \subset \boldsymbol{N}$,

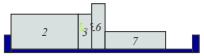
$\sum_{i \in \boldsymbol{K}} r_i < v$ and $z \notin \boldsymbol{K}$.

Binary knapsack problem (KP)

items:

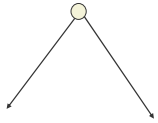
knapsack:

A possible solution:



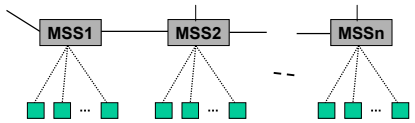
Branch Prefetch

Either item 1 or item 2 is accessed



$\{1,2, \ldots n_1\}$ $\{n_1+1, n_1+2, \ldots n_2\}$

Maintaining Caches at MHs and MSSs



Caches on mobile hosts(MHs)

Broadcasting

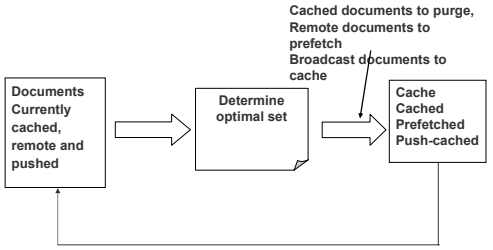
Servers and remote stations broadcast data in anticipation of need by the client

Broadcast data is pushed by the server

Broadcast data may compete for space with other data items

Broadcast data may be ignored by clients.

Caching Scheme



CSE 6345
Mobile Computer Systems

Topic 7 : Mobile Databases

With Dr. Mohan Kumar

Topics

- **Mobile Databases**
  - Architecture
  - Applications
- **Challenges in data management**
- **Data dissemination**
- **Data consistency**
- **Mobile transactions**
  - Challenges
  - Research
- **Location Management**
- **Location dependent data**
- **Location dependent queries**
- **Query optimizations**
- **Data recharging**
- **Commercial Mobile Databases**

Characteristics

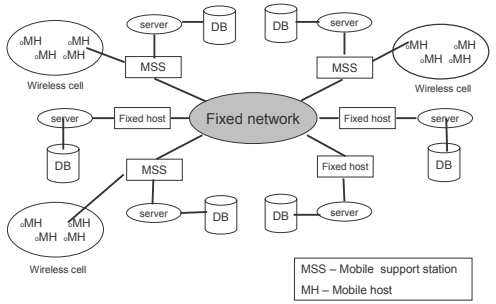
Mobile users will be producers as well as consumers of data

Mobile clients query and update databases over the wireless communication channels *anywhere anytime*

Mobile clients may be often disconnected

Mobile clients may be frequently relocated and connect to different data servers at different times

Mobile databases architecture



Mobile Database applications

Information Services (Yellow Pages)
Law Enforcement and Medical Emergencies
Sales
Weather
Traffic
Sports
Entertainment

Challenges in data management

Mobility and Disconnection

- User's location stored in the database may not be latest.
- Location dependent data and location specific queries
- Maintaining cache/data consistency
- Switch off or hand off in the middle of a transaction execution

Challenges (Contd.)

Mobility and Disconnection

Wireless medium

- Broadcasting is more economical
- Downstream/Upstream bandwidth differences

Data dissemination

Data broadcasting

- Server continuously broadcasts data to the clients.
- Fits very well with the mobile system, where communication bandwidth is asymmetric in upward/downward direction.
- Mobile unit may or may not have a cache
- Cost does not depend on the number of users listening
- Allows location dependent data access

Data dissemination

Push-based broadcast/multicast

- **Sending data to the clients without waiting for specific requests**
  - Servers avoid interruptions caused by requests
  - But cannot decide on the relevance of the data to the client

Data dissemination

No broadcast program can perfectly match the needs of the individual clients

Compensation for this mismatch achieved at the client by

- **Intelligent Caching**
- **Prefetching**

Data dissemination (Contd.)

Broadcast Disks

- **Simulate multiple disks of variable sizes and speeds. Data of higher interests on smaller faster disks (broadcasts more frequently)**
- **Each "disk" contains data with similar access behavior**
- **Combination of caching and broadcast disks**

Data dissemination (Contd.)

Broadcast Disks Contd.

- **No need to store hottest pages, they may be broadcast frequently**
- **Store in cache if the probability of access is more than the frequency of broadcast (cost based page replacement).**

Data Consistency

Clients can read and write from any one of the servers available creating data inconsistency.

Data replication is also essential to enable data availability, when replicated data is updated

Consistency of the core copies(updateable copies) needs to be maintained.

Mobile Transactions

- Transactions are long-lived
- Migration of transaction state, data objects and location information
- Support replicated data objects
- MSS to support computation/ communication
- Split computation operations

Mobile transactions

Semantic based transaction processing

- **Good for situations where data objects can be fragmented like sets, aggregates, stacks and queues**
- **Fragments of data and each fragmented data object has to be cached independently and manipulated synchronously**
- **Fragments are merged at the server**

Mobile transactions

Semantic based transaction processing

Optimistic concurrency control based schemes

- **Cached objects can be updated without coordination, but updates need to be propagated and validated at the database server for the commitment of the transactions**

Mobile transactions

Semantic based transaction processing
Optimistic concurrency control based schemes
Pessimistic schemes
- Cached objects can be locked exclusively and mobile transactions can be done locally
- Leads to unnecessary transaction blocking

Mobile transactions

Semantic based transaction processing
Optimistic concurrency control based schemes
Pessimistic schemes
Dynamic object clustering
Open nested transaction
- Model mobile transactions as a set of sub-transactions
- Allows transactions to be executed while disconnected

Mobile transactions

Semantic based transaction processing
Optimistic concurrency control based schemes
Pessimistic schemes
Dynamic object clustering
- Database is divided into clusters
- Use *weak read*, *weak write*, *strict read*, *strict write*, *weak transaction* (with *local* and *global* commits)
- *Local* commit is same as pre-commit and *global* commit is same as final commit. However a *weak transaction* after a *local* commit can be aborted and is hence compensated.

Mobile transactions

Kangaroo transaction
- Uses the property that transactions in mobile computing hops from one base station to another
- Use split transactions that are *serialisable* sub-transactions
- Transactions are split when hopping occurs

Mobile transactions

Prewrite transaction model

Prewrite operation before a write operation

A *prewrite* operation does not update the value but only makes visible the future value that the data object will have after the final commit

Mobile transactions

Prewrite transaction model (Contd.)

Once a transaction reads all the values and declares all the *prewrites* it can *pre-commit* at the mobile host

Mobile transactions

Once a transaction reads all the values and declares all the *prewrites* it can *pre-commit* at the mobile host

The remaining transaction, that includes the *writes* that takes network time, bandwidth and computing power is shifted to the MSS.

Location Management

Tracking the location of the mobile user

Location of a user can be regarded as a data item whose value changes with every move.

Mobile IP helps to identify a mobile client and locate its current location.

Location dependent data

Value of data depends on the location

Temporal Replication
- **One consistent value at one time**

Spatial Replication
- **Multiple different correct data values at one time**

Location dependent queries

Results depend on the location

Different from the traditional distributed goal of location independence
- **e.g. yellow pages, weather, directions**

Predicates based on the location
- **e.g. "find the nearest hotel in Dallas"**

Location constraints
- **e.g. "Find the nearest hotel"**

Query Optimizations

How best to satisfy the information request made by the client?

