Mobile Wireless Networking
The University of Kansas EECS 882
Wireless and Mobile Internet

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Mobile Wireless Networking

Wireless and Mobile Internet

WI.1  Impact of untethered operation in the Internet
WI.2  Mobile IP
WI.3  TCP over wireless links
WI.4  Internet applications
Wireless and Mobile Internet

WI.1: Untethered Internet Operation

WI.1  Impact of untethered operation in the Internet
WI.2  Mobile IP
WI.3  TCP over wireless links
WI.4  Internet applications
Internet History

- ARPANET ~1970 considered variety of links
  - leased PSTN lines
  - packet radio
  - satellite
- Internet evolved into primarily wired infrastructure
  - TCP/IP protocol suite developed under these assumptions
    *problems*?
Internet History

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  - no direct support for lossy wireless links
  - no support for mobility
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  – no support for mobility: static binding of IP addresses

*Solution?*
Internet History

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  – TCP/IP protocol suite developed under these assumptions
  – no direct support for lossy wireless links
  – no support for mobility: static binding of IP addresses

• Solution attempts
  – mobile IP to support end-system movement
  – TCP modifications to support wireless links
Wireless and Mobile Internet

WI.2: Mobile IP

WI.1 Impact of untethered operation in the Internet
WI.2 Mobile IP
WI.3 TCP over wireless links
WI.4 Internet applications
IP Mobility
Overview

• Problem: node mobility between IP subnets
  – need to revisit IP-address/node bindings
DHCP
Overview

- DHCP: dynamic host configuration protocol [RFC 2131]
- Allows node to dynamically obtain IP address
  - as well as other configuration parameters, e.g. DNS server
- Benefits
  - reduces manual configuration
  - allows mobile nodes to easily move attachment point

Limitations?
DHCP
Overview

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- Allows node to dynamically obtain IP address
  - as well as other configuration parameters, e.g. DNS server
- Benefits
  - reduces manual configuration
  - allows mobile nodes to easily move attachment point
- Problems
  - no handoff capabilities
  - flows and sessions interrupted during move
Mobile IP

Overview

- Mobile IP [RFC 3220] (designed by C.E. Perkins)
  - designed to enable untethered Internet access
  - with limited mobility
  - without disrupting higher level protocol flows
Mobile IP

Overview

- Mobile IP [RFC 3220] (designed by C.E. Perkins)
  - designed to enable untethered Internet access
  - with limited mobility
  - without disrupting higher level protocol flows
- Simple way of forwarding IP packets to mobile nodes
Mobile IP Architecture

Home Network

- **Home network**: permanent (normal) home of MN
  - MN: mobile node
  - permanent address assigned from home network block
    - e.g. 128.119.40.86 assigned from 128.119.40/24
Mobile IP Architecture

Visited Network

- **Home network** permanent (normal) home of MN
- **Visited Network**: temporary location of MN
  - e.g. 79.129.13/24
Mobile IP Architecture

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*problem?*
Mobile IP Architecture

Visited Network

- **Home network** permanent (normal) home of MN
- **Visited Network**: temporary location of MN
  - home IP addr not in visited block: packets fwd to wrong net
    - e.g. 128.119.40.86 \(\notin\) 79.129.13/24
Mobile IP Architecture

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    solution?
Mobile IP Architecture
Visited Network

- **Home network** permanent (normal) home of MN
- **Visited Network**: temporary location of MN
  - home IP addr not in visited block: packets fwd to wrong net
  - use DHCP to get address in visiting net: all flows interrupted
Mobile IP Architecture

Visited Network

- **Home network** permanent (normal) home of MN
- **Visited Network**: temporary location of MN
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  *solution?*
Mobile IP Architecture

Visited Network

- **Home network** permanent (normal) home of MN
- **Visited Network**: temporary location of MN
  - home IP addr not in visited block: packets fwd to wrong net
  - mobile IP *agents* forward on behalf of MN
• **Home network** receives traffic destined for MN
  – *home agent* (HA) receives traffic destined for MN
Mobile IP Architecture

