SEMESTER II EXAMINATIONS - 2011/2012

EEEN 20060 Communication Systems

Outline Solutions

*These are **example** solutions to the exam questions. Many of the questions have a design component, and therefore may have many good solutions. The fact that a particular solution is chosen here does not necessarily mean that it is the only valid solution, or even that it is the best solution.*

These solutions are written in very brief English, and do not include diagrams. Something better would be expected in an exam.

Question 1

Answer any **four** parts of this question. All parts carry equal marks.

a) A TV news gathering van transmits a signal at 14.8 GHz to a geostationary satellite for onward transmission to the TV studio. Its maximum transmit power is 20 W. The van is required to operate throughout Europe, where distance to the satellite varies between 38 000 km and 41 000 km.

The satellite needs a minimum receive power of 2.6 pW. The receive antenna on the satellite, at 14.8 GHz, has gain of 40 dB in the centre of the beam (near Luxembourg). In more distant parts of Europe, the gain can fall by up to 5 dB.

What is the minimum gain required of the transmit antenna on the van? Give your answer in dB, as an integer. What assumptions did you make in arriving at this answer?

Equation derived in lectures: $P_{RX} = \frac{P_{TX}G_{TX}G_{RX}\lambda^2}{(4\pi r)^2}$. Also have $\lambda = \frac{c}{f}$.

Algebra gives $G_{TX} = \frac{P_{RX}}{P_{TX}G_{RX}}\left(\frac{4\pi r f}{c}\right)^2$.

Using worst case values, G_{RX} = 35 dB or 3162 as a ratio. Distance $r = 41\times10^6$ m.

Get G_{TX} = 26559, or 44.2 dB. Round upwards to 45 dB.

Only assumption made is that transmit antenna will be pointed directly at satellite.

b) Figure 1 shows a small network that uses simple distance-vector routing. The number beside each link indicates the distance or cost associated with that link, which is fixed. Write down the first distance vector that node F would send to its neighbours. Draw up the routing table that you would expect to find at node F when the network has been operating for some time.

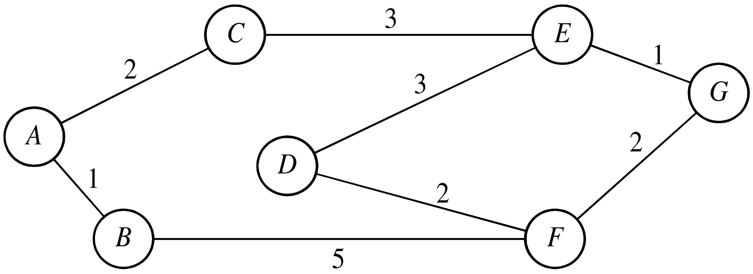

Figure 1: Network Diagram

Initially, F only knows about its neighbours. Sends B:5, D:2, G:2.

In steady state, F has learned from incoming distance vectors, and stores distance to each node in the network, via each of its neighbours. Table as shown below.

Distance to	Via B	Via D	Via G
A	6	10	8
B	5	9	9
C	8	8	6
D	12	2	6
E	11	5	3
G	12	6	2

c) A cordless telephone system is designed to have a range of up to 300 m, and supports up to 5 handsets on one radio channel using TDMA with 10 time slots in a 15 ms TDMA frame. The base unit uses the first 5 time slots to transmit data to each handset in turn, and then each handset transmits in turn to the base unit. Each handset transmits a fixed time after it receives its data from the base unit.

Explain how the system can avoid collisions if handset 2 is used at maximum range while handset 3 is close to the base unit. Draw a diagram of one TDMA frame, and propose a suitable duration for each transmission.

As it is 300 m from the base unit, there will be a delay of 1 μs before HS2 receives its signal from the base unit, and its response will take another 1 μs to get back to the base unit. Thus there will be a delay of 2 μs in the arrival at the base unit of the data from handset 2, relative to that from handset 3.

As the HS transmit times are fixed relative to the signals arriving from the base unit, there is no adjustment for this. The guard times between transmissions must be long enough to allow for it. A guard time of 5 μs or more would not be unreasonable, in a time slot of 1.5 ms.

Diagram could show 10 equal time slots in a 15 ms TDMA frame. There should be guard times (with no transmission) between the transmissions. A suitable duration for each transmission could be 1.4 ms to 1.49 ms. Maximum would be 1.498 ms, but that would leave no time for other errors.