Different Cost Factors: I/O, network

Query Optimizations

Different Cost Factors: I/O, network

Different access options: cache, broadcast

Query Optimizations

Different Cost Factors: I/O, network

Different Access Options: cache, broadcast

Dynamic and Adaptable - environment changes

Deciding (based on state of MH and environment) whether to access in the cache at the MH, to request a mobile transaction, or to obtain from a broadcast disk.

Data Recharging

Mobile clients need to efficiently "recharge" their data cache anytime, anywhere.

- **With current technology the data stored on the devices should be manually maintained and synchronized with the fixed data source and only at specific locations**

Data recharging should function in a flexible and geographically independent manner

Data Recharging

The choice of data that must be sent to a device for data recharging depends on the user of the device and applications that will be using the data.

The data recharging infrastructure must therefore maintain information about the data needs of the user

- **Use of user profiles**

Commercial Mobile databases

Sybase's SQL Anywhere

- **Serves 68% of the mobile database market**

IBM's DB2 Everyplace 7

Microsoft SQL server 2000 Windows CE edition

Oracle 9i Lite

Gupta Technologies' SQLBase

CSE 6345
Mobile Computer Systems

Topic 8 :Enabling Technologies

With Dr. Mohan Kumar

New Technologies

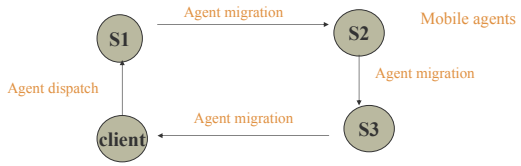
Mobile Agents
- **Software Agents**
- **Autonomous**
- **Code Mobility**

Active Networks
- **Hardware Devices**
- **In-network processing**

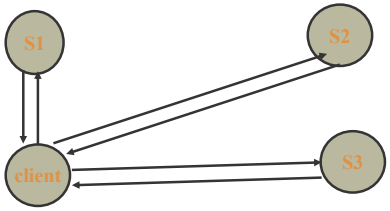
New Technologies

Mobile Agents
- **Software Agents**
- **Autonomous**
- **Code Mobility**

Mobile Agents

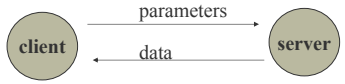


No Agents ?



Why Agents ?

Remote Procedure Call



Back and forth several time

RPC for controlling a device/instrument?

Mobile Agents

Client can maintain its own interface at the server node
- **A mobile node serves as a proxy**

A given task can be divided into multiple tasks and distributed among mobile agents
- **Achieve parallelism**

Mobile Agent paradigm can be used
- **For low level system management**
- **For middleware user-level applications**

Advantages of Mobile Agents

Reduce network use

Increase asynchrony between clients and servers

Add client specified functionality to servers

Mobile agents can be user/client specific

In Mobile environments
- **Agents can server foreign hosts which are unfamiliar with mobile clients or device specifics**

Mobile Agents and bandwidth

RPC

Repeated client-server interactions

- **Maintain Connections over long periods**
- **Several separate requests**

Mobile Agents

No need for continuous connection with the use of mobile agents

- **Resource can be freed up for other use**

Agent Applications

Low Level

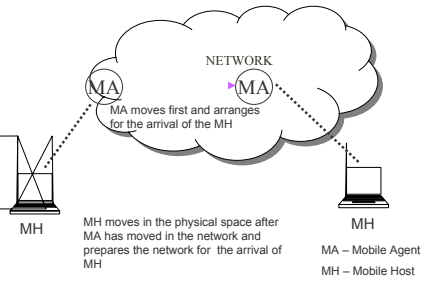
- **Network maintenance**
- **Testing and fault diagnosis**
- **Installation and software upgrade**
- **Mobile Environments**

Mobile Agents and Device Mobility

Particularly useful in mobile computers and wireless networks

- **Not connected all the time**
- **Mobile user agent**
- **Battery power conservation**

Agents for Mobile Applications

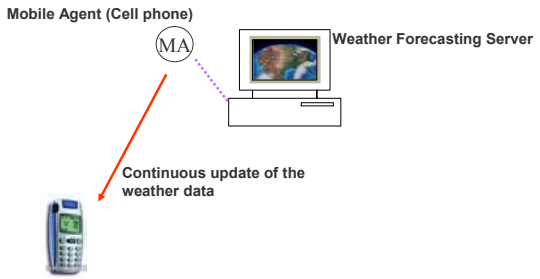


Agent Applications

Low level
- **Network Maintenance**
- **Testing and fault diagnosis**
- **Installation and software upgrade**

Middleware – user applications
- **Electronic market place**
- **Active mail messages**

An example Agent application



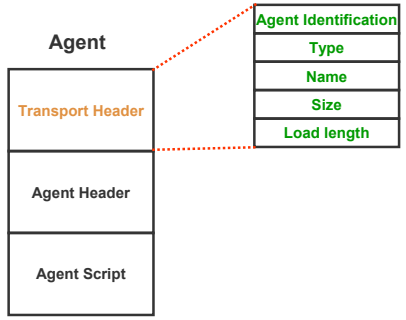
Domains for Mobile Agent Applications

Data intensive applications
- **Data is remotely located (and is owned by the remote service provider).**
- **The user has specialized needs.**
- **The agent is sent to the server.**

Where application launches (pops) agents

Extensible Servers
- **User can ship and install an agent representing him more permanently on the remote server.**
- **Similar to autonomous migration.**

An Example Agent

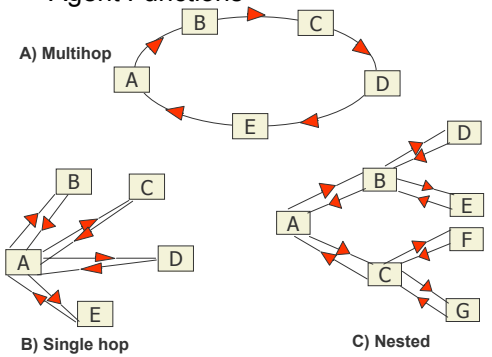


Path of Agents

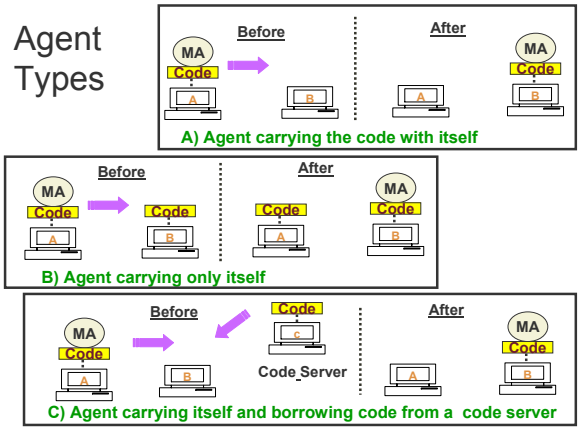
Predetermined

Agents determine paths dynamically

Agent Functions



Agent Types



Types

Agent Server

Agent carries code

Agent carries data and invokes code on remote server

Agent Server

Agent code execution

Primitive operations

- **Migrate**
- **Communicate**
- **Access resources**
- **Application specific services**

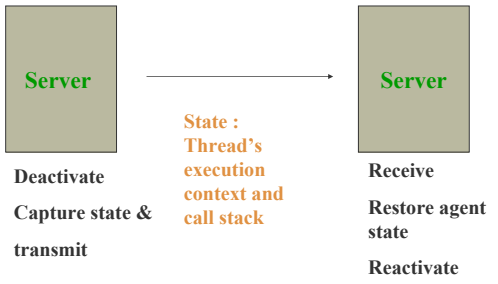
Transfer Code

Agent carries all code with it
- **Execute on any server**

Agent code preinstalled on the servers
- **Does not carry the code**

Reference to code base
- **A code server keeps all the code**

Migration



Naming an agent

Location dependent
- **Easy to implement**
- **Cumbersome to track**

Location transparent names
- **Complex – encapsulation**
- **System updates location info when MA moves**

Global Location independent names
- **Do not change when the entity relocates**
- **Name service maps symbolic names to the current location**

Security

Agent privacy and integrity

- **Part of the agent may be sensitive**
- **Agent may not trust all servers**
- **Selective – servers**
- **Secure communications**

Security - Server

Security breaches in the code

- **Hard to prevent but detectable**

Agent programming primitives

- Basic agent management
- Agent-to-agent communication and synchronization
- Agent monitoring and control
- Fault-tolerance
- Security related

Agent-to-agent coordination

Client-Server

Agent-to-agent coordination (contd.)

