18-452/18-750
Wireless Networks and Applications
Lecture 16: The Internet and Cellular

Peter Steenkiste

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http://www.cs.cmu.edu/~prs/wirelessF18/

Wireless and the Internet Challenges

- IP addresses are used both to forward packets to a host and to identify the host
  - » Active session break when a host moves
  - » Mobile hosts are hard to find
- TCP congestion control interprets packet losses as a sign of congestion
  - » Assumes links are reliable, so packet loss = full queue
  - » Not true for wireless links!
- Applications generally assume that they are continuously connected to the Internet
  - » Can access servers, social networks, …
  - » Mobile apps must support "disconnected" operations

Outline

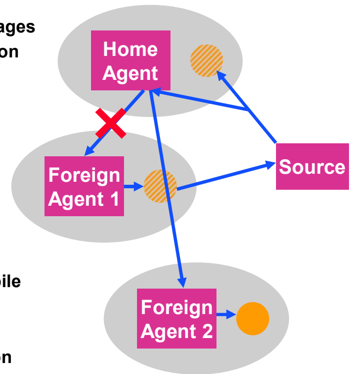
- The Internet 102
- Wireless and the Internet
- Mobility: Mobile IP
- TCP and wireless
- Disconnected operation
- Disruption tolerant networks

Mobile IP Goals

- Communicate with mobile hosts using their "home" IP address
  - » Target is "nomadic" devices: do not move while communicating, i.e., laptop, not cellphone
  - » Allows any host to contact mobile host using its "usual" IP address
- Mobility should be transparent to applications and higher level protocols
  - » No need to modify the software
- Minimize changes to host and router software
  - » No changes to communicating host
- Security should not get worse

Mobile IP Operation

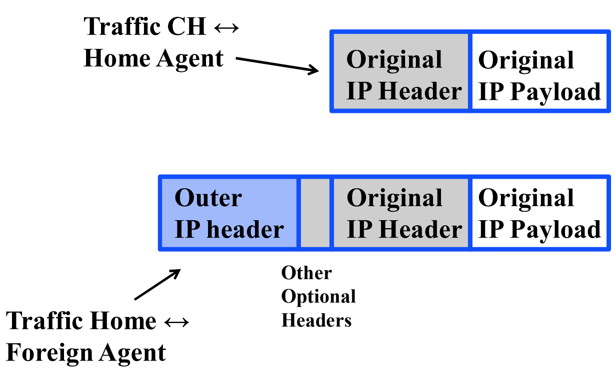
- Agents advertise their presence.
  - Using ICMP or mobile IP control messages
  - Mobile host can solicit agent information
  - Mobile host can determine where it is
- Registration process: mobile host registers with home and foreign agent.
  - Set up binding valid for *registration lifetime*
- Tunneling
  - forward packets to foreign agent
  - foreign agent forwards packets to mobile host
- Supporting mobility
  - invalidating old caches in a lazy fashion



Mobile IP

- Home network has a home agent that is responsible for intercepting packets and forwarding them to the mobile host.
  - E.g. router at the edge of the home network
  - Forwarding is done using tunneling
- Remote network has a foreign agent that manages communication with mobile host.
  - Point of contact for the mobile host
- Binding ties IP address of mobile host to a "care of" address.
  - binding = (IP address, foreign agent address)
  - binding includes time stamp

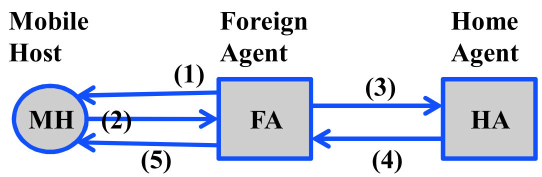
Tunneling IP-in-IP Encapsulation



Optimizations

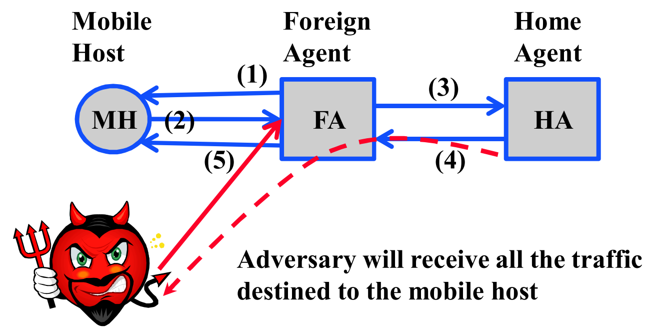
- Mobile host can be its own the foreign agent.
  - Mobile host acquires local IP address
  - performs tasks of the mobile agent
- Short circuit the home location by going directly to the foreign agent.
  - Routers in the network store cache bindings and intercept and tunnel packets before they the mobile host's home network
  - Need a protocol to update/invalidate caches
  - Raises many security questions and is not in the standard