Alternatively, as guard times are not needed between base unit transmissions, the diagram could show 5 consecutive base transmissions, then 5 handset transmissions with guard times (6 guard times in total). With, for example, 10 μs guard times, each time slot could be 1.494 ms in duration.

d) Some communication systems first establish a connection between the devices that want to communicate; then transfer information over this connection; and then close the connection when finished. Outline some advantages of this method. Explain why other communication systems do not use connections.

Advantages: Connection allows network to guarantee delivery of data with no errors and in correct sequence. (Message may be broken into packets by the network, and different packets could take different routes, and arrive out of sequence. Without a connection, cannot have sequence numbers to allow re-assembly of message, rejection of duplicates, etc.)

In systems where messages are short and independent, so will not be broken into smaller pieces, arrival in the wrong order does not arise. Connection setup takes time, and in some cases the connection (virtual circuit) uses network resources for its duration. Some systems, e.g. real-time video or audio streaming, give priority to timely arrival of data, even if it has errors. The time needed to arrange re-transmission of a bad or lost section of data would halt the delivery to the user, so it is preferable to continue without the bad or lost data. For these reasons, connections are not always used.

e) An error detection code adds 4 check bits to a group of 20 data bits, using an interleaved parity check with odd parity. The check bits are transmitted last. Show how to calculate the check bits, using the data bits below as an example (leftmost bit transmitted first). Explain why this code might be preferred to a simpler code, which added one check bit to each group of 5 data bits.

1 0 0 1 1 0 1 1 1 0 0 0 0 0 1 0 1 1 1 0

With 4 check bits, each can protect a group of 5 data bits. With interleaving, these bits should be separated as far as possible. Here, the first group will be bits 1, 5, 9, 13, 17.

This can be shown by arranging the bits in a rectangular array, then calculating a check bit on each column.

1 0 0 1

1 0 1 1

1 0 0 0

0 0 1 0

1 1 1 0

1 0 0 1 ← check bits chosen so odd number of 1s in each column.

This would be preferred to a simpler code in cases where the channel produces bursts of errors. A simple parity code would protect a group of consecutive bits, and would fail if there were 2 or 4 errors in the group. By interleaving, only a burst of length 5 or more could produce 2 errors in one group.

Question 2

A building management system controls and monitors all the electrical and mechanical systems in a large building. This includes the heating, ventilation, lighting, fire alarm, burglar alarm, etc. There are many sensors (sensing temperature, smoke, movement, light-level, etc.) and many control devices (controlling heating equipment, lights, alarms, etc.) distributed around the building. All of these devices are connected to a central computer, which gathers information from all the sensors, makes all the decisions, and sends instructions to the control devices.

The connections use twisted pairs of wires, with the computer at one end and up to 30 devices connected in parallel along each pair of wires. Each connection operates at 100 kbit/s, and the maximum length of each pair of wires is 600 m. The messages exchanged are never more than

80 bits long. You may make reasonable assumptions about the other details of this system, but you must state these assumptions clearly in your answer.

a) Discuss some of the options that could be considered in the design of the medium-access control protocol for this system. Consider the advantages and disadvantages of each, in the context of this system. (50%)

The discussion should be in the context of this system – a discussion of medium-access control protocols in general will not get anywhere near full marks. The following is an example of points that could be discussed.

At 100 kbit/s, a message of 80 bits, in a frame of say, 100 bits, can be transmitted in 1 ms. Time delay in passing messages along 600 m of cable is about 3 μs, or 6 μs for a round trip. As sensors etc. are unlikely to need to communicate more than once or twice per second, giving at most 60 messages per second, there is plenty of time available on each pair of wires.

A fixed TDMA scheme could be used, with, for example, the central computer transmitting first, with data for all the devices in the group. The other devices could take their timing from this, and transmit in turn in a pre-defined order (with guard times between transmissions as mentioned in Q1c). This lacks flexibility – some devices may need to communicate more often than others, but this allocates the same time to each.

The TDMA frame would need 30 device time slots (say 1.1 ms each), and one longer slot for the central computer – maybe a total of 60 ms. That still allows adequate traffic.

Demand assignment could be used, with devices requesting time slots at the start of each time frame. As the central computer is a natural master device, it could arbitrate and announce the assignments. This could work well here – time slots need only be long enough for the 80-bit messages. Time frames could vary in length, depending on the demand, but would typically be quite short (< 10 ms?), so no long delays.

