Examination Mobile & Wireless Networking (192620010)
April 08, 2020
13.45 – 16.45

Notes:

- *The only sources that will be allowed during this exam are:*
    - *The book "Wireless Communication Networks and Systems" by Cory Beard & William Stallings, in any format (printed or electronically)*
    - *The reader (printed or electronically)*
    - *The slides used in the lectures (printed or electronically). If there is at most 4 A4, 11 pt font worth of personal notes on the sheets, that is allowed.*
    - *A dictionary (only printed)*
    - *A calculator (only a dedicated device or a dedicated calculator program on your computer, online calculators are not allowed)*
    - *If explicitly approved by the lecturer: 2 double-sided sheets of notes (max. A4, any font size/density)*
- *Please note that in all cases, you will have to formulate the answer to questions yourself. Answers to questions containing text copied verbatim from one of the sources will be rewarded with 0 points.*
- *Indications like "[10]" at questions mean that you can obtain 10 points for that question.*
- *Please write your name and student number at the top of the document you are going to hand in.*

Abbreviations

ACK	-	ACKnowledgement
Addr	-	Address
AODV	-	Ad-hoc On-demand Distance Vector
AP	-	Access Point
CSMA/CA	-	Carrier Sense Multiple Access with Collision Avoidance
CTS	-	Clear To Send
CW	-	Contention Window
DCF	-	Distributed Coordination Function
Dest	-	Destination
DIFS	-	DCF Inter Frame Spacing
EDCA	-	Enhanced Distributed Channel Access
eNodeB	-	evolved Node B (base station in LTE)
FDD	-	Frequency Division Duplex
IEEE	-	Institute of Electrical and Electronics Engineers
LAA	-	License-Assisted Access
LAN	-	Local Area Network
LTE	-	Long Term Evolution
LTE-U	-	LTE Unlicensed
LWA	-	LTE-WiFi Aggregation
MPR	-	Multi-Point Relay
NBR	-	NeighBouR
OFDM	-	Orthogonal Frequency Division Multiplexing
OLSR	-	Optimized Link State Routing
PRMA	-	Packet Reservation Multiple Access
RREP	-	Route REPly
RREQ	-	Route REQuest
RTS	-	Request To Send
Seq#	-	Sequence number
SIFS	-	Short Inter Frame Spacing
TC	-	Topology Control (message)
TV	-	TeleVision
WEP	-	Wired Equivalent Privacy

0 Integrity Statement

Please read the following paragraph carefully and copy the text below it verbatim to your answer sheet. To find more information, please consult https://www.utwente.nl/en/education/student-services/remoteassessmentwebsite.pdf.

By testing you remotely in this fashion, we express our trust that you will adhere to the ethical standard of behaviour expected of you. This means that we trust you to answer the questions and perform the assignments in this test to the best of your own ability, without seeking or accepting the help of any source that is not explicitly allowed by the conditions of this test.

Text to be copied:

I will make this test to the best of my own ability, without seeking or accepting the help of any source not explicitly allowed by the conditions of the test.

1 Wireless Communications [13]

Consider two hypothetical cellular systems. The first system operates at the 400 MHz frequency band and the second system operates at the 60 GHz band. Assume both systems use isotropic antennas, and both transmit with a transmission power of 1 W. The pathloss exponent of the environment is 3. For a receiver to successfully decode the incoming traffic, the received power of the signal must be above -110 dBW.