Client Server

Meeting Oriented

Blackboard

Linda-like

- **Blackboard + associative mechanisms**
- **Tuple spaces – access by content rather than id**

Problems

Group Communication

- **Hard to achieve even for agents in client server model**

Security

- **Denial of Service attacks**

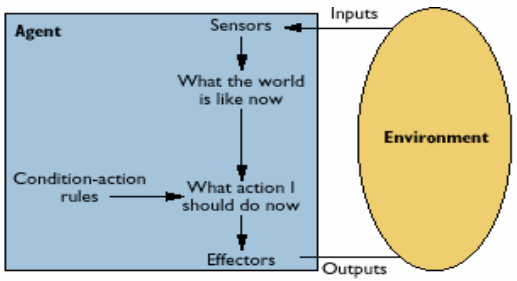
Agent Integrity

- **Malicious Agents and servers**

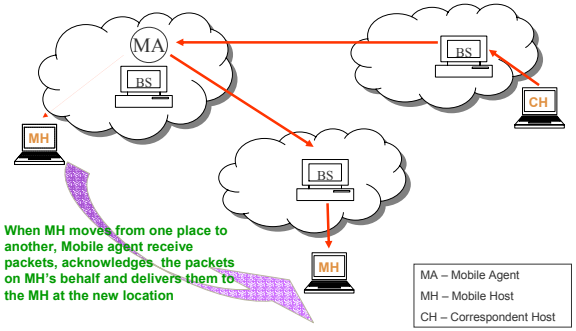
Lack of user friendly agents

- **These are needed for the widespread use of agents**

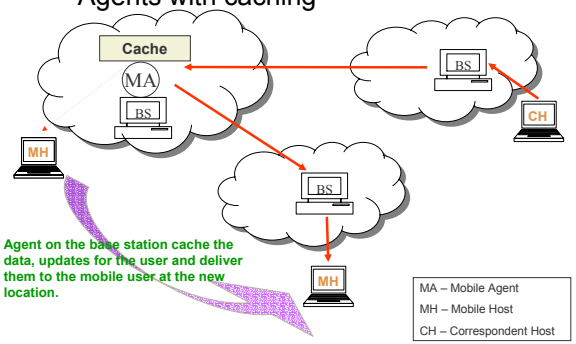
Event based agent model



Agents for Mobile IP



Agents with caching



CSE 6345
Mobile Computer Systems

Topic 9 :Enabling Technologies Continued – Active Networks

With Dr. Mohan Kumar

Agents for maintaining profiles

User Profile

Device Profile

Application Profile

Why active networks

Traditional networks

- **Vertically Integrated**
- **Inflexible**

Active Networks

Open, programmable infrastructure

Hardware, software separation

Extensible and programmable

Rapid creation and delivery of new network services

Main Concerns

Security

- Untrusted user code and executing in core routers – *Is it safe?*

Efficiency

- Dynamic code distribution consumes bandwidth
- Every packet now requires additional processing

Applications

Network Management

Application Services

- Multimedia over wireless

Mobile and wireless environments

Proxies

Firewalls

Programmable Networks

Network service can improve application performance

Additional work in the network may sometimes be more effective than additional work by the application

Active Networks makes network infrastructure programmable without compromising local forwarding performance and network security properties

Network programmability does not necessarily come at the cost of performance and security

Active Network Architecture

Network architecture that allows

- *Application customized code* to be dynamically deployed in the network
- Could be executed in a controlled framework within the network

Types of code execution

First approach

- **Code is carried in the message packet itself**
- **When the message packet arrives at an active node, the code can be executed**
- **This is also called capsule approach**

Second approach

- **The code is available at the active node**
- **This code can be executed when required**

Network performance vs. Application performance

Network performance measures evaluate the performance of the network rather than the performance of the applications using the network

An active network can perform operations that make fewer packets to be sent or delivered and packets to experience longer latencies

- **While these effects would appear to degrade performance, may actually result in improved overall application performance because of reduced demand for bandwidth at endpoints and reduced network congestion**

Why use active networking in Mobile networks?

- Location Management
- Traffic considerations
- Adaptability to changing network topology
- QoS Adaptations
- Security
- Reuse of states

Active network based solutions

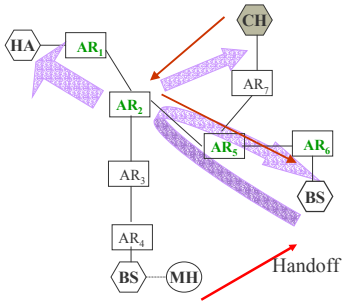
Registration Latency
Binding update Latency
} Home agent's role moved to routers

In transit packets - Smart Buffer

Smooth Handoffs
Binding update delivery
} Multicast like mechanism at the routers

Aggregation of location update messages

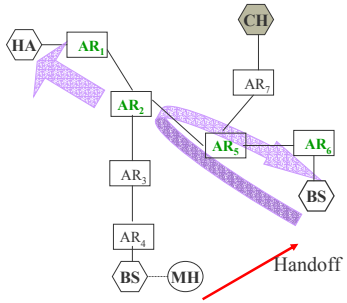
Active Delivery Scheme (ADS)



For example AR_2 handles:

- Registration Reply
- Redirection of packets
- Programming
- CH Notification

Active Delivery Scheme (ADS)



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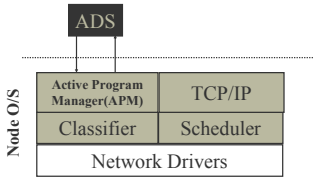
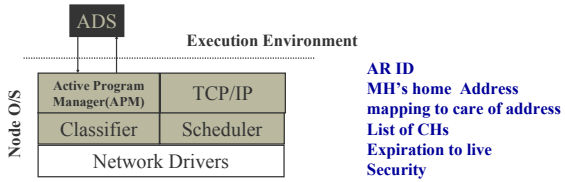
Architecture

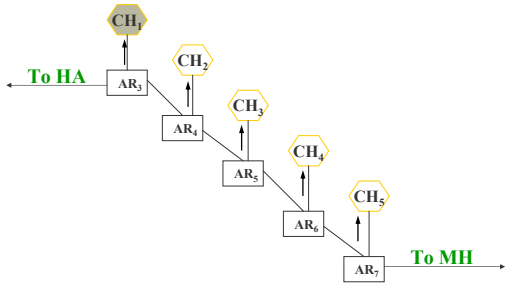


Architecture

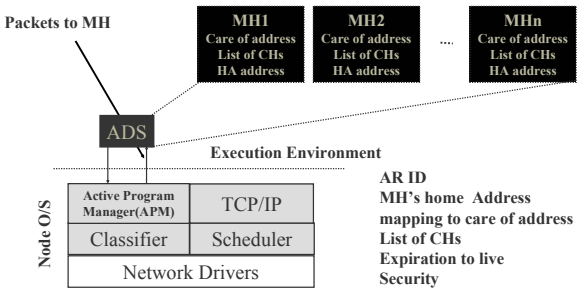


AR ID
MH's home Address
mapping to care of address
List of CHs
Expiration to live
Security

