SYSC 5306: Mobile Computing Systems
Sample Solution to Final Exam, Winter 2005

1) Media Access Control (10 marks)

CDPD and GPRS (among others) employ a random access strategy. In essence, a node that wants to transmit data, competing for access to a shared channel with other nodes. As a result, collusions can occur. For a cellular network, could you envision other approaches for packet data transmission over a shared channel that would

- Reduce/minimize/do away with collisions
- Allow an arbitrary (or at least large number) of nodes in a cell to transmit some data
- Does not pre-allocate resources to each node (i.e., nodes will only access the channel if and when they have data to send

Are there any disadvantages to your proposal?

Answer (10 marks):

Essentially there is a whole different group of MAC protocols that are based on a reservation scheme. The nice thing about the cellular environment is that there is a well-identified entity to manage the schedule: the base station. In essence, this is what Bluetooth does in a more dynamic way in each PicoNet, where the Master controls the operation of all slaves, or IEEE 802.11's PCF mode, where the Access Point polls the devices. Since stations can only transmit when they are told (or have otherwise acquired permission to access the channel) and other stations will NOT transmit at the same time, collisions are avoided. As every computer network textbook will show, reservation-based approaches are superior to random access approaches under heavy load.

One of the biggest issues with reservation-based approaches is how to let the base station know that you have data to send and therefore would like to be included in the schedule. If it is done in a way similar to IEEE 802.11 PCF or token ring networks, each station that is known to be in the cell (part of the location management) is given the right to transmit or at the least the base station periodically inquires whether a given station has data to send. This can be wasteful if not everyone has data to send all the time. If on the other hand the station sends a message to the base station every time it wants to be included in the schedule (i.e., it now has data to send), there is a chicken-and-egg problem: how does the station do this without having been given a reserved slot before? In essence, to start a new communication burst, stations will have to use a separate random access control channel, similar to GSM, to become part of the schedule. Once a station is part of the schedule, changes to its schedules can probably be communicated together with the data (for example, the flags in CDPD to indicate that there is more data to follow). However, now there is a (smaller) collision problem on the random access channel.

2) CDMA (20 marks)

a) You are to assign 4 DS-CDMA senders a chip sequence. Below, three potential sets of 4 chip sequences are given. Which of these four sets would you choose, and why?

(i)
```
−1 +1 +1 −1 +1 +1 +1 −1 −1 −1 −1 −1 −1 +1 +1 +1
+1 +1 +1 +1 −1 −1 −1 −1 −1 +1 +1 −1 −1 +1 +1 −1
+1 +1 +1 −1 −1 +1 +1 +1 +1 +1 −1 −1 −1 +1 −1 +1
+1 −1 +1 −1 −1 −1 +1 −1 +1 −1 +1 −1 +1 −1 +1 −1
```

(ii)
```
+1 +1 +1 −1 +1 +1 −1 −1 −1 −1 −1 −1 +1 +1 +1
+1 +1 +1 +1 −1 −1 −1 −1 −1 +1 +1 −1 −1 +1 +1 −1
+1 +1 +1 −1 −1 +1 +1 +1 −1 −1 −1 −1 −1 −1
+1 −1 +1 −1 +1 −1 +1 −1 +1 −1 +1 −1 +1 −1 +1 −1
```

(iii)
```
−1 +1 +1 −1 +1 +1 +1 −1 −1 −1 −1 −1 −1 +1 +1 +1
+1 +1 +1 +1 −1 −1 −1 −1 −1 +1 +1 −1 −1 +1 +1 −1
+1 +1 +1 −1 −1 +1 +1 +1 +1 +1 −1 −1 −1 −1 −1 −1
+1 −1 +1 −1 +1 −1 +1 −1 +1 −1 +1 −1 +1 −1 +1 −1
```

Answer (5 marks):

Chip sequences must be orthogonal (as many pairs are the same as are different), that is the inner product of each pair of chip sequences is 0. Based on this:

(i) Not valid since the last two chip sequences are not orthogonal
(ii) Not valid since chip sequences are not of the same length
(iii) Valid, all pairwise inner products are 0.

b) Assume a receiver receives the signal:
`(+1 –1 +1 –3 +1 +1 +3 +1 +3 –1 –1 –1 +1 –3 –1 –1).`
Which stations send what data bit?

