1. Answer the following questions about IEEE 802.15.4
   A. Explain all the power saving features of IEEE 802.15.4. Also, explain the situations in which features could be useful. 5 points, -1 points per one missed item
      i. CCA detection is performed only when the backoff counter becomes zero rather than every time slot. This can be useful when the network load is not very high, so that the wireless medium is idle most of the time.
      ii. Inactive mode in superframes. There exist inactive mode in a superframe, so that a 802.15.4 device can be in sleep mode during this inactive mode. This can be useful when the device performs periodic operations, e.g., sensing the environment, which do not need to be done very frequently.
      iii. GTS for other devices. GTS is guaranteed time slot for a certain devices to transmit a frame. So a 802.15.4 device can be in sleep mode during the GTS for other devices. This can be useful especially when the device is not given any GTS.
      iv. Extracting pending messages from coordinator. A 802.15.4 device does not need to be awake all the time, so that the 802.15.4 device utilized data request command to extract the pending messages form coordinator, which has been pended at the coordinator during the sleep duration of the destination device. This can be useful when the downlink frames are rare.
   B. Under slotted CSMA-CA of IEEE 802.15.4, a MAC frame is transmitted after two CCA operations. Explain why such operation is required. 5 points
      i. To protect the potential ACK frame transmission. ACK frame transmission requires more than a slot time to be transmitted after DATA frame transmission, whose end might not be aligned with the time slot.
2. Answer the following questions about IEEE 802.16
   A. An IEEE 802.16 station is running a single VoIP connection and a single FTP connection. How many CIDs is this station maintaining? List up all possible cases with the explanations about each case.
      i. Two flows can be aggregated into a single connection, or each flow can associate different connection, respectively. Moreover, CID of 802.16 std is directional, i.e., uplink and downlink flow requires separated connection Therefore, there can be 2 or 3 or 4 connections for VoIP and FTP flows, because both of the UL/DL transport connections can be aggregated, or only UL or DL transport connection can ne aggregated, or both UL/DL transport connections can be separated. Furthermore, 2 or 3 connections for management connections.

      -> 4, 5, 6, 7 connections.

      State all the cases with correct explanations: 5 points

      State just one example with correct explanation: 2points
   B. Explain all possible bandwidth request methods defined for IEEE 802.16
      i. Bandwidth stealing

1. Stealing the allocated BW for data transmission.
2. Using BW request header.

ii. Piggy-Backing
1. Sending BW request with data. (using subheader)
2. Piggybacked case can use only incremental type.

iii. Polling
1. BS allocates to the SSs the bandwidth for the purpose of making bandwidth requests.
2. Unicast or multicast or broadcast polling.

iv. Using PM bit
1. SSs with active UGS connections to be polled to request bandwidth for non-UGS connections.
2. The SSs which have UGS connection shall not be polled unless PM bit is set in the packet header

v. Contention-based CDMA bandwidth request:
1. Select code with equal probability among a Ranging codes from the code subset allocated to Bandwidth Request.
2. Transmitted during the ranging subchannel

Name of each bandwidth request scheme: 0.5 points*5 = 2.5 points

Explanations for each bandwidth request scheme: 0.5 points*5 = 2.5 points

3. Answer following questions.

A. What is “cell breathing”? Normally, it is considered a bad phenomenon. Explain why.

i. Cell breathing implies that the cell size in the CDMA cellular network varies depending on the number of users in the cell due to the cumulated transmission power. The SIR(SINR) increases as the number of users in a cell increases, which results in reduced cell size. Since the users reside at the cell boundary cannot be serviced if the cell size shrinks, it is considered a bad phenomenon.

5 points. Partial point depends on your reasoning

B. “Cell breathing” might be useful if it is used in a controlled manner. Give an example where it could be useful by explaining how to achieve it and why it is useful.

i. Using this cell breathing, we can control the number of users in a cell. For instance, in case of dense cellular network, a base station with too many of users compared with the others, the cell size shrinks as explained in (A). The network load in a cell thus can be controlled via cell breathing phenomenon.

5 points. Partial point depends on your reasoning

4. Answer the following questions about error control

A. What is code puncturing? How does it work in the incremental redundancy HARQ?

i. Code puncturing: Code puncturing is the process of removing some of the parity bits after encoding with an error-correction code. This has the same effect as encoding with an error-correction code with a higher rate, or less redundancy. However, with puncturing the same decoder can be used regardless of how many bits have been punctured, thus puncturing considerably increases the flexibility of the system without significantly increasing its complexity.

ii. Code puncturing in IR-HARQ: In the incremental redundancy HARQ, a transmitter usually punctures the original code and sends the punctured code at the first transmission. In the first transmission, it seems that the code rate is increased because of the code puncturing. If the packet is delivered erroneously, the receiver stores the erroneous packet and notifies the failure to the sender. After that, the additional punctured code which contains the other part of parity is re-transmitted from sender and the receiver combined the first packet and the second packet. As a result, the code rate of punctured code increases when the retransmission occurs. → rate adaptation effect

Correct answers for both sub questions: 5 points

Correct answer for one sub question: 2 points

B. CRC can be used to detect errors, where CRC-r can detect all burst errors less than r+1 errors. For example, CRC-8 with generator polynomial x8 + x7 + x6 + x4 + x2 + 1 can detect all burst errors less than 9 errors. Assume that we use this CRC-8 for a packet composed of two bits "00." List all possible erroneous packets (of 10 bits) whose errors will not be detected by CRC-8 at this receiver.