Efficient delivery of binding updates



Architecture



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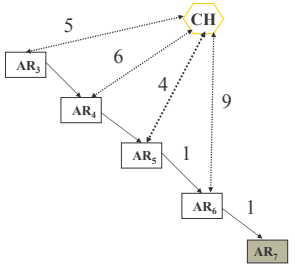
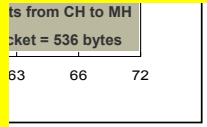




Aggregation

Adaptive waiting time

Based on observed arrival rate of loc

Reduces network load and congestio

Single message instead of multiple m

Host)

Multicasting in mobile networks

Latency/Disruption time after handoff

Inappropriate time to live (TTL) value

Difficulty in choosing Core/RP in shared tree approach

Source migration in shortest path tree

Multicasting Schemes

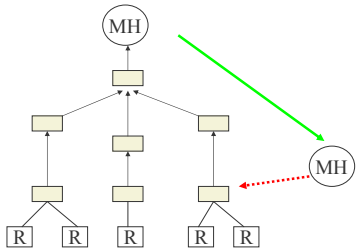
Bi-directional home agent (HA) tunneling
- **Tunnel convergence problem**

Remote subscription
- **Rebuilding multicast tree**

DVMRP – Distance Vector Multicast Routing Protocol
- **One separate tree for each source**

PIM – Protocol Independent Multicast
- **Does not support mobile source**

Problem of Source migration



Active Multicast Tree

Adaptive to source movement

On demand optimization

Scalable
- **State of each router is O(N)**
- **Filtering of unnecessary signaling messages**

Incorporates the advantages of both shared and shortest path tree

Active multicast tree

Join process

Step 1: MH makes a request to the local active router (AR)

Step 2: AR queries LD (Location Directory) for contact point

Step 3: AR sends a JOIN-REQUEST message to the contact point

Step 4: Intermediate ARs forward the JOIN_REQUEST

Step 5 : AR creates soft-state if no other subscriber's exist under its purview

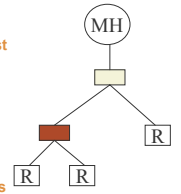
Active Multicast Tree

Send process

Step 1 : MH indicates its interest to local AR

Step 2: Local AR registers with LD of current contact point

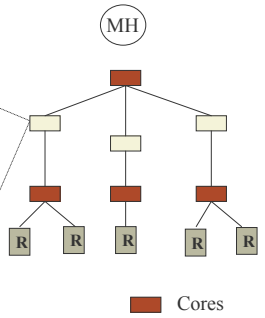
Step 3: AR starts transmitting only when there are subscribers



Active Multicast Tree

States Maintained:

- Upstream AR's Address
- Subscribers' Address
- Multicast Address
- TTL
- Contact Point



Active Multicast Tree

Source Handoff

New local AR register – new care of address at LD

New local AR sends HO_UPDATE message to previous contact point

Old contact point then multicasts CORE_DISCOVERY message down the tree

Cores send a CORE_CONNECT message to MH's current care-of-address

A Core is identified

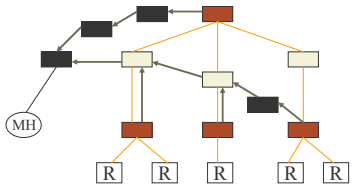
Active Multicast Tree

Core Discovery

To find the nearest core/AR to the MH's new location

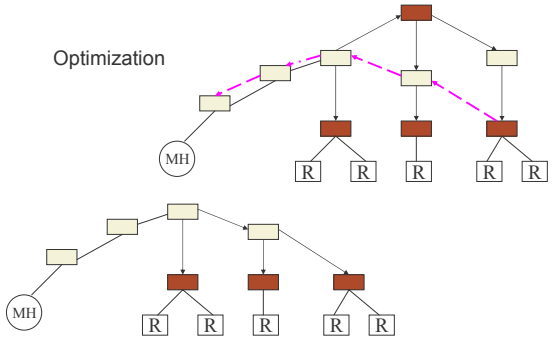
CORE_CONNECT Message

- Hop Count
- Designated Core
- Multicast Address
- MH's Care-of-address



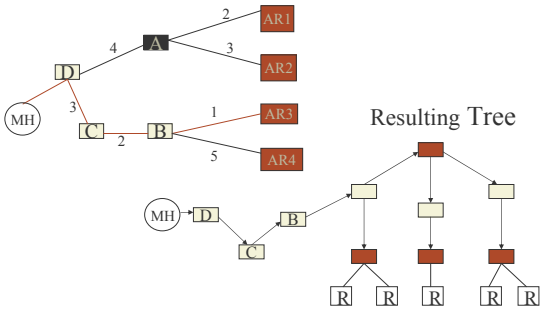
Active Multicast Tree

Optimization



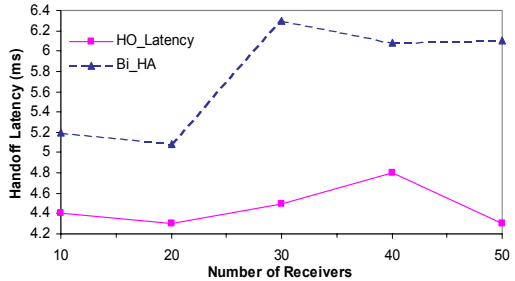
Active Multicast Tree

Finding the nearest core.

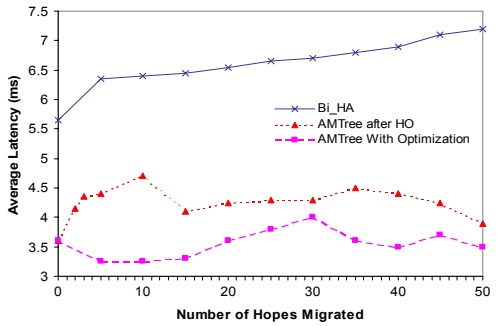


Resulting Tree

Hand off Latency



Hop count



Wireless Multimedia

Source and channel coding schemes

Wireless broadband communication system (WBCS)

CSE 6345
Mobile Computer Systems

Topic 10 : Wireless Multimedia, QoS, and Location Tracking

With Dr. Mohan Kumar

Wireless Multimedia

Networks and protocols

Source Coding

Channel Coding

Mobility

Networks and Protocols

TCP

Real-time

Call admission

- **Bandwidth allocation**

Mobility and wireless support

Channel Coding

Convolution codes and *block codes* for bursty channels

In *Turbo coding* the sequence is encoded twice using convolution codes with an interleaving stage between the two coding stages

- **Interleaving stage introduces randomness into the bit stream and reduces correlation between the two encoded streams**

Joint source-channel coding

- **Source and channel coders are optimized in tandem.**
- **Immense applicability in wireless multimedia communications**