Registration via Foreign Agent



1. FA advertizes service
2. MH requests service
3. FA relays request to HA
4. HA accepts (or denies) request and replies
5. FA relays reply to MH

Authentication



Mobile IP Authentication

- Without security, an adversary on any network with a FA could issue a registration request for a host on any network (with a HA)
  - » HA would begin to forward datagrams to the bad guy
- Registration messages between a mobile host and its home agent must be authenticated
  - » Uses mobile-home authentication extension
- Mobile hosts, home agents, and foreign agents must maintain a mobility security association for mobile hosts, indexed by…
  - » Security Parameter Index (SPI)
  - » IP address (home address for mobile host)

Discussion

- Mobile IP not used in practice
- Not designed for truly mobile users
  - » Designed for nomadic users, e.g. visitors to a remote site
  - » It only solves the initial contact problem, but …
- Mobile devices are typically clients, not servers, i.e., they initiate connections
  - » The problem Mobile IP solves is rare in practice
- IETF defined solutions that are more efficient
  - » But they are quite heavy weight: effectively creates overlay with tunnels and special “routers”
- Ultimately all solutions are similar: need a “relay” that knows location of the device

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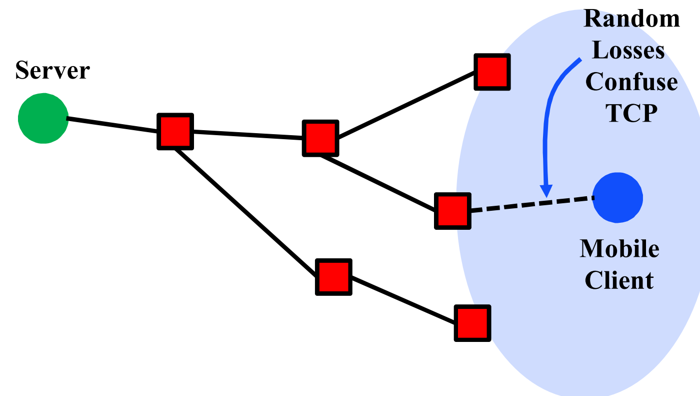
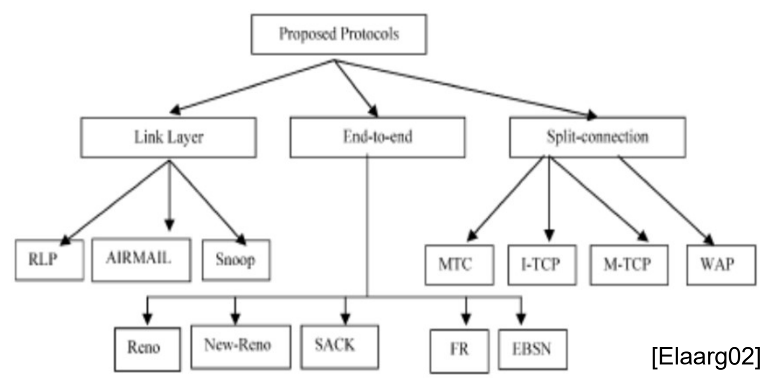
Solution Ideas?



Solution Space

- **Modify TCP for wireless paths**
  - » Would maintain status quo for wired paths
  - » What would wireless TCP look like?
  - » Difficult to do: there are many Internet hosts
  - » Traditionally, hosts have no information about path properties
- **Modify TCP for all paths**
  - » Not clear what that modification would be!
  - » Similar problems: need to modify many hosts
- **Modify TCP only on the mobile host**
  - » A more practical idea – but what would the change be?
- **Keep end hosts the same but tweak things at the wireless gateway**
  - » Keep end-end TCP happy despite wireless links

Possible Classification of Solutions



[Elaarg02]

An Internet Style Approach

- Use aggressive retransmission in the wireless network to hide retransmission losses
  - » Most deployed wireless network in fact do that already
  - » Would sell few products if they did not
- Wireless losses translate into increased delay
  - » But TCP roundtrip time estimation is very conservative, e.g. increases if variance is high
- Also: persistent high loss rate results in reduced available bandwidth → congestion response is appropriate and needed
- Works remarkably well!
- Other solutions only needed for "challenged" networks