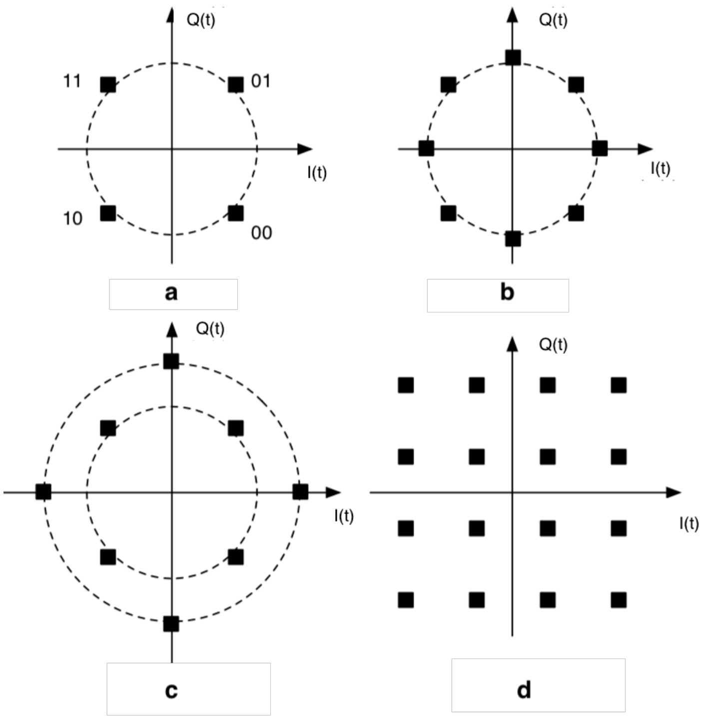
a) It is known that the range and hence the coverage area of a transmitter depends on the frequency used. How many transmitters at the frequency giving the smaller range would you need if you want to cover the same area as a transmitter at the frequency giving the larger range? *Please show your calculation. You can round your range and number of transmitter values to integer values.* [3]

b) For the above-mentioned cellular systems operating at 400 MHz and 60 GHz, calculate the length of an antenna if the antenna length is one-half the wavelength of the transmitted signal. Based on the calculated antenna sizes, discuss whether it would be possible to have one or more such antennas at a mobile handset. [2]

c) Consider a 40 MHz OFDM system. Suppose that the length of one OFDM symbol including the cyclic prefix is 4μs and 20% of this duration is due to the cyclic prefix. How many subcarriers does this OFDM system have? [2]

d) Consider the following figure showing the signal constellation diagrams of four modulation schemes. For each of the 4 modulation schemes, briefly answer the following 4 questions (so, 16 answers in total): [4]

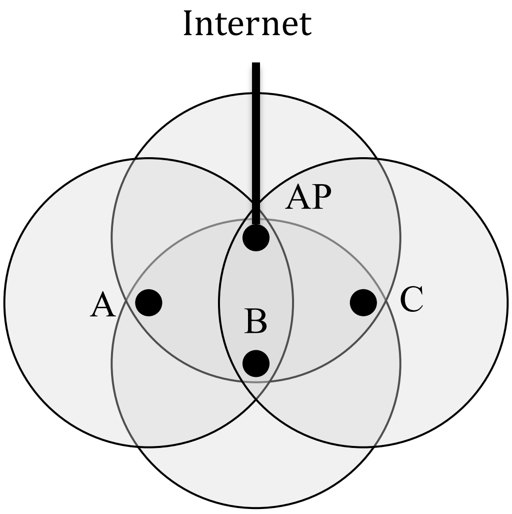
   i) How many *amplitude* values are used for the modulation in each scheme?
   ii) How many *phase* values are used for the modulation in each scheme?
   iii) What is a logical name for each constellation type?
   iv) How many bits can be transmitted at a time with a symbol?



e) Explain the pros and cons of spread spectrum communications. [2]

2 Medium Access Control and Wireless LAN [18]

Please consider an IEEE 802.11-based CSMA/CA system with the node layout as depicted in the figure below. In this scenario, nodes A, B, and C are all within transmission range of an access point AP. Nodes A and B, and nodes B and C are also within each other's range. However, nodes A and C cannot receive (and detect) each other's transmissions.