Source Coding

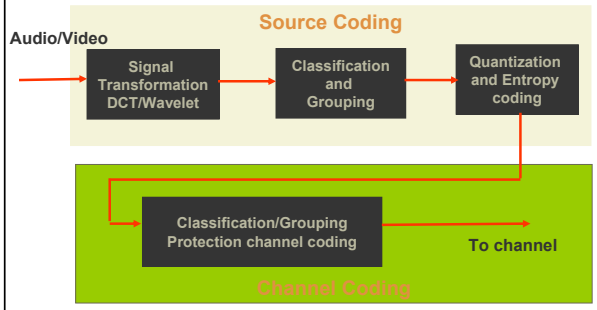
Multimedia is compressed before transport over wireless channel

Source coding schemes offer graceful degradation with loss of data

Error recovery and Error Concealment

- **Error concealment techniques use underlying source compression techniques and exploits the fact that video compression schemes use motion compression.**

Joint Source-Channel coding



Mobility and wireless support

Design of wireless multimedia systems are affected by the velocity of mobility
- **Pedestrian (few feet/sec)**
- **Vehicular (few miles/hour)**
- **High speeds(100s of miles/hour)**

Handoff in cellular networks

Tracking of mobile systems for delivering multimedia content to the mobile users

WBCS for Multimedia

Two approaches for the development of WBCS
- **Wireless local area network (WLAN)**
  - Mainly for indoor applications
  - 802.11
- **Mobile broadband systems (MBS)**
  - Provide full mobility to broadband integrated services digital network (B-ISDN)
  - Examples: UMTS and IMT-2000 (International Mobile telecommunications)

ATM can handle variable bit rate
- **Broadband infrastructure for multimedia systems.**

Physical Layer Issues

Spectrum considerations
- **High frequencies**
- **Complex and expensive techniques**

Channel characteristics
- **Fading and shadowing effects**

Modulation and channel coding schemes
- **Co-channel interference**

Data Link Layer Issues

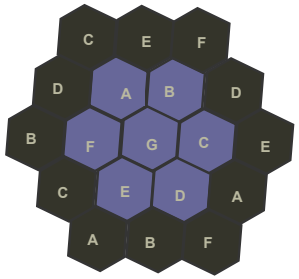
Multiple Access Scheme
- **Minimize or eliminate the chance of collisions**

Error Control

Higher Layer Issues

Channel Allocation

Handoff



Quality of Service

QoS parameters

- Transmission rate error rate, average delay, jitter, cell losses etc.
- measured, improved and to some extent guaranteed in advance

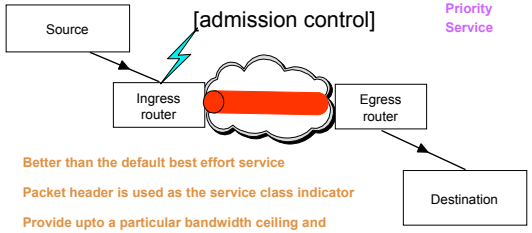
QoS is a concern for continuous transmission of high bandwidth video and multimedia

RSVP(Resource reservation protocol)

QoS mechanisms

Differentiated Services

Classes of diff-serv
- Strict separation
- Priority
- Service



Better than the default best effort service

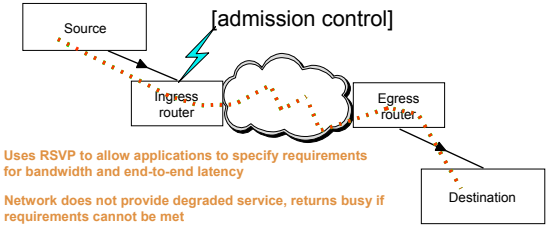
Packet header is used as the service class indicator

Provide upto a particular bandwidth ceiling and Guarantees such as upper bounds on packet loss rate and latency

QoS mechanisms

Integrated Services

End-to end QoS guarantees for particular data flows



Uses RSVP to allow applications to specify requirements for bandwidth and end-to-end latency

Network does not provide degraded service, returns busy if requirements cannot be met

Not scalable and are difficult to handle if they cross network boundaries

Multimedia Issues

Dynamic Bandwidth control

Flow Control

Wireless call admission control

Wireless in-home interconnect

Home RF

Call Admission

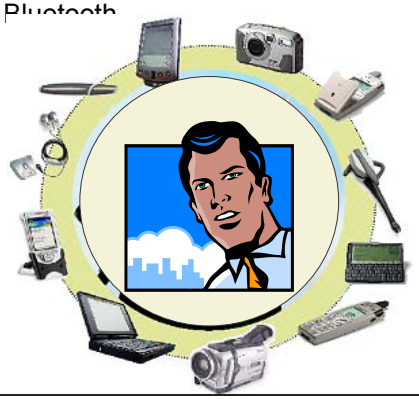
Call admission control focuses on how to block originating calls to reduce forced-termination probability

- **Forced-termination probability is the probability that an accepted call will be forced to terminate before the completion of the service**

Fading and *mobility* is the main reason for variability in resources in wireless networks

- **Algorithm to allocate bandwidth for each call should depend on the traffic load**

Bluetooth



Location Tracking of Mobile Units

Goals

- **Reduce the location update cost**
- **Reduce the call delivery time**

Mobility Tracking Procedures

Location update procedure (LU)

- **Reporting the location of a mobile unit to a system database and maintain it up-to-date**
- **Lot of signaling between the mobile unit and the base station is required**

Mobility Tracking Procedures (Contd.)

Location update procedure (LU)

Call delivery procedure (CD)

- **Delivering the call to the mobile unit, which is roaming around in the network, in a minimum possible time**
- **The location of the mobile unit needs to be identified first before delivering the call.**

Location Update (LU)

Static or Global strategy

Dynamic or Local Strategy

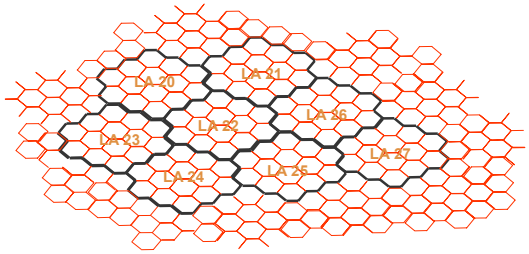
Static or Global Strategy

The whole coverage area is divided into "Location Areas" (LAs)

Each time an a mobile unit crosses the border between two LAs it triggers an LU message to the system databases via a base station

- **Visitor Location Register (VLR) – for LA**
- **Home Location register (HLR) – for each mobile unit**

Location Areas (Contd.)



Location Areas (LAs)

The borders are fixed

Each LA is composed of one or more cells

One or more LAs share a visitor location register (VLR)

Dynamic or local Strategy

No LAs exist

A mobile unit updates it location according to a policy based on

- **Time elapsed**
- **Number of cells visited**
- **The distance to the cell in which the last LU message was triggered**

Call Delivery (CD)

Two major functions

- **Interrogation**
- **Paging**

Call Delivery (Contd.)

Interrogation

- **Entirely supported by the *fixed network***
- **The mobile unit is searched by the database**
- **In the case of global strategy the output of the interrogation would be a LA**
- **In the case of local strategy the output of interrogation would be a cell**

Call Delivery (Contd.)

Paging

- **After a successful interrogation, paging is started**
- **Mobile unit is searched using some paging algorithm for the cell in which the unit is currently roaming.**
- **Many paging algorithms has been proposed**
  Some of these work on the basis of *probability factor.*

Example of LU and CD Algorithms

LU

- **The mobile unit sends a LU signal (registration request) to the new VLR of the LA it is entering**
- **If it is a first time request, then a notification is sent to the local HLR of the mobile unit**

Example of LU and CD Algorithms

CD

When a number is dialed by the caller, the caller's VLR is first queried for the entry of the callee. If the callee is found to be registered in the same VLR then the callee is paged and the call is delivered to it directly

Otherwise the VLR sends a location request to the callee's HLR

CSE 6345
Mobile Computer Systems

Topic 11 :Mobile Ad hoc Networks

With Dr. Mohan Kumar

What are Ad Hoc networks?