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Disconnected Operation

- Mobility means that devices will occasionally be disconnected from the network
  - » Seconds ... Minutes … Hours .. Days
  - » Mostly an issue for clients
- This can confuse systems and applications that assume a wired/stationary model
  - » Clients cannot access servers, e.g., mail, calendar applications, …
  - » Distributed file systems
  - » Systems for back up or systems management
- Must adapt the applications and systems to make them "disconnection aware"

Two Examples

- E-mail: users must be able to "work on" e-mail offline and operations are performed when the mobile client is redirected
  - » Compose, read and delete e-mail
  - » Possibly others: manage folders, etc.
- Calendars and tasks are similar: operations performed offline must be executed later
  - » Adding or removing appointment and tasks, …
- Must sometimes resolve conflicts when multiple clients are used offline
  - » E.g., mail is deleted on one client and moved to another folder on another – delete or keep?
  - » Tend to be minor – ask user for help if needed

More Complex Case: File System

- A distributed file system can be accessed from many computers
  - » Files tend to be cached in the computers
- Creates opportunities for inconsistencies
  - » E.g., a file is modified on two different computers – how do you merge the changes? Who is responsible?
- The consistency model depends on the file system
  - » Stronger consistency requires that the system can keep track of all copies and remove/lock them if needed
- Disconnected operation makes the consistency problem harder!
  - » Some file copies my be inaccessible for long periods!

Mobility is Common Today

- Many applications are designed to work on mobile clients so they deal properly with disconnections
  - » Many apps on mobile devices are designed for mobility
  - » Most clients server applications can work offline with at least partial functionality
- Does not work for interactive applications
  - » Games, etc.
- Disconnection can still be very inconvenient
  - » Need state that is not cached on your client device
  - » Things like back ups cannot be performed
  - » Unpredictable delays in communication

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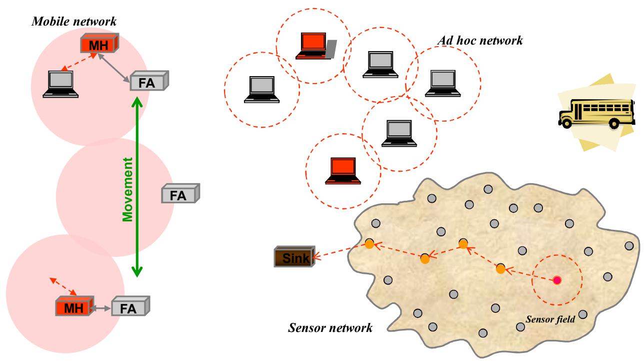
Based on slides by Kevin Fall

Challenged Networks

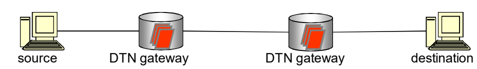
- Violate one or more of Internet's assumptions
  - » End-points may rarely/never be online at the same time
  - » Very long delay path, frequent disconnections, …
  - » Have naming semantics for their particular application domain
  - » Not be well served by the current end-to-end TCP/IP
- Examples
  - » Terrestrial mobile networks
  - » Some ad-hoc networks
  - » Sensor/actuator networks
- Goals for "disruption tolerant" networks
  - » Achieve interoperability between very diverse types networks
  - » Sometimes also called disruption tolerant

Background



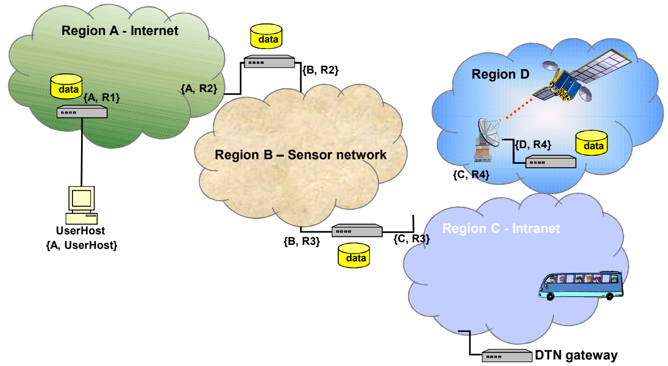
High-level Architecture

- Characteristics:
  - » Operate as an overlay above the existing transport layers
  - » Based on an abstraction of message switching
    - – Bundle
    - – Bundle forwarder (DTN gateway)
    - – Store-and-forward gateway function between different networks