Ans)

G = 1 1101 0101

$D \cdot 2^8$ = 00 0000 0000

```
                        00 ← Q
              ______________
1 1101 0101  )   00 0000 0000
                 00 0000 0000
              ______________
                     )   00 ← R
```

Therefore, CRC bits: 0000 0000

Erroneous bit patterns in that errors will not be detected satisfy $Q \cdot G + R = D \cdot 2^{16}$

From the above, the quotient (Q) for the error free packet is 00, so Q that is 01, 10, or 11 can generate bit patterns that cannot be detected by the given CRC-16.

Q=01 Packet: 01 1101 0101

Q=10 Packet: 11 1010 1010

Q=11 Packet: 10 0111 1111

Correct answer: 5 points

Small mistake: 2 points

5. Answer the following questions about OFDM(A)

A. Explain the advantage of OFDM(A) systems compared with other schemes.

i. Robust to the ISI due to the longer symbol duration, compared with the TDMA scheme with the same data rate.

ii. Less interference among the subcarriers due to the orthogonality.

iii. Flexible resource (bandwidth/time) allocation.

5 points for at least three different reasons. -1 point per one missed item.

B. Explain the differences among Single-User OFDM, Multi-User OFDM, and OFMDA. Which schemes do IEEE 802.11a PHY and WiBro use out of them?

i. Single-User OFDM stands for point-to-point OFDM communication. All the subcarriers are dedicated to a single receiver(1 point). IEEE 802.11a PHY is Single-User OFDM(1 point).

ii. Multi-User OFDM stands for point-to-multipoint OFDM communication. A part of subcarriers out of the whole band are dedicated to a specific receiver, which can be multiple(1 point).

iii. OFDMA stands for multipoint-to-point OFDM communication. Each transmitter leverages separated part of subcarriers, while the single receiver receives all the subcarriers(1 point). WiBro uses OFDMA(1 point)

c.f. WiBro Downlink: Multi-user OFDM / WiBro Uplink: OFDMA is also considered as correct answer.

C. When an OFDM system is designed, two key parameters are the OFDM symbol duration (without guard interval) and the guard interval (or cyclic prefix) duration. Explain all the factors which should be considered to determine these two values.

i. The shorter symbol duration is, the wider inter-subcarrier space is, which can result in frequency selective channel considering coherence bandwidth. While if the symbol duration is too long, inter-subcarrier space goes narrower, so that small amount of frequency shift due to the Doppler effect can deteriorate the system performance, as well as it becomes harder to adjust accurate frequency offset.

ii. Guard interval is required to compensate the inter-symbol interference due to the multi-path environment. The rich the multi-path effect is, the longer guard interval is needed.

5 points for at least two key words out of four: non-frequency-selective channel, Doppler effect, frequency offset, multi-path effect (delay spread).

6. Answer the following questions.

A. When the PCF is used in IEEE 802.11, CF_MAX_Duration cannot be as long as the entire beacon interval. Why is it?

If CF_Max_Duration is as long as the entire beacon frame, DCF may not be used at in entire frame. It causes some crucial problems.

i. DCF is essentially needed for some management purposes. Newly arriving stations cannot be polled from the AP, because AP does not know that the station exist in the area. Furthermore, there is no way to notify the entrance of station to the AP. In order to notify it to AP, random access based DCF duration is essentially needed.

ii. In IEEE 802.11 standard, it is specified that the DCF duration should be longer than the time to transmit the maximum size of MSDU with the lowest rate.

5 points: DCF is required for initial access for the newly entering stations

2 points for inaccurate, but not incorrect reasoning (e.g., DCF is mandatory)

B. Explain why CSMA/CD cannot be used in wireless networks. Consider both when a station is equipped with a single transceiver and two transceivers.

i. Single transceiver: In order to detect collision, the station should be able to receive the signal while it transmits. It is impossible when only one transceiver is used in the station.

ii. Multiple transceivers: Collision detection is very difficult in wireless network as the transmission power in the area of the transmitting antenna is several magnitudes higher than the receiving power.

5 points for both correct answers, and 3 points for half

7. The following figure shows the header format for the 802.11 MPDU. Answer the following questions.

A. How many types of MPDU are defined? What are they?

i. Control, Data, Management (3 types)

3 points. No partial points

B. Address 4 does exist only in the MPDUs used for a special case. What is it? Also, specify the values in "ToDS" and "FromDS" for this case.

i. WDS(Wireless Distributed System) case. Access points are connected in wireless manner to form a relaying chain. ToDS = FromDS = 1.

3 points. 2 points for explaining WDS correctly, while wrong ToDS and FromDS values. Note that specifying only ToDS and FromDS values cannot get any partial points.