Further, we make the following assumptions regarding the parameters of the system under consideration: 1 slot = 20 μs; SIFS = 10 μs; DIFS = 2 slots + SIFS; CWmin = 1 slot; CWmax = 255 slots; transmission of a complete data frame takes 250 μs; transmission of control packets such as ACK, RTS, and CTS takes 65 μs; propagation delay is negligible, and no transmission errors occur (if transmitter and receiver are within range and no collision occurs).

a) We consider the situation in which both A and AP want to send a packet to each other, and do not use RTC/CTS. Node B is currently transmitting. A and AP start their CSMA/CA access procedure at exactly the same time, while B is still transmitting. What is the probability that the transmission of A is successful? Explain your answer. [2]

b) If the transmission of A is not successful, i.e., there was a collision between the packet of A and the packet of the AP, what is the probability that A's **re**transmission is successful? Explain your answer. [2]

c) Now suppose the same scenario as above: Initially, B was transmitting. During B's transmission, A and AP started their access procedure, and the transmissions of A and the AP collided in the first attempt. Now, suppose during the transmissions of A and AP, which caused this collision, node C also starts the access procedure for a transmission. What is the probability that the AP manages to do a successful retransmission before C transmits? Explain your answer. [2]

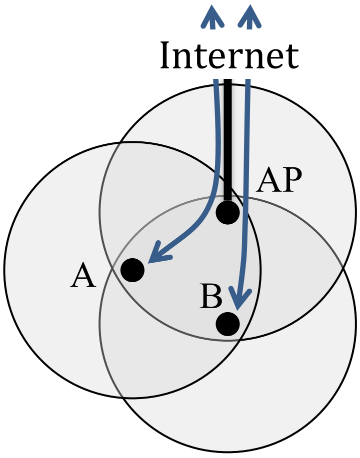
d) For the last case, what is the probability that A manages to do a successful retransmission before C transmits? Explain your answer. [2]

Consider the same system in the figure depicted above. Now, the assumption is that all nodes do use RTS/CTS. Further, let's assume that at $t=t_0$ both A and C start their access procedure to transmit a packet to the AP. However, the medium is still busy until t_1 because of a transmission of node B.

e) Describe a possible sequence of events, or packet transmission (attempts), after which both A and C are able to successfully transmit their packet. How long does it take at least from t_1 until both packets have been received at the AP? Explain. [4]

Note: Write down events like "A and C wait DIFS (+50μs)", "A transmits RTS (+65μs)", and add all durations at the end. Do not feel discouraged if there are quite a few events.

Now, consider the following scenario, depicted in the figure below. The AP in this case is supporting two stations, A and B, all in each other's range. In both node A and node B bi-directional video applications are running, which communicate with peers in the Internet through the AP.



Although the CSMA/CA mechanism in the Distributed Coordination Function of IEEE 802.11 Wireless LAN provides inherently fair access to all stations, in the scenario depicted above, there is unfairness at flow level. A and B each have to transmit packets for 1 flow, whereas the AP has to transmit packets for 2 flows. To achieve fairness at flow level, the AP should therefore be able to transmit twice as many packets as A and B in high load situations.

f) As described in the course, the Enhanced Distributed Channel Access (EDCA) allows for different treatment of packets from different access categories. Suppose A, B, and the AP, each have a single transmit queue, but we would give (the transmit queue of) the AP a different access category, with different parameters than (the transmit queues of) A and B. How would you achieve flow-level fairness between the AP and other stations by choosing appropriate access category parameters? Describe how the parameters should be set (e.g., how the value of a parameter chosen for the AP relates to the value for A and B) and argue why that provides flow-level fairness. [2]

g) Suppose the network described above is not using CSMA/CA as in Wireless LAN, but classical Aloha. How would you change the parameters of the Aloha access mechanism (in the individual nodes) to ensure flow-level fairness between the access point and nodes A and B? Describe your modified Aloha mechanism, including the choice of parameter(s) per node and argue why it provides flow-level fairness (e.g., through some basic modelling or calculations). [2]

h) Suppose the network described above is not using CSMA/CA as in Wireless LAN, but Packet Reservation Multiple Access (PRMA), as described in Section 3.4.6 in Part 1 of the reader. How would you modify the PRMA access mechanism to give flow-level fairness between the access points and nodes A and B? Describe your modified PRMA mechanism, including the choice of parameters per node and argue why it provides fair access at the flow level. [2]