Infrastructure-less mobile networking

A collection of mobile nodes forming a temporary network without a fixed infrastructure

Examples

- In airplanes, ships, trucks, cars
- On people, Personal area networks (PANs)
- Sensor networks

Characteristics

Nodes move around arbitrarily

Characteristics

Nodes move around arbitrarily

A MANET system may operate in Isolation

Characteristics

Nodes move around arbitrarily

A MANET system may operate in Isolation

MANET nodes are equipped with wireless transmitters and antennas

Characteristics

Nodes move around arbitrarily

A MANET system may operate in Isolation

MANET nodes are equipped with wireless transmitters and antennas

Energy-constrained operation

Topology

Dynamic

Decentralized

Self-organizing

Multihop

Communication

Bandwidth-constrained variable capacity links

- **Multiple access**
- **Fading**
- **Noise and Interference conditions**

Applications

Applications involving cooperative mobile data exchange

- **Personal area networking**
  - Cell phone, laptop, ear phone, wrist watch etc..

Alternatives or enhancements for cell based mobile network infrastructures

Security

Limited physical security

- **More prone to**
  - Eves-dropping
  - Denial of service
  - Impersonation
  - Disclosure

Applications (Contd.)

Wearable computing and communications

Fire/safety/rescue operations

Military applications

- **Soldiers, tanks, planes etc..**

Civilian operations

- **Meeting rooms, taxi cab network, Sports etc..**

Challenges in Ad- hoc networks

Routing
No infrastructure, constantly changing nodes

Challenges in Ad- hoc networks

Routing
No infrastructure, constantly changing nodes

Security
New vulnerabilities, nasty neighbors

Small devices
Batteries, little computing power

Challenges in Ad- hoc networks

Routing
No infrastructure, constantly changing nodes

Security
New vulnerabilities, nasty neighbors

Routing in Ad-hoc networks

No infrastructure and hence the participating nodes should have routing functionalities

The source to destination route is formed through many nodes and these nodes forward the packets

Many potential routes and hence, the best path in the mesh needs to be determined

Routing protocols

Distributed operation

Loop-freedom

- **Packets spinning around in the network**
- **TTL may be one solution**

Demand-based operation

- **Adapt to the traffic patterns on a demand or need basis.**

Routing protocols

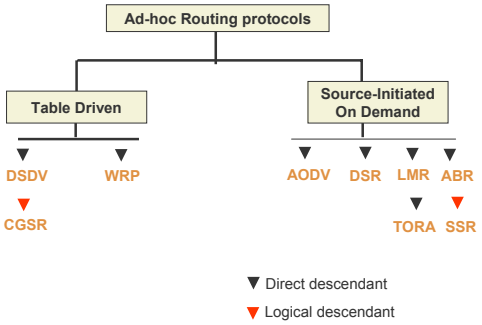


Table Driven Routing protocols

Each node to maintain one more tables for storing up-to-date routing information.

Respond to changes in the network topology by propagating updates throughout the network

Differ in the number of routing related tables required and the methods of network change broadcasting.

Source initiated on-demand routing

Source initiated on-demand routing

- **Creates route only when desired by a source node**
- **The source node initiates a route discovery process**
- **A route is found after examining all possible route permutations**
- **This route is maintained until the route is no longer required**

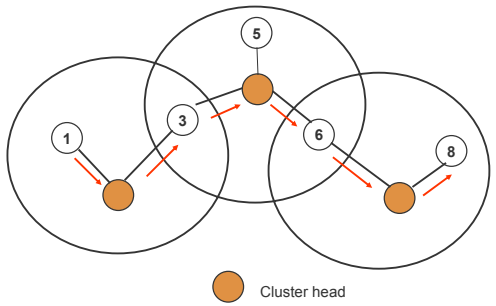
Destination Sequenced Distance Vector Routing (DSDV)

- Hop-by-hop distance vector routing protocol
- Loop freedom guaranteed
- Sequence number used for making decision
- Periodic route updates
- Complexity grows as $O(n^2)$

Clusterhead Gateway Switch Routing (CGSR)

- CGSR is a clustered multihop network
- DSDV used as underlying routing protocol
- A cluster head table is necessary in addition to the routing table
- Hierarchical clustered-to-gateway routing approach to route traffic from source to destination

CGSR Routing



Wireless Routing Protocol (WRP)

- Requires each node to maintain 4 tables
  - **Distance table , Routing table, Link-cost table and Message retransmission list (MRL) table**
- Uses hello packets when ever there are no recent transmissions from a node
- Informs only the neighboring nodes about the link status change
- Loop free

Ad-Hoc On-Demand Distance Vector (AODV)

- Combination of both DSR and DSDV
- Assumes symmetric links between the nodes
- Route discovery and route maintenance from DSR
- Hop-by-hop routing, sequence numbers and periodic updates from DSDV
- Support multicasting

Dynamic Source Routing (DSR)

Intended for networks in which the nodes move at moderate speed with respect to the packet transmission latency

No need for intermediate nodes to maintain up-to-date routing information. Packets carry the route information.

Involves route discovery and route maintenance

Temporally-Ordered Routing Algorithm (TORA)

Best suited for networks with dense population

Distributed routing protocol based on a "link reversal" algorithm

Nodes maintain information about one-hop nodes

Associativity Based Routing (ABR)

- Uses connection oriented packet forwarding approach
- Loop free, deadlock free and packet duplicate free
- Route selection is based on the degree of association stability of nodes along the path
  - **Association stability is the connection stability of one node with respect to another node over time and space**
- Beaconing to signify existence by each node
- Partial route recovery (from intermediate nodes)

Signal Stability Routing (SSR)

A logical descendant of ABR

Routes selected based on the signal strength between nodes and node's location stability
- **Selects routes with stronger connectivity**

Route recovery initiated from the source

Comparison of table-driven and on-demand routing protocols

	On-demand	Table-driven
Availability of Routing information	Available when needed	Always available regardless of need
Routing philosophy	Flat	Mostly flat, except for CGSR
Periodic route updates	Not required	Required
Coping with Mobility	Use localized route discovery as in ABR and SSR	Inform other nodes to achieve a consistent routing table
Signaling traffic generated	Grows with increasing mobility of active routes (as in ABR)	Greater than that of on-demand routing
Quality of service support	Few can support QoS, although most support shortest path	Mainly shortest path as the QoS metric

Multicast protocols in Ad-hoc networks

Multicasting in ad-hoc networks faces many challenges due to
- **Device mobility**
- **Limited storage capacity on devices**
- **Limited power and channel bandwidths**
- **No distinction between nodes and end routers**

Multicast protocols

On Demand Multicast routing protocol (ODMRP)
- **On-demand technique to establish membership**
- **Use broadcast nature of links**
- **Reactive beacons**
- **Sender has to join multicast group**
- **Creates a mesh of nodes to provide redundant multicast routes**
- **Routing decision on flags**

Research areas in Ad-hoc networking

Architecture
Access control and discovery
Multicasting protocols
Performance
Quality-of service
Routing protocols
Scalability
Secure services
Self-configuration

Where are we headed?