Answer (5 marks):

Let **Sc** be the received signal, then

```
S1.Sc: –1 –1 +1 +3 +1 +1 +3 –1 –3 +1 +1 +1 –1 –3 –1 –1  = 0 / 16 = 0
S2.Sc: +1 –1 +1 –3 –1 –1 –3 –1 –3 –1 –1 +1 –1 –3 –1 +1  = –16 / 16 = –1
S3.Sc: +1 –1 +1 +3 –1 +1 +3 +1 +3 –1 +1 +1 –1 +3 +1 +1  = 16 / 16 = 1
S4.Sc: +1 +1 +1 +3 +1 –1 +3 –1 +3 +1 –1 +1 +1 +3 –1 +1  = 16 / 16 = 1
```

The results show that:

- S1 sent nothing
- **S2 sent 0**
- S3 sent 1
- S4 sent 1

c) Assume a receiver receives the signal
`(+1 +2 +2 0 0 –1 0 –2 –2 0 0 –1 –2 +1 +2 0).`
Which stations did send what data bit?

Answer (5 marks):

Let Sd be the received signal, then

```
S1.Sd: –1 +2 +2 +0 +0 –1 +0 +2 +2 +0 +0 +1 +2 +1 +2 +0  = 12 / 16
S2.Sd: +1 +2 +2 +0 +0 +1 +0 +2 +2 +0 +0 +1 +2 +1 +2 +0  = 16 / 16
S3.Sd: +1 +2 +2 +0 +0 –1 +0 –2 –2 +0 +0 +1 +2 –1 –2 +0  = 0 / 16
S4.Sd: +1 –2 +2 +0 +0 +1 +0 +2 –2 +0 +0 +1 –2 –1 +2 +0  = 2 / 16
```

The results are not conclusive! It would seem that there must have been some interference (data loss/noise) in the signal.

There are two ways to handle this kind of situation:

1. Pessimistic approach: The packet is invalid and must be re-sent
2. Optimistic approach: Adopt error tolerance and rely on the levels above to determine if there really was an error in the transmission.

   Using the following assumptions regarding the inner product result:
   - Results of –16 / 16 to –7 / 16 is considered as –1
   - Results of –6 / 16 to +6 / 16 is considered as 0
   - Results of +7 / 16 to +16 / 16 is considered as +1

   We thus end up with the following Results:
   - S1 sent 1
   - S2 sent 1
   - S3 sent nothing

- S4 sent nothing

d) In both frequency and time division multiplexing, there is a need for guard "space" to make sure that "adjacent" users do not interfere with each other. In frequency division multiple access, this is done by not using small guard bands separating the individual channels. In time division multiple access, guard bands exist in the time domain (i.e., between one sender stopping transmission and the next sender starting up, there is a brief pause). Does DS-CDMA require guards? If so, where are they? If not, why not?

Answer (5 marks):

Indeed DS-CDMA requires guards, i.e., separating the communication channels in the appropriate space. The guard bands in DS-CDMA are the orthogonality requirement on the spreading codes. To return to the language analogy, if one pair of speakers were using German and the second set the Swiss dialect of German, it would be difficult to keep them apart. So the codes used by each "speaker" have to be sufficiently different.

3) Mobile IP (10 marks)

CDPD allows an end-user to run TCP/IP applications in a cellular network, roaming between cells and/or service providers. Summarize the main similarities and differences in the mobility management for MobileIP and CDPD. Will the end-user see/experience any difference?

Answer:

Both solutions use the notion of Home and Visiting Location/Agent. However, in CDPD, a node keeps its (single) IP address while roaming in a CDPD network, mobility is managed independently from the IP layer, and provides optimized location management in case a mobile node stays within a domain/subarea. In Mobile IP, a node has more than one IP address, the care-of-address changes with each visited IP network, resulting in a registration message back to the Home Agent and potentially its correspondent nodes. The user, working above the IP layer, will, to a first approximation, not see any differences.