3 Cellular Network Principles [8]

Consider a cellular network with hexagonal cells of the same size. An average user in this network generates a call request every 10 minutes. 20% of the users have a call duration uniformly distributed between 2 minutes to 8 minutes, while the call for the remaining users takes between 2 minutes and 6 minutes, again uniformly distributed.

For the following questions, please show all your calculations. When you think you do not have the value of some of the parameters (e.g., because you could not find it in one of the earlier sub-questions), you can assume a particular value for that missing variable. Please state explicitly in that case your assumption.

a) What is the expected traffic intensity generated by a user? [2]

b) Assume that the operator of this network has licensed 280 MHz of paired spectrum, i.e., 280 MHz for the uplink and 280 MHz for the downlink. Each channel is 2 MHz in bandwidth. The operator reserves one channel in each cell as a control channel. How many communication channels would the operator allocate to a cell if the frequency reuse factor is 4? [2]

c) Let us assume that *t* shows the hour of the day taking values between [0,24). The number of users per km^2 in each cell varies over time *t* according to the following function:

   $N(t) = 61 - 30 \cos(2\pi t/24)$ users/km^2.

   What should be the cell radius for the cellular operator to maintain a maximum blocking probability of 2% during the whole day? [2]

   *Hint: Cells are hexagonal, and the area of a triangle is b*h/2 where b is the base of the triangle and h is the height. Moreover, you will need the Erlang-B table in the last page as well as the results from (a) and (b).*

d) Assume that another network operator has 100 channels and uses a *frequency reuse factor* of 5. Assume also that all its channels can be used for actual communications (i.e., you do not need to reserve some channels for control messages). Initially, its total traffic load in a cell is 13 Erlangs. Later, the traffic intensity increases by 10%. What can this operator do to keep its blocking probability the *same as* or *lower than* the earlier (before the increase in its traffic load)? Discuss at least two approaches, not only qualitatively, but also quantitatively. Note that decreasing number of subscribers is not preferred by the network operator. [2]

   Note: Write down two approaches, e.g., "the operator can change its operation parameter x from 5 to 7", stating the parameter x, and discussing why this approach leads to the desired blocking probability.

4 LTE cellular networks [6]

a) Consider Alice and Bob sitting in the same room and they are both customers of the same LTE operator. Alice is searching for the latest announcements on the university web page while Bob is having a video call with his friends. Does the LTE network treat these two users' communications in the same way while allocating its resources? [2]

b) An LTE network has a bandwidth of 40 MHz at each of its cells. It operates in FDD mode and allocates equal amount of bandwidth for its uplink and downlink. How many resource blocks can an LTE eNodeB have for its downlink communications during a time period of 20 ms? [2]

c) Compare the core network of 3G, 4G, and 5G. Briefly explain how they differ from each other. [2]

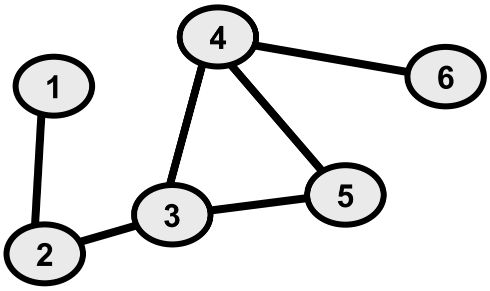
5 LTE-WiFi inter-working and coexistence [5]

a) Assume that you are working for an LTE network operator which needs to expand its coverage area to serve a population who lives in a region where the network infrastructure is destroyed, e.g., due to same natural disaster. The operator is looking for a solution that is easiest and fastest to realize and asked you to propose a solution. Which of the following options would you propose if installing a single BS under these frequencies has roughly the same cost? Why? [2]
   - use TV white space bands
   - use 5GHz spectrum bands

b) Now, consider that an LTE operator in the Netherlands needs to increase the capacity in its coverage area in a short time to meet a sudden increase in traffic demand. Discuss how each of the following options might (or might not) help for capacity expansion. [3]
   - LAA
   - LTE-U
   - LWA