350 million mobile devices
Increase to 1 billion very soon

Smart phones and e-commerce

$200 billion mobile commerce market by 2004

CSE 6345
Mobile Computer Systems

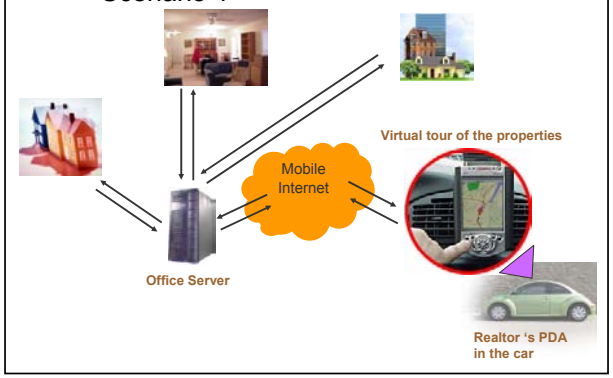
Topic 12 : Wireless Internet Applications

With Dr. Mohan Kumar

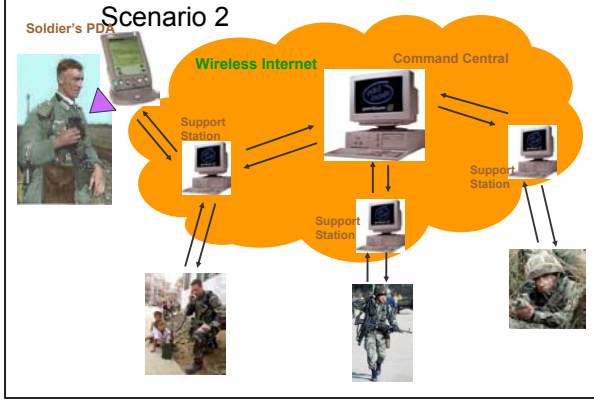
Applications

Mobile commerce
Telemedicine
Education
Transportation and Traffic control
Aged care
Security and crime prevention
Military
Crisis management

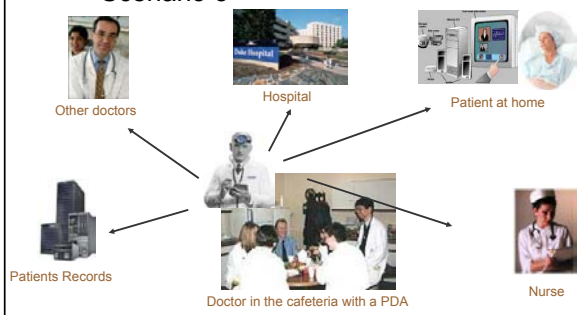
Scenario 1



Scenario 2



Scenario 3



Realizing Mobile Applications

Technology to realize mobile computing application is present today

Wireless Internet and mobile devices

Need to glue together the software and hardware components

Wireless and Mobile Electronic Commerce

Wireless and mobile e-commerce
- m-commerce

Mobile commerce market is expected to rise to $200 billion by 2004

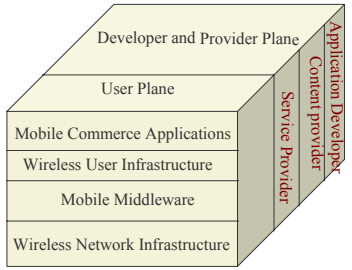
M-Commerce

Acceptance of m-commerce applications depends on
- **How fast these applications can be deployed**
- **Cost-value ratio**
- **Easy to use and uniform interfaces**
- **Secure transactions while on the move**

Requirements of M-Commerce

Wireless QoS
Location Management
Reliable and survivable wireless networks
Heterogeneity

Framework for M-Commerce



Framework for M-Commerce

Mobile Commerce Applications

Wireless User Infrastructure

Mobile Middleware

Wireless Network Infrastructure

M-Commerce Applications

Mobile financial applications

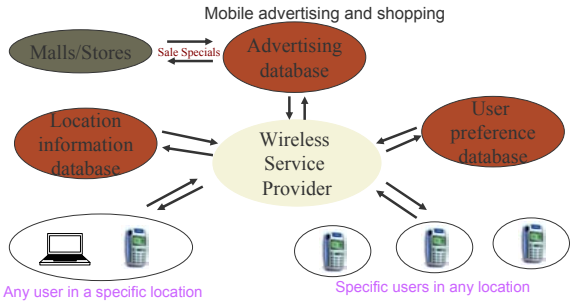
- **Mobile banking**
- **Brokerage service**
- **Mobile money transfer**
- **Mobile micro-payments**
  - User could make a call to a certain number where per-minute charges equals the cost of the vending item
  - Payments via using pre-paid numbers purchased from a service provider

M-Commerce Applications

Mobile advertising

- **Targeted advertising using information collected by wireless service providers and information on the current location of the mobile users**
- **Personalized advertising messages**
- **Location sensitive advertising**
  - Any user in a specific location
  - Specific users in any location
- **Advertisements can be performed by Short Messaging Service(SMS)**

M-Commerce Applications



M-Commerce Applications

Mobile inventory management

Location tracking of goods, services and people

Example: Rolling inventory

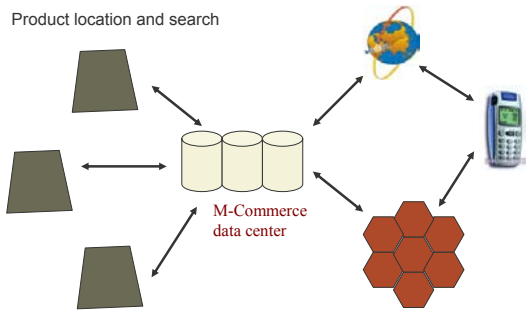
Multiple trucks carrying a large amount of inventory on the move

When a store needs certain items/goods it can locate a truck and just in time delivery of items can be performed

Product location and search

M-Commerce Applications

Product location and search



M-Commerce Applications

Proactive service management

Collecting information about current or near-future user needs and providing services to users proactively

Example: Collection of information about the ageing components of an automobile

Automobiles can be equipped with small smart sensors that keeps track of how much wear and tear a component has gone through and can relay that information to appropriate parties.

M-Commerce Applications

Mobile Auctions, entertainment and other services

Continued connectivity is a real issue as it may affect the perceived quality of the service.

Mobile office

Providing services for the business people such as traffic jam reports, airport and flight information, vacation reservations etc.

Mobile distance education

Offering classes using streaming audio and video

Wireless data center

Providing downloadable information from data warehouses

Framework for M-Commerce

Mobile Commerce Applications

Wireless User Infrastructure

Mobile Middleware

Wireless Network Infrastructure

Wireless User Infrastructure

Mobile devices with sufficient power, memory, display and communication facilities

Hand held device is the entry point for most m-commerce applications

Devices available today are either communication-centric or computing-centric.

Wireless User Infrastructure

An example of handheld device

PDA/Cell phone integrated unit

- Send and receive email with attachments from anywhere
- Send and receive video clips, digital images and music
- Download JPEG, GIF, TIFF, BMP images
- Play Real video and Macromedia Flash
- Browse the web wirelessly and see it in full color
- Talk hands free on the speaker phone
- Participate in video conferences

Wireless User Infrastructure

User infrastructure requirements for the deployment of m-commerce applications

Dynamic, adaptable and smart user interface that learns from the user

Ability to accept user input in many forms including video

Ability to display rich and useful contents

Location awareness and ability to track users, products and devices

Multi-network interfaces for increased and reliable wireless access

Wireless User Infrastructure

User infrastructure requirements for the deployment of m-commerce applications (Contd.)