To facilitate detailing the similarities/differences of the mobility management in MobileIP and CDPD, the following **terms** will be used:

Mobile Unit (MU): The *M-ES* in CDPD and *Mobile Node (MN)* in MobileIP
Router (RT): The *MD-IS* in CDPD and the *Agent* in MobileIP
Home Router (HR): The *Home MD-IS* in CDPD, and the *Home Agent* in MobileIP
Serving Router (SR): The *Serving MD-IS* in CDPD, and the *Foreign Agent* in MobileIP
Cell: In CDPD multiple cells, *MDBS*, belong to the same *MD-IS*. In MobileIP, the cell is the *Home/Serving Agent* itself.

1. **Registration:** *When* does an MU registers itself with an RT
   - *CDPD:* MU investigates possible registration after a channel hop. Decision is based on relevant parameters on previous RF channel and current RF channel. Registration is only required if change resulted in cell transfers between cells belonging to the same or different RTs.
   - *MobileIP:* MU must perform a registration whenever the RT advertisement lifetime expires or when the network pre-fix found in the RT advertisement differs from the one in the MU's care-of address.

2. **Registration:** *How* does an MU registers itself with an RT
   - *CDPD:* If cells are within same RT, MU sends link-layer receive ready to RT which acknowledges and updates its MU physical layer association. If cells are from different SRs, the procedure starts as before, then MU sends ESH message to new SR, new SR informs HR of new MU location, HR acknowledges, new SR confirms ack to MU, then HR flushes old SR indicating MU has moved.

- *MobileIP:* MU sends Registration Request to HR (relayed through SR). HR creates and modifies mobility bindings for MU with new lifetime. HR sends Registration Reply to MU (relayed through SR).

3. **Discovery:** How does an MU find new internet attachment
   - *CDPD:* The cells broadcast adjacent cells RF parameters on the beacon channel. MU picks up the RF parameters after a channel hop (or at initial connection) and performs registration if required.
   - *MobileIP:* RTs transmit agent advertisements every second, serving as beacons. If no advertisement is received, MU's can issue agent solicitation message. These messages are used to determine if a registration is required.

4. **Tunnelling (Routing):** How does an MU receives packets when it is away from its HR
   - *CDPD:* Any packets destined for the MU is sent to the HR then forwarded to the SR then to the MU. (Triangular routing)
   - *MobileIP:* Same as CDPD (Triangular routing), except when a route optimization scheme is used. The care-of addresses are used to route packets directly to the SR unless the MU has moved. If the MU has moved (registration expired), then the SR may forwards the packets back to the HR which then forwards them to the new SR and then to the MU.

5. **Routing:** How does an MU sends packets to a target mobile/stationary location
   - *CDPD:* Any packets sent by an MU are sent to the SR and then follow the standard IP routing. They need NOT be sent to the MU's HR. (Direct routing).
   - *MobileIP:* Same as CDPD (Direct routing).

Conclusion: The end-user would not experience any difference in the mobility management as both CDPD and MobileIP offer seamless mobility. From the TCP/IP perspective, there is no difference in functionality. However, Mobile-IP offers seamless mobility across all sorts of wireless technologies, CDPD's solution only works within a CDPD world (i.e., a user cannot seamlessly move from a CDPD network to a WLAN network, for example).

4) Ad-Hoc Networks (10 marks)

Describe the AODV protocol. Your discussion should, among other things, focus on:

- route discovery,
- route maintenance, and
- the role of sequence numbers.

