This is a written exam for the course *"Performance Analysis of Communication Networks"*
Lecturers: prof.dr. R.D. van der Mei and dr. T. Kielmann
Date and location of exam: Thursday, April 3, 2008, 18.00-21.15

Rules for the exam:

1. Allowed material: This is an open book exam. For answering the questions, you are allowed to use all kinds of written material like textbooks, printouts of the lecture slides, your own notes, etc. You are allowed to bring your laptop for looking up electronic versions of the course reading material, but electronic communication during the exam is strongly prohibited.

2. Language disclaimer: You are kindly asked to answer the questions using the English language. However, if it helps clarifying your answers, you may use some Dutch here and there. Doing so, will not affect your result.

3. Calculation of end grade for the course: the end grade for the course is built up in two parts: homework assignments and a written exam.

   - *Homework assignments*: during the course 3 homework assignments have been distributed among the students and placed on the Web site. The average of the 3 grades counts to 50% of the final grade.
   - *Written exam*: for this written exam you get a grade between 1 and 10. This grade will count for the remaining 50% of the final grade.
   - *Final grade*: the final grade is calculated as the average of the grade for the written exam on the one hand, and the average homework grade on the other hand, with the restriction that the grade for the written exam must be at least 4.0.

4. Credits: This written exam consists of three questions (A, B and C), each of which consists of a number of sub-questions. The maximum number of credits you can get is distributed as follows amongst the sub-questions.

	1	**2**	**3**	**4**	**5**	**6**	**total**
A	4	3	8	3	3	3	**24**
B	5	3	5	3			**16**
C	4	4	4	4	4	4	**24**

Good luck!

QUESTION A: GSM network dimensioning problem

A mobile operator of a GSM network wants to determine how many base stations are needed to satisfy its customers' Quality of Service (QoS) demands. To this end, the operator smartest wants to determine the maximum size of a cell for the call blocking probability is small enough. Voice telephone calls are generated with rate 2 calls per minute *per square kilometer* (i.e., km^2), and the call duration has a gamma distribution with mean 2 minutes. Assume that each voice call requires a single 14.4 kbps channel to the nearest base station, and that each cell can support only 4 channels in parallel.

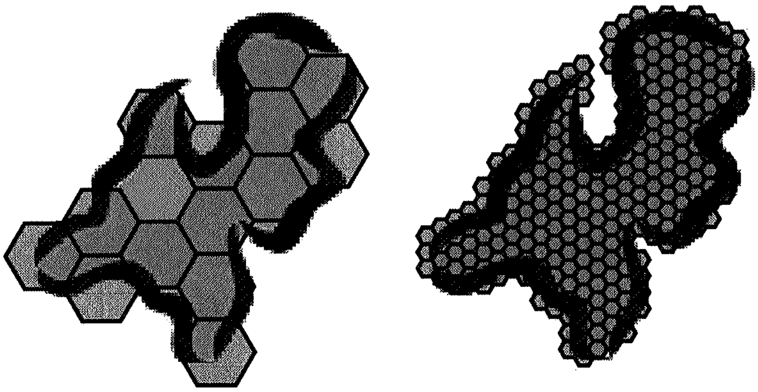

Figure 1. Illustration of GSM network dimensioning problem.

To make a proper decision on the number of base stations to be placed to offer good QoS to its customers, the operator wants to understand the impact of the cell size (in km^2) and the call blocking probability.

A.1 Formulate a simple model description for the problem. Be precise, motivate your assumptions and clearly define any notation!

A.2 Calculate the call blocking probability for cell size values 0.25 km^2, 1 km^2 and 5 km^2.

Now suppose the service provider wants to offer a new *additional* service to its customers: video conferencing. Each video conferencing call requires a 43.2 kbps connection (3 parallel channels). Video conferencing calls arrival according to a Poisson arrival process with rate 0.1 calls per minute per km^2, and the mean conference call duration is 20 minutes. A conference call attempt is blocked when there are less than 3 lines available.

A.3 Determine the blocking probability for *both* the voice telephone calls and the video conferencing calls if the cell size is 1 km^2 if the new service is added.

A few basics...