- **Basic security features**
- **Possible support for context awareness**
- **Ability to discover and download upgraded applications proactively**
- **An operating system that can manage resources to support many of these functions**

Framework for M-Commerce

Mobile Commerce Applications

Wireless User Infrastructure

Mobile Middleware

Wireless Network Infrastructure

Mobile Middleware

Middleware for m-commerce applications

- **An enabling layer software that is used by application developers to connect their m-commerce applications with different networking and operating systems without introducing mobility awareness in the applications**

The use of middleware allows applications to run with better response times and much greater reliability

- **Optimization techniques such as header compression, delayed acknowledgements and concatenation of several packets into one.**

Mobile Middleware

An example

- **ExpressQ from Nettech**
  - Stores messages when mobile user is out of the network range and forwards them when the mobile user comes within the range the next time.

Using WAP architecture, wireless middleware can be deployed as a client on a mobile terminal and as a server on the gateway or intermediate server

However, middleware does introduce additional complexity and significant initial cost

Framework for M-Commerce

Mobile Commerce Applications

Wireless User Infrastructure

Mobile Middleware

Wireless Network Infrastructure

Wireless Network Infrastructure

General Network requirements for m-commerce applications

Location management

- Location tracking for determining the location of an object
- Location accuracy and response time
- Frequency of location tracking
- Horizontal and vertical location tracking

Wireless Network Infrastructure

General Network requirements for m-commerce applications (Contd.)

Multicast support

- Support of multicast in infrastructure wireless networks
- Support of multicast in ad-hoc networks
- Group connectivity under mobility/failure
- Synchronization and atomicity of transactions from multiple users

Wireless Network Infrastructure

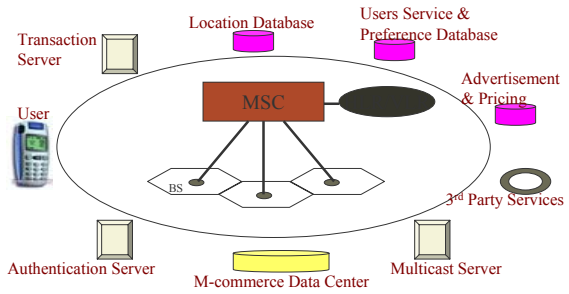
General Network requirements for m-commerce applications (Contd.)

Network dependability

- Figure of network dependability
- Impact and frequency of component failure
- Fault-tolerant design
- User access to multiple networks
- Levels of network availability

Wireless Network Infrastructure

Possible components in a m-commerce transaction



Wireless Network Infrastructure

Quality of service

Bandwidth requirements

Delay and delay variation

Tolerable loss characteristics

Roaming across multiple networks

Handoff among multiple wireless networks

Keeping track of users across networks

CSE 6345
Mobile Computer Systems

Topic 12 : Pervasive Computing

With Dr. Mohan Kumar

Mark Weiser's prophecy

"The most profound technologies are those that disappear. They weave themselves into the fabric of everyday life until they are indistinguishable from it."

Pervasive Computing

Mobile computing
- Mobile networking
- Mobile information access
- Infrastructure Support
- Location sensitivity

Mobile Computing is about anytime anywhere computing

Thrust areas

Effective use of smart spaces

Pervasive Computing

Mobile computing
- Mobile networking
- Mobile information access
- Infrastructure support
- Location sensitivity

+

Pervasive Computing
- Automated
- Continuous
- Invisible
- Heterogeneous

Thrust areas

Effective use of smart spaces
Invisibility

Thrust areas

Effective use of smart spaces
Invisibility
Density of Interactions
Heterogeneity
Uneven conditions
Proactivity
Privacy and Trust

Scenario 1 – Aura at CMU

Challenges

Proactivity
QoS
Authentication and Security
Heterogeneity
Pervasive computing devices

Authentication and Security

Context-awareness

The system should be aware of

- **User's state and surroundings**
- **Application characteristics**

Projects

Aura at CMU
Oxygen at MIT
PIMA at IBM
Endeavor at UC Berkeley
Situated Computing at HP
Sentient at Cambridge
PICO at UTA

Aura

"Personal Information Aura"

Components of Aura

- **Task-driven computing**
- **Energy aware adaptations**
- **Fidelity computations**
- **Intelligent networks**
- **Human Computer Interface**
- **Agent deployment**

Web site: http://www-2.cs.cmu.edu/~aura/

Oxygen

"Very large all encompassing initiative
Current emphasis on Human Computer Interface"

Environment-enabled devices

- H21 – Handheld
- N21 – Network
- E21 – Embedded
- And 5 others

Improve quality of life

- Speech
- Knowledge access
- Collaboration
- Automation

Web site: http://oxygen.lcs.mit.edu/

PIMA

"PIMA : Platform-Independent Model for Applications"

Components

- ***Development environment***
- ***Specialization Engine***
  - Tasks
  - Interactions
  - Behavior
- ***Thin-Client***
  - **Connected**
- ***Java/native Fat-Client***
  - **Disconnected**
- ***Interactive Web Application***
  - **Full funnction**

Web site: http:// www.research.ibm.com/PIMA

Endeavour

"Endeavor's approach centers on enhancing the endeavor of understanding"

- **Applications**
  - Learning Classroom
  - E-book
  - Automobiles
- **Information Utility**
  - Human activity
  - User Interface
- **Information Devices**
  - PDA, Laptop, Camera, MEMS
- **Event Modeling**
- **Transcoding, Filtering**
- **Nomadic Data Processing**
  - Cache
  - Replication
- **Data management**
  - Stream
  - Path

Web site: http://www.cs.berkeley.edu/~randy/Endeavour/

Situated Computing

"Situated computing -- ability of computing devices to detect, interpret and respond to aspects of the **user's** local environment"

- Augmented Reality
- Localized information
- Context-aware retroieval
- Situated reminders
- Agents
- Monitoring

- Health
- User Identity
- Companions
- Location
- Time
- Computing resources
- Physical environment

Web site: http://www.hpl.hp.com/techreports/97/HPL-97-66.html

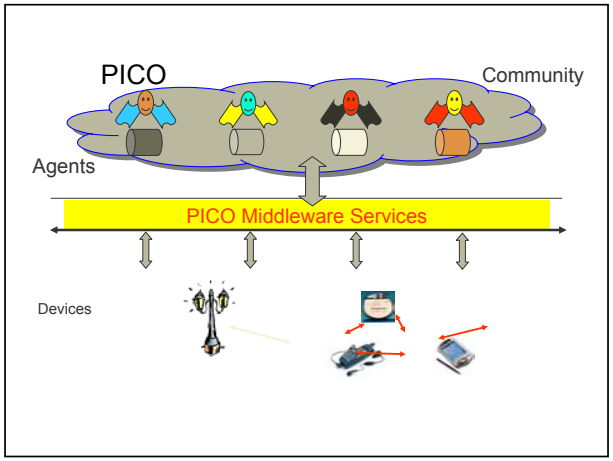
Sentient Computing

"Using sensors and resource status data to maintain a model of the world which is shared between users and applications"

- **Shared perceptions**
- **Ultrasonic technology**
  - **BAT devices**
- **Programming with Space**
- **Context-aware retrieval**
- **Ubiquitous user interfaces**

Working prototype throughout our 10000 square foot building at AT&T Labs in Cambridge, England.

Web site: http://www.uk.research.att.com/spirit/



Future of pervasive computing

Pervasive computing is much more than mobile computing

The goal is to provide services that can automatically and continuously adapt to user needs

The rapid progress in pervasive computing will enable users to use computers subconsciously.