- Constituent of DTN architecture
  - » Region: internally homogenous, i.e. same network stack, addressing, …
  - » DTN gateway: Interconnection point between region boundaries
  - » Name Tuple: {Region name, Entity name}

Example DTN



Overview

- Cellular principles – "classic" view
  - » Cellular design
  - » Elements of a (generic) cellular network
  - » How does a mobile phone call take place?
  - » Handoff
  - » Frequency Allocation, Traffic Engineering
- Early cellular generations: 1G, 2G, 3G
- Today's cellular: LTE

Some slides based on material from
"Wireless Communication Networks and Systems"

Cellular versus WiFi

	Cellular	WiFi
Spectrum		
Service model		
MAC services		

- Implications for level of service (SLAs), cost, nature of protocols, …?

The Advent of Cellular Networks

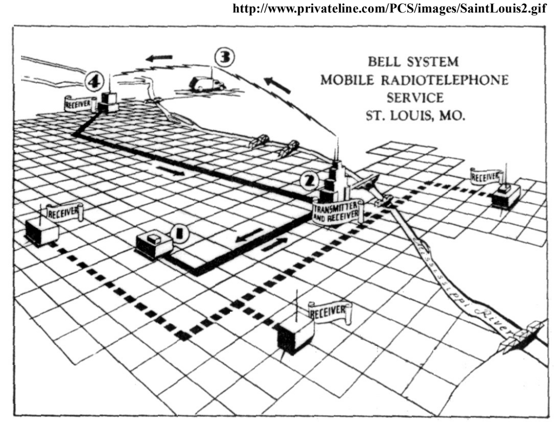
- "Mobile radio telephone system" was a predecessor of today's cellular systems
  - » High power transmitter/receivers
  - » Could support about 25 channels
  - » in a radius of 80 Km
- Over time, to increase network capacity:
  - » Multiple lower power transmitters (100W or less)
  - » Smaller transmission radius -> area split in cells
  - » Each cell with its own frequencies and base station
  - » Adjacent cells use different frequencies
  - » The same frequency can be reused at sufficient distance
- These trends are continuing …

The Cellular Idea

- In December 1947 Donald H. Ring outlined the idea in a Bell labs memo
- Split an area into cells, each with their own low power towers
- Each cell would use its own frequency
- Did not take off due to "extreme-at-the-time" processing needs
  - » Handoff for thousands of users
  - » Rapid switching infeasible – maintain call while changing frequency
  - » Technology not ready

The MTS network

http://www.privateline.com/PCS/images/SaintLouis2.gif



The Early Mobile Phones

- First mobile phones bulky, expensive and hardly portable, let alone mobile
  - » Phones weighed ~40 Kg
  - » Some early prototypes were much bulkier than shown in the pictures (think: large backpack)
- Operator assisted with 250 maximum users

… the Remaining Components

- In December 1947 the transistor was invented by William Shockley, John Bardeen, and Walter Brattain
- Why no portable phones at that time?
- A mobile phone needs to send a signal – not just receive and amplify
- The energy required for a mobile phone transmission still too high for the high power/high tower approach – could only be done with a car battery

… and the Regulatory Bodies

The FCC commissioner Robert E. Lee said that mobile phones were a status symbol and worried that every family might someday believe that its car had to have one.

Lee called this a case of people "frivolously using spectrum" simply because they could afford to.

From The Cell-Phone Revolution, AmericanHeritage.com

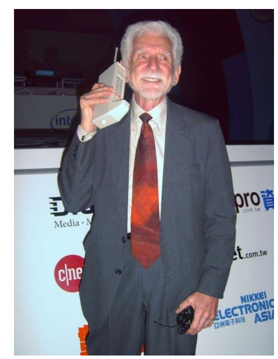
DynaTAC8000X: the First Cell Phone

The "brick":
- weighed 2 pounds,
- offered 30 mins of talk time for every recharging and
- sold for $3,995!

It took 10 years to develop (1973-1983) and cost $100 million! (delay due to infrastructure)

Size primarily determined by the size of batteries, antennas, keypads, etc.

Today size determined by the UI!



Dr. Martin Cooper of Motorola, made the first US analogue mobile phone call on a larger prototype model in 1973

Overview

- **Cellular principles**
  - » Cellular design
  - » Elements of a cellular network
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  - » Handoff
  - » Frequency Allocation, Traffic Engineering
- **Early cellular generations: 1G, 2G, 3G**
- **Today's cellular: LTE**

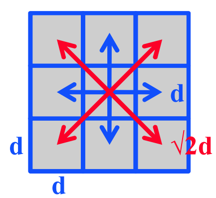
Some slides based on material from
"Wireless Communication Networks and Systems"

How To Design a Cellular Network?