C. What is the maximum MSDU size supported by the 802.11 MAC? What is the reason why the maximum frame body size in the figure us 2312, which is different from the maximum MSDU size?

i. 2304 bytes. Additional 8 bytes comes from encryption overhead.

3 points. No partial points

D. The "Sequence Control" field is subdivided into "Sequence Number" and "Fragmentation Number." What is the purpose of "Sequence Number"?

i. Sequence number is unique identifier for an MPDU. It is used for 1) reassembling fragmented MSDU out of multiple MPDUs with same sequence number and continuous fragmentation number; 2) delivering MSMUs to the upper layer of MAC layer in order.

3 points for two purposes. 2 points for single answer.

E. How many bits are allocated for "Fragmentation Number," and why?

i. 4 bits. The maximum number of possible fragments is 11.

3 points. No partial points

8. In a downlink TDM system, the scheduler in base station sends data according ti the proportional fair queuing (PFQ), i.e., by sending data to the mobile that has the highest DRC/R, where DRC is the rate requested by the mobile. Let's assume that R is the average throughput received by the mobile. For each user i, R_i is updated by the following equation at each slot. $R_i(t+1)=(1-1/t_c)R_i(t)+1/t_c\cdot r_i(t)$, where $r_i(t)$ is the current transmission rate of user i in time slot *t*. Let's assume that initial $R_i(0)=1$ for all users. Answer the following questions about scheduling.

A. Explain why it achieves the proportional fairness in the long term.

Ans)

Conceptually, the reason can be explained as below.

Objective of PF: $\text{maximize}\sum \log R_i$

Utility in this formulation: $\sum \log R_i$

The scheduler should select the flow which can increase the total utility most.

$$\arg\max_i \Delta U = \arg\max_i \left(\Delta\sum \log R_i \mid R_i\ is\ selected\right)$$

With the assumption that the average throughput Ri is not changed very much according to the single scheduling results, utility increase can be approximated to the linear function as below.

$$\left(\frac{d}{dR}\log R\right)_{R=R_i}\Delta x_i=\frac{\Delta x_i}{R_i}\text{, where }\Delta x_i\text{ is the increase of utility when the flow i is selected}$$

Therefore, proportional fairness can be achieved by sending data to the mobile that has the highest $\frac{\Delta x_i}{R_i}$.

Because Δx_i is proportional to DRC_i, $\arg\max_i \frac{DRC_i}{R_i}$ achieves the proportional fairness.

Correct answer: 5 points

Some points (2~4) can be given according to the explanations

B. What happens if $t_c=1$ is used? What kind of scheduler is it in this case? Let's refer to this scheduler as S1.

Ans) If t_c = 1, $R_i(t+1)$ = $r_i(t)$. As a result, only the station which is selected in the previous slot has non-zero value of $R_i(t)$. Therefore, one station is randomly selected among all the stations except for the station which is selected in the previous slot.

i. When the number of user is 2: Round-robin scheduler

ii. When the number of user (=N) > 3: Random choosing scheduling (among N-1 users)

Correct answer: 4 points

If it is stated that all the users can be selected in the next slot (purely random choosing scheduling): 2 points

C. What happens if $t_c = \infty$ is used? What kind of scheduler is it in this case? Let's refer to this scheduler as S2.

Ans) If t_c has infinite value, $R_i(t)$ = 1 for all i when the time is finite. Therefore the scheduler sends data to the mobile that has the highest DRC.

In the finite time: Maximum DRC scheduler

Correct answer: 4 points

Small mistakes: 2 points

D. When $t_c \neq 1,\ t_c \neq \infty$, what is the role of t_c? Let's refer to this scheduler as S3.

Ans) S3 is the PF scheduler in the finite time. t_c. t_c determines the maximum starving time of a user. The larger t_c, the shorter the starving time. However, it is wrong to say that t_c itself is the maximum starving time since the R_i(t) update algorithm is not based on moving window, but auto regressive algorithm.

Correct answer: 4 points

If just stated that t_c is the weight between averaged throughput and DRC: 2 points

If it is stated that t_c is "maximum" or "minimum" time for starvation: 2 points

E. In terms of the expected system aggregate throughput, rank S1, S2, and S3. Explain why.

i. S2 > S3 ≒ S1. When the DRC of all the stations are fixed.

In the finite time, S2 achieves the highest throughput because it always selects the station which has the highest DRC.

It is very hard to compare S3 and S1 because of the randomness in S1. S3 and S1 will achieve the similar throughputs because both schedulers allocate the same number of slots to all the users, statistically. However, the throughput can be different because S3 always provides the fair slot allocation, but S1 does not guarantee the fair slot allocation. If the stations which have large DRC values are allocated many times as a result of random experiments, S1 achieves the higher throughput than S3, vice versa.

ii. S2 > S3 > S1. When the DRC values fluctuate.

In the finite time, S2 always selects the station which has the highest DRC. S1 has small aggregate throughput because it will randomly choose one station in every slot. Efficiency of DRC cannot be considered. However, for the S3, a station which has relatively high DRC (comparing with its averaged throughput) is selected in every slot, and it improves the throughput efficiency.

Correct answer which stated all the two cases: 3 points

Answer in number 2 with reasonable explanation: 2 points