VU VRIJE UNIVERSITEIT AMSTERDAM

This is a **written exam** for the course “**Performance of Networked Systems**” (X_405105)

Lecturer: prof.dr. R.D. van der Mei
Date: March 26, 2019, 12.00-14.45 (rooms S623, S631 and S635)

Rules for the exam:

1. Allowed material: This is a closed-book exam. You are not allowed to use any kind of written material or your laptop, and electronic communication during the exam is strongly prohibited.

2. Calculation of end grade for the course: the end grade for the course is built up in two parts: (1) homework assignments, and (2) this written exam.

   - Homework assignments: Both homework assignment grades counts for 20% each 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 60% of the final grade.
   - Final grade: the final grade is calculated as the weighted average of the grade for the written exam and the two homework assignment grades, with the restriction that the grade for the written exam must be at least 5.5.

3. Credits: This written exam consists of four questions (A, B, C and D), 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	4	4	4	4		**20**
B	4	4	4	4	4		**20**
C	3	3	3	3	3	3	**18**
D	4	4	4				**12**

4. Please hand in the exam after you are finishing answering the questions.

Good luck!

QUESTION A: Poisson processes, the multi-rate model and Kaufman-Roberts

A.1 What is a Poisson process, and why is it a natural way to model random events?

A.2 A discrete random variable N is said to have a Poisson distribution with parameter λ if for k=0,1,2,…

$$\Pr\{N = k\} = \frac{e^{-\lambda}\lambda^k}{k!}.$$

What is the relation between a Poisson *process* and a Poisson *distribution*?

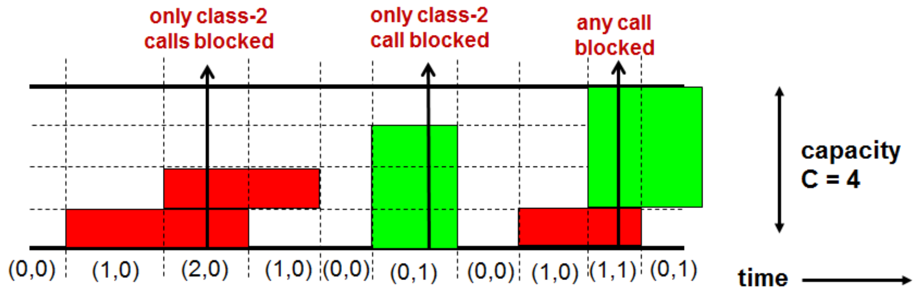

Figure 1: Illustration of the multi-rate model (with two classes and capacity C=4).

A.3 During the course we have extensively discussed the **multi-rate model** as an extension to the Erlang-B model, often referred to as the **single-rate model**. This name suggests that the Erlang-B model is simply a special case of the multi-rate model. But is that indeed the case? If you think so, then explain why; if you think it is not, then explain why think that.

A.4 In the multi-rate model with K classes, class-k jobs wants to occupy b_k channels simultaneously (for k=1,…,K). Suppose now that there are three job classes, and that class 1 and class 2 require the *same* number of channels, thus $b_1=b_2$ (note that b_3 may be different). Then are the blocking probabilities for class 1 and class 2 always the same, or not? Motivate your answer.

A.5 During the course we have discussed the so-called Kaufman-Robert (KR) recursion for the multi-rate model. Explain **in words** what the KR-recursion is and what the **basic idea** is (notation is not required).

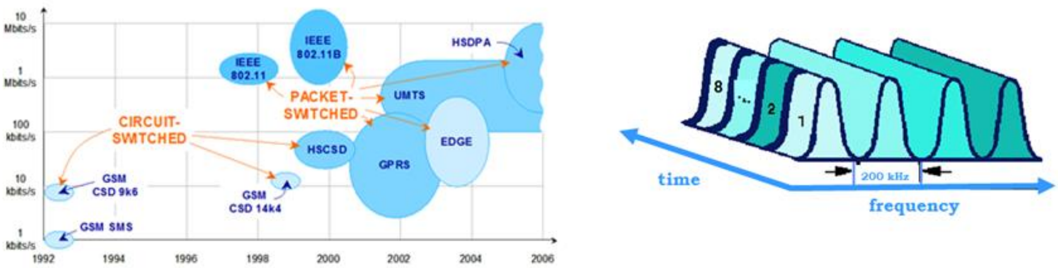

Figure 2: Evolution of mobile and wireless network technologies (left) and illustration of GSM medium access (right).

QUESTION B: Performance models for cellular wireless networks

During the course, a number of mobile and wireless network technologies and their performance models have been discussed, including GSM, GPRS, UMTS, HSDPA and WLAN (see Figure 2).

B.1 In mobile networks there are different medium access protocols, such as Time Division Medium Access (TDMA), Frequency Division Medium Access (FDMA) and Code Division Medium

Access (CDMA)? What are the main differences between TDMA, FDMA and CDMA, and what are their impacts on performance?

B.2 What are the main differences between UMTS and HSDPA from a performance point of view?

B.3 For the WLAN 802.11 protocol, the performance model of Bianchi was discussed extensively. Describe what the **basic ideas** of the Bianchi model are (no details are required, just give the intuition and the basic ideas).

B.4 What are mobile ad-hoc networks? Explain what problems may occur in transporting data between the different nodes in such networks.

B.5 How does a wireless network pose extra performance challenges for web applications, compared to a wired network?

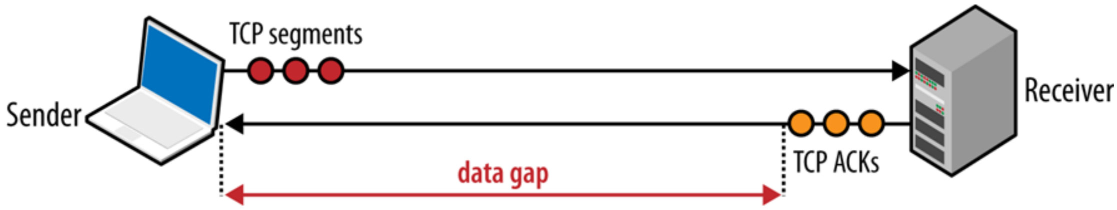

Figure 3: Illustration of the TCP sliding-window mechanism.

QUESTION C: IP Traffic Management and transport layer performance

C.1 Explain the term "bandwidth-latency product" and its impact on the performance of a TCP connection (see Figure 3). How big must the send window be to allow the sender to send without interruption (in the absence of packet loss)?

C.2 How does a TCP connection detect packet loss occurs or network congestion?

C.3 What is the difference between TCP Slow-Start and TCP Additive Increase Multiplicative Decrease?

C.4 Why is it that TCP and HTTP are somehow conflicting (as discussed during the course), and why does TCP usually work better with FTP?

C.5 What is the difference between QoS control and bandwidth (over-)provisioning in terms of performance?

C.6 Equivalent Bandwidth (EBW) is a powerful concept to perform Admission Control (AC) in IP networks. What is the idea behind EBW? And why is the EBW-concept useful to for AC-purposes?

QUESTION D: Fundamental performance models

D.1 Explain why the combination of Markov chains, PASTA and Little's formula provide a powerful means to obtain mathematical expressions for performance metrics like mean waiting times, response times and sojourn times.

D.2 Why does a Continuous-Time Markov Chain (CTMC) for a queueing model typically assume that inter-arrival times and service times are exponentially distributed?

D.3 We have seen that the mean waiting times in an M/G/1 queueing model strongly depends on the variability of the service times, but that the mean sojourn time in the M/G/1 Processing Sharing model is insensitive the variability. Give an intuitive explanation for this phenomenon.