6 Ad-hoc Networks [18]

Please consider the following network. The numbered nodes (vertices) in the graph represent nodes in an ad-hoc network, which are within each other's transmission range when they are interconnected by a link (edge). For this exercise, you may also assume that nodes do not cause interference beyond their transmission range.



a) It is said that without special measures, broadcasting in ad-hoc networks suffers from increased contention and more collisions because rebroadcasts are often synchronized. To what extent does this problem apply in the network given above for a broadcast initiated by node 1? Explain this phenomenon using the above network and indicate between which nodes increased contention takes place (if any), and which nodes might not receive the broadcast message due to collisions (if any). [1]

b) Suppose the probabilistic rebroadcasting scheme is used, with probability $P = 0.5$. What is the probability that node 6 receives a broadcast initiated by node 1? Explain your answer. [2]

c) Suppose the counter-based rebroadcasting scheme is used with $C = 2$. What is the probability that node 6 receives a broadcast initiated by node 1? Explain your answer. [2]

Let us now assume that in the network depicted above, the AODV protocol is used for routing. Initially, all routing tables are empty. Suppose node 1 is initiating a `RREQ` message with

```
Source_Addr: 1 (the address of node 1),
Source_Seq#: 24,
Broadcast_ID, 27,
Dest_Addr: 6
Dest_Seq#: 42,
Hop_Count: 0.
```

d) How many rebroadcasts of this initial *`RREQ`* (so excluding the first one by node 1) will be done? Explain your answer. [2]

e) When node 6 receives a `RREQ` initiated by node 1, and replies with a `RREP`, how does node 4 know what to do with the received `RREP` message? [2]

Now, assume that some time after establishing the route between node 1 and node 6 (via nodes 2, 3, and 4), while the route is still active, node 5 initiates a `RREQ` with

```
Source_Addr: 5,
Source_Seq#: 22,
Broadcast_ID, 27,
Dest_Addr: 1
Dest_Seq#: 32,
Hop_Count: 0.
```

f) What will node 4 do upon receiving this `RREQ` message? Explain your answer. [2]

Consider again the same network. Now, rather than AODV, OLSR is used as a routing protocol.

g) For each of the 6 nodes, give the other nodes that it selects as multipoint relay (MPR). [2]

h) Give all the messages that are transmitted by all the nodes, including the relevant fields of the message, from initialization until routes are known to all nodes. [3]

Note 1: If there is a choice of order of the messages, as much as possible assume that similar messages are sent in rounds, and that within a round nodes transmit in ascending order.

Note 2: Please use the following notation: For a HELLO message transmitted by node *u*, indicating that *u* has neighbours *v*, *w*, and *x*, and MPR *x*, write:
`u: HELLO(NBR(u)={v,w,x}, MPR(u)={x}).`
For a Topology Control message transmitted by node *u*, in which the links from node *v* to nodes *w*, *x*, and *y* are advertised, write:
`u: TC(v)=<w,x,y> .`

i) Which links in this network are advertised in both directions? [2]

7 Bluetooth/WiFi Security [6]

a) Why is WEP not recommended as a security scheme for WiFi? Highlight the weaknesses of WEP in terms of its vulnerability to attacks considering both the authentication and encryption steps. [2]

b) Assume that you connect to the Internet using *eduroam* to watch a video from NetFlix. Can you be sure that your communication is secure? Why or why not? [2]

c) There is a plethora of Bluetooth devices from simple headphones or smart watches to more computationally capable smart TVs. Can we expect the same security level when connecting to these wide range of Bluetooth devices? Why or why not? [2]

Hint: Consider Bluetooth devices with Bluetooth 2.1 or newer versions.