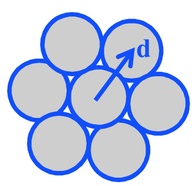
- **Need to get good coverage everywhere**
- **Must be able to plan network based on demand**

Cellular Network Design Options

- **Simplest layout**
  - » Does not match any propagation model
  - » Adjacent antennas not equidistant – how do you handle users at the edge of the cell?

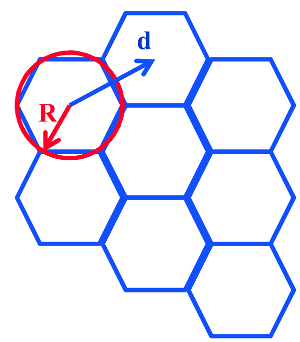


- **"Ideal" layout**
  - » Based on a naïve propagation model – bad approximation but better than squares
  - » Does not cover entire area!



The Hexagonal Pattern

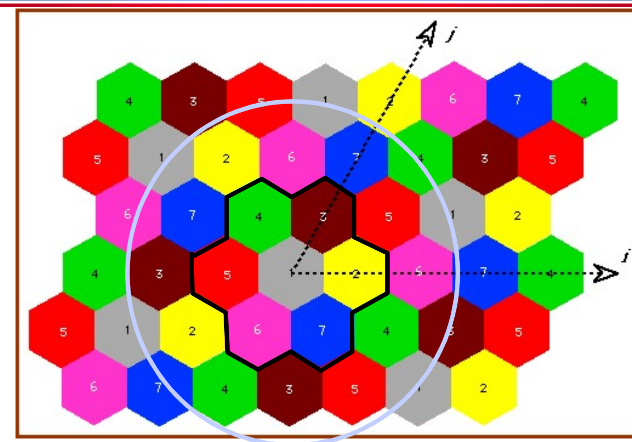
- **A hexagon pattern can provide equidistant access to neighboring cell towers**
- **d = √3R**
- **In practice, variations from ideal due to topological reasons**
  - » Signal propagation
  - » Tower placement



Frequency reuse

- Each cell features one base transceiver
- Through power control the tower covers the cell area while limiting the power leaking to other co-frequency cells
- The number of frequency bands assigned to a cell dependent on its traffic
  - » 10 to 50 frequencies assigned to each cell (early systems)
- How do we determine how many cells must separate two cells using the same frequency?
  - » Need to control the “power to interference” ratio

Minimum separation?



Frequency reuse characterization

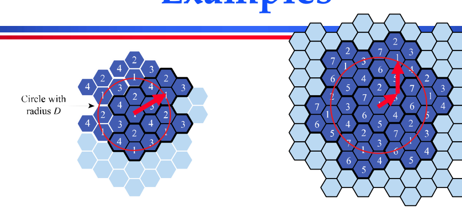
- D = minimum distance between centers of co-channel cells
- R = radius of cell
- d = distance between centers of adjacent cells
- N = number of cells in a repetitious pattern, i.e. reuse factor
- Hexagonal pattern only possible for certain N:

$$N = I^2 + J^2 + (I \times J), \quad I, J = 0, 1, 2, 3, \ldots$$

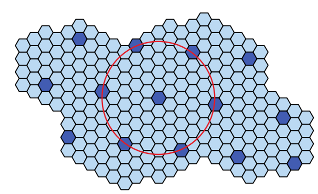
- The following relationship hold

$$\frac{D}{R} = \sqrt{3N} \quad \text{or} \quad \frac{D}{d} = \sqrt{N}$$

Frequency Reuse Pattern Examples



(a) Frequency reuse pattern for $N = 4$ (b) Frequency reuse pattern for $N = 7$



(c) Black cells indicate a frequency reuse for $N = 19$

Capacity and Interference

- S = Total # of duplex channels available for use
- k = Total # of duplex channels per cell
- N = Size of cluster, i.e., cells that collectively use the complete set of available frequencies

$$\frac{S}{k} = N \qquad \Rightarrow S = kN$$

- If a cluster is replicated M times within the system, the total # of duplex channels C can be used as a measure of capacity

$$\Rightarrow \qquad C = MkN = MS$$