Foreign Agent

- **Home agent (HA)** forwards on behalf of MN to visited
- **Foreign agent (FA)** intercepts and relays to MN
Mobile IP Architecture

Foreign Agent

- **Home agent** (HA) forwards on behalf of MN to visited
- **Foreign agent** (FA) intercepts and relays to MN
Mobile IP Architecture
Reverse Path

- **Home agent (HA)** forwards on behalf of MN to visited
- **Foreign agent (FA)** intercepts and relays to MN

Does MN need to use agents to send to CN?
Mobile IP Architecture
Reverse Path

- **Home agent (HA)** forwards on behalf of MN to visited
- **Foreign agent (FA)** intercepts and relays to MN
- MN can address datagrams directly to CN

**Problem?**
Mobile IP Architecture
Triangle Routing

- **Home agent** (HA) forwards on behalf of MN to visited
- **Foreign agent** (FA) intercepts and relays to MN
- MN can address datagrams directly to CN
  - *triangle routing*: forward path ≠ reverse path
Mobile IP Architecture

Direct Routing

• Direct routing
  – overcomes triangle routing problem

• Correspondent requests care-of address
  – home agent replies
  – correspondent sends packets directly to COA

• Problem
  – additional signalling complexity and handoff latency
Mobile IP Protocol

Overview

What steps must be taken?
Mobile IP Protocol
Overview

- Agent discovery
- Registration
- Tunneling
- Handoff
Mobile IP Protocol
Agent Discovery

- Agent discovery process
  - home and foreign agents advertise their service
  - mobile nodes solicit the existence of an agent

- ICMP message
  - router advertisement: type = 9
  - mobility agent advertisement extension: code = 16
Mobile IP Protocol

Registration

• Registration process for mobile nodes
  – request forwarding services from foreign agent
  – registers care-of address with home agent
    • directly
    • via foreign agent
  – renew binding about to expire
  – deregister from foreign agent

• UDP messages
  – mobile IP message header
Mobile IP Protocol

Tunneling

- Tunneling
  - home agent tunnels datagrams to care-of address

- Methods
  - IP-in-IP encapsulation
  - minimal encapsulation [RFC 2004]
    - eliminates redundant fields from IP-in-IP
  - GRE (generic routing encapsulation) [RFC 1701, 1702]
Mobile IP Protocol

Handoff

- **Handoff**: mobile node moves to new visited network
- **Procedure**
  - mobile node deregisters with old foreign agent
  - mobile node registers with new foreign agent
  - new foreign agent registers with home agent
  - home agent updates care-of-address for mobile
  - packets continue to be forwarded to mobile
    - new care-of-address
Mobile IP Protocol

Handoff

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Problem?
Mobile IP Protocol

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  - packets continue to be forwarded to mobile
    - new care-of-address
- **Problem**
  - hand-off delay
  - packet loss during handoff
Mobile IP Protocol
Advantages and Disadvantages

Advantages?
Mobile IP Protocol
Advantages and Disadvantages

• Advantages
  – very simple mechanism
Mobile IP
Advantages and Disadvantages

- Advantages
  - very simple mechanism

Disadvantages?
Mobile IP
Advantages and Disadvantages

• Advantages
  – very simple mechanism

• Disadvantages
  – hand-off latency may be seconds
    • registration
    • authentication
    • many optimisations proposed
  – triangle routing
    • different forward and reverse paths: problem for TCP
  – security issues
    • ingress and firewall address filtering of address mismatches
  – no support for policy
Mobile IP
Reality

• IP routers
  – most supported mobile IP for a long time

• Service providers
  – some deployment within cellular telephony service providers

• Users
  – very little actual use

  *why?*
Mobile IP

Reality

- **IP routers**
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- **Service providers**
  - some deployment within cellular telephony service providers

- **Users**
  - very little actual use
  - DHCP reattachment sufficient for many applications
    - email and Web transactions
  - not yet much continuous wireless coverage
    - very few users roam among 802.11 hot spots
  - could change with 802.16 and PDAs
Wireless and Mobile Internet