With a master device in place, and involved in all data transfers, a centralised polling system could be used. Polling messages would need address, so might be 10 or 20 bits long. With a similar reply from the polled device, the time to poll all the devices (assuming no data sent) could be ~13 ms. However, polling allows immediate detection of broken devices or broken wires, which could be useful in this application. If some devices are known to need to send data more often than others, they could be polled more often.

Random-access systems could be considered here, and might work well as the traffic is light. However, the unpredictable delays due to collisions and re-transmissions would make it impossible to guarantee performance. This could be a problem in an emergency situation, where many smoke or fire detectors might be triggered at about the same time.

b) Choose a suitable medium-access control protocol, and give reasons for your choice. Specify the details of your proposed system, and estimate the throughput that it could provide, in terms of messages per second, on each pair of wires. (50%)

There are many suitable protocols. Any of the scheduled-access systems above could work well. For example, choose a polling system, for the fault detecting benefit.

Assume 8-bit device addresses, carried in a 20-bit polling message, separate from data being sent by the master. Devices with data to send can transmit one message, in a frame of 100 bits. Devices with no data can send a 20-bit response. The master device can send a message (in a frame of 100 bits) to any device whenever it needs to, as it is in control.

For maximum throughput, assume that there is a lot of data to send. The easiest assumption is that the master has a message for every device and every device has data to send to the master (many other possibilities here). Also assume that all messages are 80 bits, in 100-bit frames. (These are optimistic assumptions – uniform traffic would make even fixed TDMA look good! If the traffic were concentrated in a small number of devices, the throughput would be lower.)

Thirty messages from the master take 30 ms, and the polling and device transmissions take ~1.2 ms each, so another 36 ms. That gives a cycle of 66 ms, with 60 messages transferred, corresponding to about 900 messages per second.

Question 3

A physical-layer protocol uses ternary (3-level) signals to send binary data along a cable, which has attenuation 1.6 dB/km at the important frequencies. The transmitter collects a group of four data bits, and transmits a sequence of three ternary signals to represent each group of four data bits. Each ternary signal is represented by a fixed voltage, which is transmitted for 1 µs. The next ternary signal follows immediately.

a) What voltage would you use to represent each of the ternary signals? Give reasons for your proposal. Sketch an example of the transmitted signal, showing the scale on each axis. (30%)

The voltages chosen should be equally spaced and symmetrical about 0 V, to minimise the transmitted power for a given probability of error at the receiver. For example, use -1 V, 0 V and +1 V.

Sketch should show the three voltage levels, each sent for 1 µs, with a sudden change to the next value.

b) What considerations would you take into account in designing the mapping from groups of bits to sequences of ternary signals? There are 27 possible sequences of three ternary signals, and only 16 of these will be used. Give examples of sequences that you would avoid, with reasons. (30%)

Considerations could be:

Transitions: May want to minimise transitions to reduce bandwidth, but that is not likely to be a major issue on cable. Definitely want to have some minimum number of transitions, to allow receiver to extract timing information.

DC Component: May want to avoid DC component, but that may be difficult here.

Group Identification: Receiver will need to identify groups of three ternary signals in the stream of ternary signals arriving, so that they can be converted back to binary correctly.

Obvious sequences to avoid are -1 -1 -1, 0 0 0, +1 +1 +1, as they lack transitions. For example, could avoid all sequences where the first two signals are the same (there are 9 such). This would allow the groups of three to be identified by watching a long sequence of signals.

c) Explain how and why the signal might be changed on the channel. Sketch an example of the eye diagram that you might see at the receiving end of the system, at a distance of 25 km. Show the scale on each axis. Explain how the receiver should make decisions. (40%)

Explanation should mention:

Attenuation – change in power or amplitude of the signal.

Distortion due to attenuation and/or time delay varying with frequency, which changes the shape of the signal. In particular, rounded pulses and overlapping pulses due to limited bandwidth.

Noise, interference, which are added to the signal.

Eye diagram should show 3 distinct levels, matching voltages chosen, but scaled down by 40 dB, or a factor of 100 in voltage. For example voltages chosen in part a, the expected voltages at the receiver would be -10 mV, 0 V, +10 mV. There should be rounded pulses with a variety of shapes, due to different neighbouring signals, plus random variations. There should be two clear eye openings at the centre of each 1 μs time interval.