Answer:

Basic idea: create routes only "on demand" to eliminate overhead of periodic broadcasts
AODV assumes symmetric links between two nodes
Discover new nodes in neighborhood using local *hello* messages

Primary objectives of AODV:

- broadcast discovery packets only when necessary
- distinguish between local connectivity changes and general topological maintenance
- disseminate information about local changes only to those neighboring mobiles that are likely to need information

Route/Path Discovery and the role of Sequence Numbers:

- Initiated whenever a source needs to talk to another node and does not have routing information
- Every node maintains two separate counters: *node sequence number* and *broadcast id* (incremented for each RREQ)
- Broadcast RREQ to neighbors, containing these fields

- Neighbors either reply with RREP (if they have route to destination) or pass RREQ on to their neighbors
- Drop RREQ if received more than once
- If RREQ is passed on, keep some information to temporarily establish a reverse path for RREP and potential establishment of path
- Eventually, RREQ will reach a node with route to destination
  - problem: what if route is old?
  - solution: source includes *destination sequence number* in RREQ to indicate desired "freshness"
  - if node's destination sequence number is less than the one in RREQ, keep forwarding RREQ to neighbors (obviously if the node is the destination, always reply)
- If acceptable route information, unicast RREP back to neighbor who sent out RREQ, which follows reverse path back to source, setting up route along the path
- Nodes that are not on reverse path will timeout and delete temporary information (timeout interval chosen appropriately, make sure that there is enough time for route to be discovered….)
- If node receives multiple RREP, propagate first, and additional ones only if they indicate better path (using DSDV criteria):
  - greater destination sequence number ("fresher" route)
  - same destination sequence number with smaller hopcount

Route Maintenance:
- If path breaks (hello messages, link-layer acknowledgements, passive acks), upstream nodes propagate unsolicited RREP with higher sequence number and hop count of ∞ to all active upstream nodes
- According to protocol, these RREPs get forwarded to other active nodes, eventually all active correspondents will be informed of link failure

If needed, correspondents can start establishment of new route by issuing RREQ with destination sequence number one higher than last known sequence number

5) TCP over Wireless (10 marks)

a) Describe the principle problem that TCP faces when employed in a cellular architecture, where one of the connection endpoints is connected over a single wireless hop to the fixed network.

Answer (3 marks):

- TCP originally designed for wired networks
  - low error rate
  - requirement to share bottlenecks
- key assumptions in TCP are:
  - packet loss is indication of congestion, not transmission error
  - rather aggressive response to congestion is needed to ensure fairness and efficiency
- wireless links and mobile computing violate these assumptions:
  - packets lost due to unreliable physical media
  - packets can get lost due to handover

b) What are the strengths and weaknesses of split-TCP solutions?

Answer (4 marks):

<u>Advantages:</u>

BS-MH connection can be *optimized* independent of FH-BS connection
- Different flow / error control on the two connections

Local recovery of errors
- Faster recovery due to relatively shorter RTT on wireless link

Good performance achievable using **appropriate** BS-MH protocol

- Standard TCP on BS-MH performs poorly when multiple packet losses occur per window (timeouts can occur on the BS-MH connection, stalling during the timeout interval)
- Selective acks improve performance for such cases

Disadvantages:

End-to-end semantics violated

- ack may be delivered to sender, before data delivered to the receiver
- May not be a problem for applications that do not rely on TCP for the end-to-end semantics

BS (MSR in I-TCP) retains hard state

- BS failure can result in loss of data (unreliability)
- Hand-off latency increases due to state transfer
    - Data that has been ack'd to sender, must be moved to new base station

Buffer space needed at BS for each TCP connection

- BS buffers tend to get full, when wireless link slower (one window worth of data on wired connection could be stored at the base station, for each split connection)

Window on BS-MH connection reduced in response to errors

- may not be an issue for wireless links with small delay-bw product

Extra copying of data at BS

- copying from FH-BS socket buffer to BS-MH socket buffer
- increases end-to-end latency

May not be useful if data and acks traverse different paths (both do not go through the base station)

- Example: data on a satellite wireless hop, acks on a dial-up channel

c) Are there additional problems that would occur if TCP was to be deployed in an ad-hoc network?

Answer (3 marks):

In standalone ad-hoc networks, no handoffs exist. However, packet loss may occur either to the use of a stale route or the breakage of an existing route. These again are not due to congestion, so the reduction in congestion window is not an appropriate reaction.