WI.3: TCP over Wireless Links

WI.1 Impact of untethered operation in the Internet
WI.2 Mobile IP
WI.3 TCP over wireless links
  WI.3.1 TCP error and congestion control
  WI.3.2 TCP loss discrimination
  WI.3.3 TCP modifications for wireless
WI.4 Internet applications
Wireless and Mobile Internet

WI.3.1: TCP Error and Congestion Control

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TCP Error Control

Overview

• TCP uses end-to-end ARQ (automatic repeat request)
  – go-back-$n$ by default
  – numbers bytes in stream rather than packets
E2E Error Control

Closed Loop Retransmission: Go-Back-$n$

- Go-back-$n$: pipeline transmissions
E2E Error Control
Closed Loop Retransmission: Go-Back-$n$

- Go-back-$n$: *pipeline* transmissions
  + multiple packets simultaneously in flight
E2E Error Control
Closed Loop Retransmission: Go-Back-\(n\)

- Go-back-\(n\): *pipeline* transmissions
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- Packets are *sequentially* acknowledged
E2E Error Control
Closed Loop Retransmission: Go-Back-\( n \)

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  + multiple packets simultaneously in flight
- Packets are sequentially acknowledged

*how is packet loss detected?*
E2E Error Control
Closed Loop Retransmission: Go-Back-$n$

- Go-back-$n$: *pipeline* transmissions
  + multiple packets simultaneously in flight
- Packets are *sequentially* acknowledged
  - previous ACK retransmitted for
    - subsequent packets after loss
    - out of sequence packet
E2E Error Control
Closed Loop Retransmission: Go-Back-$n$

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  - sender timer fires if ACK not received

Implication?
E2E Error Control
Closed Loop Retransmission: Go-Back-

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*disadvantages?*
E2E Error Control
Closed Loop Retransmission: Go-Back-\(n\)

- Go-back-\(n\): pipeline transmissions
  - multiple packets simultaneously in flight
- Packets are sequentially acknowledged
  - previous ACK retransmitted for
    - subsequent packets after loss
    - out of sequence packet
  - sender timer fires if ACK not received
    - reset transmission beginning at lost packet
      - significant loss penalty for high bw-x-delay
        - go back and retransmit all since loss
        - many unneeded retransmissions
        - significant additional delay
E2E Error Control
Closed Loop Retransmission: Go-Back-$n$

- *Optimisation possible for go-back-$n$?*
E2E Error Control
Closed Loop Retransmission: Go-Back-$n$

- Optimisation go-back-$n$
  
  *timer the only way to detect loss?*
E2E Error Control

Closed Loop Retransmission: Selective Repeat

- Go-back-\(n\)
  - fast retransmit and delayed ACK help slightly
  - significant delay penalty for losses

- Alternative
  - don’t go back: selective repeat
E2E Error Control
Closed Loop Retransmission: Selective Repeat

- **Selective repeat**
  - all packets acknowledged
E2E Error Control
Closed Loop Retransmission: Selective Repeat

- Selective repeat
  - all packets acknowledged
E2E Error Control
Closed Loop Retransmission: Selective Repeat

- Selective repeat
  - *all* packets acknowledged
E2E Error Control

Closed Loop Retransmission: Selective Repeat

- Selective repeat
  - all packets acknowledged
E2E Error Control
Closed Loop Retransmission: Selective Repeat

- Selective repeat
  - *all* packets acknowledged
  - Missetequenced packets
    - acknowledged and held at receiver
E2E Error Control
Closed Loop Retransmission: Selective Repeat

- Selective repeat
  - all packets acknowledged
- Missequenced packets
  - packets held *and reordered* at receiver
    - increases receiver complexity
E2E Error Control
Closed Loop Retransmission: Selective Repeat

- Selective repeat
  - *all* packets acknowledged
- Missequenced packets
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- Lost packets
  - selectively retransmitted
E2E Error Control
Closed Loop Retransmission: Selective Repeat