Receiver should make decisions by taking sample of voltage at max eye opening, and comparing with threshold values. For this example, < -5 mV means -1 V sent, > +5 mV means +1 V sent. Anything between those thresholds means 0 V sent.

Question 4

You are to design a link-layer protocol to provide reliable transmission of arbitrary binary data over a link with propagation delay 8 ms. The physical layer allows transmission in both directions at the same time, and delivers 5 Mbit/s, with each bit having probability of error 10^{-5}. There are several devices at each end of this link, so data frames, and any acknowledgements, must include the address of the source and destination devices, each 6 bits long.

a) Decide how your protocol will operate. Specify what information you will include in the frame header, and in the trailer, and the number of bits you will allocate to each item. Similarly, specify the form of any acknowledgements that you use. Give reasons for your design decisions. In this part of the question, you may assume that the frame will be between 2000 and 4000 bits in length – you may need this information to decide how many bits are needed to represent sequence numbers and/or frame size information. (50%)

With shortest frame of 2000 bits, transmission time will be ~0.4 ms. Time waiting for acknowledgement is more than 16 ms, - enough to transmit about 40 frames. Thus stop and wait will not be very efficient. A sliding window protocol will be needed.

As a rough estimate, probability of success of longest frame will be 0.99999^{4000}, so ~ 0.96. Go back N would have N ~ 40, so would have a big penalty on the 4% of frames expected to fail. So choose selective reject.

Header must include something to mark the start of a frame e.g. flag of exactly 6 consecutive 1s (01111110). If the trailer also uses a flag or other marker to define the end of the frame, then bit or byte stuffing on the frame contents will be needed.

Header must include a sequence number, to identify the block of data being carried. With ~ 40 frames sent before a NAK might be received, and another 40 frames before an ACK is received for the re-transmitted data, a range of more than 80 sequence numbers will be needed. Choose 7 bits to represent the sequence number, giving a range of 128.

Header includes two 6-bit addresses as specified.

Header may include size of frame – alternative is to mark the frame end in the trailer. Problem does not specify that data is an integer number of bytes, so bit count would be needed. With a frame of up to 4000 bits, need 12 bits for this.

Header may include type field, to identify frame as data frame, as distinct from ACK, NAK, ENQ, etc. Need 2 or 3 bits for this.

Trailer needs error detecting code. For bit-oriented protocol, CRC is probably a good choice, say 16 check bits.

Trailer may also need flag or other marker to mark end of frame, if bit count not used.

Example 1: Use flag to mark frame end, as for frame start, no bit count in header.

Header length is 8 + 7 + 6 + 6 +2 = 29 bits. Trailer length is 16 + 8 = 24 bits.

Bit stuffing will be needed on entire contents of frame – add extra 0 bit after 5 consecutive 1 bits. With random data, expect this to occur with probability 1/32. So estimate ~100 stuff bits in a frame of a few thousand bits. Total overhead ~150 bits.

Acknowledgement can consist of empty frame, so 53 bits + stuff bits, estimate 55 bits in all.

Example 2: Use bit count in header, header length 41 bits. But no need for flag in trailer, so total frame overhead 41 + 16 = 57 bits.

Acknowledgement need not include bit count, so could be 29 + 16 = 45 bits.

b) Calculate the optimum number of data bits in your frame. (If you cannot do this, make a reasonable assumption, so that you can continue.) Calculate the throughput that your protocol can deliver, assuming that there is always data waiting to be transmitted. Show how you arrive at your answers, and explain any other assumptions that you make. (50%)

From lectures, efficiency for sliding window with selective reject is $\eta = \frac{DP_S}{D+H}$, where $P_S = (1-p)^{(D+H+A)}$, p is probability of bit error, D = data bits in frame, H = frame overhead, A = bits in acknowledgement.

Differentiate with respect to D to find maximum throughput,
get $D^2 \ln(1-p) + DH \ln(1-p) + H = 0$

Solving, get $D_{opt} \approx \sqrt{\left(\frac{H}{2}\right)^2 + \frac{H}{p}} - \frac{H}{2} \approx$ 3800 bits (using values from example 1).

Then use expressions above to find probability of successful transmission as 0.961 and efficiency 0.924. Multiply by bit rate to get throughput of 4.62 Mbit/s.

With values from example 2, get optimum $D \approx$ 2360 bits, probability of success 0.976 and efficiency 0.953. Then throughput is 4.76 Mbit/s.