A.4 Erlang's blocking formula is known to have some *insensitivity property*. What *exactly* does that mean? Be precise!

A.5 Poisson processes occur naturally in the modelling in human-initiated events, such as telephone-call initiation moments and Web-session initiation moments. Why is that? Be precise.

A.6 What is the relation between a Poisson *process* and a Poisson *distribution*? And what is the difference between them? Be precise!

QUESTION B: TCP and HTTP

B.1 For a sliding-window protocol, the achievable bandwidth between a pair of sender and receiver depends on the performance characteristics of the network in between. On which characteristics precisely? (assuming the absence of transmission errors) How can the send window size be optimized for maximizing achievable bandwidth?

B.2 Somebody tells you that he managed to optimize the achievable bandwidth of a TCP connection by setting the receiver's window size to twice the size of the sender's window. Do you follow his advice?

B.3 GridFTP, and extension of the FTP file transfer protocol, is using multiple TCP connections between a sender-receiver pair in parallel. Compare the behavior in terms of achievable bandwidth of

a. one single TCP connection with a send window size W1.
b. n parallel TCP connections each with a send window size Wn, with W1 = n * Wn.

For answering the question it is sufficient to consider the steady state of the connection(s), thus neglecting the startup phase.

B.4 Would multiple parallel TCP connections also improve the performance of HTTP 1.0? How does HTTP 1.1 try to improve performance over HTTP1.0?

QUESTION C: Internet Quality of Service

The transportation of voice over IP networks (VoIP) has become very popular over the past few years. A key problem with this is the fact that today's IP networks, such as the Internet, only offer so-called best-effort type of services.

C.1 What is meant by "*best effort*" service, and what problems can occur if VoIP is offered over a best-effort IP network?

The Internet standardization body IETF is currently working on the introduction of Quality of Service (QoS) concepts for IP networks. Within IETF there are two mainstream approaches to solve the QoS problems over the Internet: Differentiated Services (DiffServ) en Integrated Services (IntServ).

C.2 How do Diffserv and IntServ tackle the problem is realizing QoS over IP networks? Explain roughly how they work and what are their main differences. Be short and stay to-the-point.

An important QoS parameter for VoIP is the delay incurred by each of the packets in the network. Assume that both voice packets and data packets arrive at a router, which puts the incoming packets onto the outgoing link, where the voice packets have priority over data packets (see Figure 2 below).

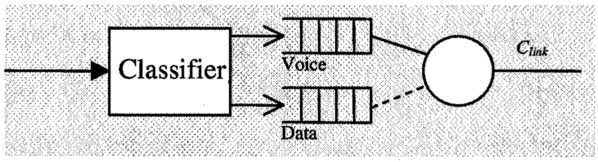

Figure 2. Voice packets have priority over data packets.

Voice packets have fixed size P_{voice} bytes. Data packets have fixed size P_{data} bytes and are only served when the voice buffer is empty. However, if a voice packet arrives during the service of a data packet, then that voice packet must wait until the data packet has been processed.

C.3 Assuming that P_{data} = 1500 bytes, P_{voice} = 150 bytes and C_{link} = 2.4 Megabits per second, what is the maximum time a voice packet has to wait (in milliseconds) if it arrives when the voice buffer is empty?

We will now analyze the queueing-performance of the system, comparing the queueing behavior of the priority system described above on the one hand (figure 2), and the same system *without* priorities on the other hand.

Let us first assume the case in which there is *no priority mechanism* in place, and that the router simply handles the packet in order of arrival.

C.4 Assuming that no priority mechanism is in place, formulate a model that describes the queueing behavior at the router. For ease of the discussion, you may assume that the packets arrive according to a Poisson process. Be precise, carefully introduce notation and formulate your assumptions.

C.5 Give an expression for the expected delay of an arbitrary packet that arrives at the router, in terms of the model parameters.

To proceed, let us now look at the queueing-performance of the *system with priorities* (as illustrated by Figure 2 above).

C.6 Formulate a model that describes the queueing behavior at the router. For ease of the discussion, you may assume that the packets arrive according to a Poisson process. Be precise and carefully formulate your assumptions.