----- end of exam -------

Erlang B Traffic Table

Maximum Offered Load Versus B and N
B is in %

N/B	0.01	0.05	0.1	0.5	1.0	2	5	10	15
1	.0001	.0005	.0010	.0050	.0101	.0204	.0526	.1111	.1765
2	.0142	.0321	.0458	.1054	.1526	.2235	.3813	.5954	.7962
3	.0868	.1517	.1938	.3490	.4555	.6022	.8994	1.271	1.603
4	.2347	.3624	.4393	.7012	.8694	1.092	1.525	2.045	2.501
5	.4520	.6486	.7621	1.132	1.361	1.657	2.219	2.881	3.454
6	.7282	.9957	1.146	1.622	1.909	2.276	2.960	3.758	4.445
7	1.054	1.392	1.579	2.158	2.501	2.935	3.738	4.666	5.461
8	1.422	1.830	2.051	2.730	3.128	3.627	4.543	5.597	6.498
9	1.826	2.302	2.558	3.333	3.783	4.345	5.370	6.546	7.551
10	2.260	2.803	3.092	3.961	4.461	5.084	6.216	7.511	8.616
11	2.722	3.329	3.651	4.610	5.160	5.842	7.076	8.487	9.691
12	3.207	3.878	4.231	5.279	5.876	6.615	7.950	9.474	10.78
13	3.713	4.447	4.831	5.964	6.607	7.402	8.835	10.47	11.87
14	4.239	5.032	5.446	6.663	7.352	8.200	9.730	11.47	12.97
15	4.781	5.634	6.077	7.376	8.108	9.010	10.63	12.48	14.07
16	5.339	6.250	6.722	8.100	8.875	9.828	11.54	13.50	15.18
17	5.911	6.878	7.378	8.834	9.652	10.66	12.46	14.52	16.29
18	6.496	7.519	8.046	9.578	10.44	11.49	13.39	15.55	17.41
19	7.093	8.170	8.724	10.33	11.23	12.33	14.32	16.58	18.53
20	7.701	8.831	9.412	11.09	12.03	13.18	15.25	17.61	19.65
21	8.319	9.501	10.11	11.86	12.84	14.04	16.19	18.65	20.77
22	8.946	10.18	10.81	12.64	13.65	14.90	17.13	19.69	21.90
23	9.583	10.87	11.52	13.42	14.47	15.76	18.08	20.74	23.03
24	10.23	11.56	12.24	14.20	15.30	16.63	19.03	21.78	24.16
25	10.88	12.26	12.97	15.00	16.13	17.51	19.99	22.83	25.30
26	11.54	12.97	13.70	15.80	16.96	18.38	20.94	23.89	26.43
27	12.21	13.69	14.44	16.60	17.80	19.27	21.90	24.94	27.57
28	12.88	14.41	15.18	17.41	18.64	20.15	22.87	26.00	28.71
29	13.56	15.13	15.93	18.22	19.49	21.04	23.83	27.05	29.85
30	14.25	15.86	16.68	19.03	20.34	21.93	24.80	28.11	31.00
31	14.94	16.60	17.44	19.85	21.19	22.83	25.77	29.17	32.14
32	15.63	17.34	18.21	20.68	22.05	23.73	26.75	30.24	33.28
33	16.34	18.09	18.97	21.51	22.91	24.63	27.72	31.30	34.43
34	17.04	18.84	19.74	22.34	23.77	25.53	28.70	32.37	35.58
35	17.75	19.59	20.52	23.17	24.64	26.44	29.68	33.43	36.72