- Selective repeat
  - all packets acknowledged
- Missequenced packets
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    - increases receiver complexity
- Lost packets
  - selectively retransmitted
    - no go-back-$n$ latency penalty
  - requires more receiver buffer space
E2E Error Control
Closed Loop Retransmission: Selective Repeat

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Closed Loop Retransmission: Selective Repeat

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    - increases receiver complexity

- **Lost packets**
  - selectively retransmitted
    + no go-back-*n* latency penalty
    - requires more receiver buffer space

- **Latency and Bandwidth reduced**
Transmission Control Protocol
Error Control

- TCP uses end-to-end ARQ (automatic repeat request)
  - go-back-$n$ by default
  - numbers bytes in stream rather than packets
  - SACK (selective acknowledgement) is option
    - implements selective repeat over three blocks within segment
Transmission Control Protocol
Congestion Control

- Slow start to probe capacity
- Implicit congestion control
  - lack of expected ACK assumed to be congestion-based loss
  - sender halves congestion window (AIMD)
- Recovery
  - then retransmits (go-back $n$ or SACK block)
  - begins increase of congestion window (AIMD)
    - 1 MSS (max. segment size) every RTT
Transmission Control Protocol

Congestion Control

- Initialisation phase: slow start
- Steady-state phase: AIMD
TCP Congestion and Error Control

Assumptions

• TCP assumes all losses are due to congestion
  *why?*
TCP Congestion and Error Control

Assumptions

• TCP assumes all losses are due to congestion
  – buffer overflow (tail drop) under congestion
  – AQM (active queue management) for congestion avoidance
  – sender throttles to reduce congestions

*Problem?*
TCP Congestion and Error Control

Assumptions

- TCP assumes all losses are due to congestion
  - buffer overflow (tail drop) under congestion
  - AQM (active queue management) for congestion avoidance
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- Problem:
  - what if loss is due to bit error in wireless channel

*what should the response be?*
TCP Congestion and Error Control

Assumptions

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• Problem:
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  – sender should retransmit, not throttle!
TCP Congestion and Error Control

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  – buffer overflow (tail drop) under congestion
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• Problem:
  – what if loss is due to bit error in wireless channel
  – sender should retransmit, not throttle!

• Note: selective repeat can help
  – but TCP SACK only covers only 3 independent loss events
    • due to implementation as TCP option
  – then reverts to go-back-$n$ behaviour
Wireless and Mobile Internet

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WI.2  Mobile IP
WI.3  TCP over wireless links
  WI.3.1 TCP error and congestion control
  WI.3.2 TCP loss discrimination
WI.4  Internet applications
TCP Loss or Delayed Arrivals

Causes

- Absence of expected packet or ACK arrival
  - three distinct and unrelated causes:
TCP Loss or Delayed Arrivals

Causes

• Absence of expected packet or ACK arrival
  – three *distinct* and unrelated causes:

  1. Congestion: packet dropped in network
     – congestion control: queue overflow (tail drop)
     – congestion avoidance: intentional packet drop
TCP Loss or Delayed Arrivals

Causes

- Absence of expected packet or ACK arrival
  - three *distinct* and unrelated causes:
  1. Congestion: packet dropped in network
  2. Corruption: packet lost or delivered corrupted
    - channel error causing bit errors
TCP Loss or Delayed Arrivals

Causes

• Absence of expected packet or ACK arrival
  – three *distinct* and unrelated causes:
    1. Congestion: packet dropped in network
    2. Corruption: packet lost or delivered corrupted
    3. Delay: packet arrival later than expected
      – store-and-forward delays in disruption tolerant network
      – long path
        • speed-of-light delay in delay-tolerant network
        • very long path around disruption

*Lecture SR and EECS 983*
Loss Discrimination

Proper Response to Loss

• Discrimination and proper response essential:
  – congestion ⇒ back off
  – corruption ⇒ retransmit
  – delay ⇒ wait or
    retransmit via lower delay path

*Lecture RS and EECS 983*
Loss Discrimination

Explicit Notification

- Discrimination and proper response essential:
  - congestion ⇒ back off
  - corruption ⇒ retransmit
  - delay ⇒ wait or retransmit via lower delay path

- Explicit notification
  - ECN: explicit congestion notification
  - ELN: explicit loss notification (due to corruption)

- ELN *cannot* be determined from ECN (& vice versa)
  - packet that first causes congestion may then be corrupted
Explicit Loss Notification
Error Control Mechanisms

- **Mechanisms**
  - observation that error has occurred (detection)
  - notification of error
  - decision on what response to take
  - action to correct error

- **Taxonomy of mechanisms**
  - each mechanism may have different implementations…
    ...(e.g. E2E vs. HBH)…
    ...but they are frequently related

- **ETEN**: explicit transport error notification
ETEN Taxonomy
Determinism and Granularity

- **Determinism**
  - deterministic (take action based on specific corruptions)
  - probabilistic (e.g. throttle source \(x\)% of the time)

- **Granularity**
- **Control feedback ...**
- **Control locus ...**
- **Control band ...**
- **Control direction ...**
ETEN Taxonomy
Determinism and Granularity

- Determinism
- Granularity
  - PETEN: per packet response
  - CETEN: cumulative error rate response
- Control feedback ...
- Control locus ...
- Control band ...
- Control direction ...
ETEN Taxonomy
Control Feedback

- Closed loop feedback from notifier nodes \{n,N\}
  - (N)ACK from end system or switch (e.g. congestion drop)

- Open loop
  - Unreliable or FEC for statistical reliability, rate control

- Hybrid open + closed loop
  - FEC for statistical reliability + (N)ACKs as needed
ETEN Taxonomy
Control Locus

- **End-to-end**
  - no changes to network infrastructure

- **Some hop-by-hop**
  - deployed as needed (e.g. optional n at wireless access links)

- **All hop-by-hop** (N indicates required notifier functionality)
  - deployment challenges: impractical for Internet as a whole

(N indicates required notifier functionality)
ETEN Taxonomy

Control Band

- **Out-of-band**
  - ETEN signalling messages
    - may be forward or backward

- **In-band**
  - ETEN information carried by packets; options:
    - corrupted packets not dropped but marked (violates RFC 1812)
    - carried by subsequent packets in flow (header field or option)
ETEN Taxonomy

Control Direction

• Forward
  – ETEN forwarded to receiver; turned back to sender
    • may be in- or out-of band
    • longer delay in response for interactive over high bw-×-delay

• Backward
  – ETEN messages returned by switches
    • out-of-band unless inserted in reverse flow
    • requires HBH ETEN
Wireless and Mobile Internet

WI.3.3: TCP Modifications for Wireless

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TCP Modifications for Wireless

Proper Response to Loss

- Modifications to TCP to improve loss response
- Research proposals using bandwidth estimation
  - TCP Westwood
  - TCP Peach
TCP Westwood

Overview

- TCP Westwood
  - based on TCP Reno
- Operation
  - monitors ACK receipt rate at source
  - computes congestion window and ssthresh
- Eliminates performance penalty from halving cwind
- No explicit cross-layering
TCP Peach

Overview

- TCP Peach
  - based on TCP Reno
- Sends *dummy segments*
  - low priority
  - receive rate indicates available BW
TCP Peach
Sudden Start

• Starts with
  – 1 real segment and
  – \( r\text{wind} - 1 \) dummy segments

• \( c\text{wind} \) incremented for real and dummy segments

• \( c\text{wind} = r\text{wind} \) after 2RTTs
TCP Peach
Rapid Recovery

- Halves congestion window after loss
  - as in Reno
- Transmits $c_{\text{wind}}$ dummy segments before loss
- Ignores first half of dummy ACKS
- $c_{\text{wind}}$ incremented for second half of dummy ACKS
Wireless and Mobile Internet

WI.4: Internet Applications

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Further Reading

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