Solution to Test #2 (open books/notes)

I pledge that this test has been completed in compliance with the Graduate Honor Code and that I have neither given nor received any aid on this test.

Student Name: __________________________________________

Signed: __________________________________________

Part I : Multiple – Choice Problems (60%). 6 points each. Select one correct answer in each problem.

1. Which one of the following statements is true regarding Stochastic Petri net (SPN) modeling?
   (a) the underlying Markov model may contain a vanishing marking
   (b) an absorbing marking is a vanishing marking
   (c) an input place will have a corresponding component in the state representation of the underlying Markov chain
   √ (d) an input place will have a corresponding component in the state representation of the reachability graph
   (e) it is impossible that the reachability graph is exactly the same as the underlying Markov chain

2. Which of the following cannot be solved by SPNP to obtain its performance measures?
   √ (a) M/M/1
   (b) M/M/1/m
   (c) M/M/b/m
   (d) a closed product-form queueing network model with exponential service times and inter-arrival times
   (e) a k-out-of-n system with exponential failure and repair times per component
3. Consider the SPN model below corresponding to the underlying Markov model to the right of it for availability modeling. State \textit{OP} means that the system is up, state \textit{FU} means that the system fails unsafely and thus is down permanently, and state \textit{FS} means that the system is down only temporarily since it fails safely and can be reconfigured to be operational again in state \textit{OP} after repair. Initially there is a token in place \textit{OP}. How many markings will be generated in the reachability graph from this SPN?

(a) 3
√ (b) 4
(c) 5
(d) 6
(e) 7

```
reward_type unknown1()
{
    if (mark("buf")<3) return mark("buf"); else return 3;
}
```

4. Refer to the SPN model on slide #168 for modeling a M/M/1/6 elevator system capable of servicing 3 customers per service whenever there are 3 customers waiting to take the elevator. If we assign rewards to markings of the SPN model based on the above reward function, the expected reward, i.e., $\text{expected(unknown1)}$, under this reward assignment is equal to:

(a) average # of customers waiting
(b) average # of customers in the elevator system
(c) average # of customers serviced per service
√ (d) average # of customers serviced per time unit

```
reward_type unknown2()
{
    if mark("buf") return 1; else return 0;
}
```

5. Refer to the SPN model for HW #3, problem #1 as posted on the class website. If we assign rewards to markings of the SPN model based on the above reward function, the expected reward, i.e., $\text{expected(unknown2)}$, under this reward assignment is equal to:

(a) customer rejection probability
(b) population
(c) throughput
(d) utilization
√ (e) response time per customer
reward_type unknown3()
{
    if (!enabled("T8") && mark("RS") == 0) return (1.0);
    else return (0.0);
}

6. Refer to the SPN model for HW #3, problem #3 as posted on the class website. If we assign
rewards to markings of the SPN model based on the above reward function, the expected
reward at steady state, expected(unknown3), under this reward assignment is equal to:
(a) population of low-priority, high-QoS clients
(b) population of low-priority, low-QoS clients
(c) population of high-priority clients
√ (d) rejection probability of low-priority clients
(e) rejection probability of high-priority clients

7. For case study #2, “Dynamic quota-based admission control with subrating in multimedia
servers,” suppose that the following reward function is defined based on the SPN model for
dynamic quota with subrating (Figure 2 on slide #199).

reward_type unknown4()
{
    return rate("T4") + rate("T5") + rate("T11");
}

What performance measure are we getting when expected(unknown4) is called in an SPNP
program?
(a) throughput of high-priority clients
(b) throughput of high-priority and low-priority clients
√ (c) throughput of low-priority clients
(d) throughput of low-priority, low-QoS clients
(e) throughput of low-priority, high-QoS clients

8. For case study #3, “Analysis of replicated data with repair dependency,” which of the
following is not true?
(a) The underlying Markov chain does not contain any vanishing marking.
(b) Under the frequent update assumption, a failure or a repair will trigger an update event.
(c) The local status-update actions taken by each site as shown in Figure 1 will take zero
time.
(d) If the enabling function $f$ on transition $tf$ in Figure 2 returns FALSE then an update
event will not change the state of the system.
\( (e) \) The steady-state site availability can be obtained by calling \texttt{expected}(f) where \( f \) is the enabling function on transition \( tf \) in Figure 2.

9. For paper [P1] entitled “Modeling and Analysis of Attacks and Counter Defense Mechanisms for Cyber Physical Systems,” for the SPN model shown in Fig. 2, which of the following is the correct reward assignment for calculating the MTTF of the system due to exfiltration failure?

(a) \( \text{if (mark("PATRIT") == 1) return 0; else return 1;} \)
(b) \( \text{if (mark("PLEAK") == 1) return 0; else return 1;} \)
(c) \( \text{if (mark("PPERVADE") == 1) return 0; else return 1;} \)
(d) \( \text{if (mark("PATRIT") == 0 && mark("PLEAK") == 0 && mark("PPERVADE") == 0) return 1; else return 0;} \)
(e) \( \text{if (mark("PATRIT") == 1 || mark("PLEAK") == 1 || mark("PPERVADE") == 1)) return 1; else return 0;} \)

10. For paper [P2] entitled “Reliability of Autonomous IoT Systems with Intrusion Detection Attack-Defense Game Design,” Figure 1 shows the SPN model for the case in which \( \beta = 1 \) such that a single mismatch of the vote cast by a node during IDS voting against the auditing vote outcome will drain the life quota of the node and evict it from the system. Suppose you assign a reward of 0 to states in which the number of tokens in place \( N_1^b \) is at least \( 1/3 \) of the total number of tokens in places \( N_1^b \) and \( N_g \), and a reward of 1 otherwise. What would be the physical meaning of the expected reward at time \( t \)?

(a) unreliability for Byzantine failure at time \( t \)
(b) reliability for Byzantine failure at time \( t \)
(c) unavailability for Byzantine failure at time \( t \)
(d) availability for Byzantine failure at time \( t \)
(e) mean time to failure for Byzantine failure
Part II: Modeling (40% + 20% bonus)

1. (20 points) For the stochastic Petri net given above, draw the underlying Markov chain, assuming that the initial state is \((P1, P2, P3, P4) = (4, 0, 0, 0)\). This SPN contains 4 places and 7 transitions. Note the following: (a) only \(t7\) is an immediate transition; (b) the transition rates of \(t1, t2\) and \(t6\) are fixed (rates are given in the figure), while the transition rates of \(t3, t4,\) and \(t5\) are marking-dependent (also specified in the figure); (c) only transition \(t6\) is associated with an enabling function; and (d) the arc multiplicity, if not equal to 1, is shown explicitly in the figure.
2. (20 points.) Suppose that a system can run only if at least 1 CPU, 1 bus, and 2 memory units are alive. Assume that initially the system has 2 CPUs, 1 bus, and 3 memory units. The mean times to failure for a CPU, a bus, and a memory unit are 720, 1440 and 2160 hours, respectively. Assume that all units share a repairman who will always repair the bus first, then the CPU and lastly the memory. Assume that during a repair period, failures of alive components can occur. The mean times to repair a CPU, a bus, and a memory unit are 48, 96, and 144 hours, respectively.

(a) Draw an SPN to model the availability of the system. Label each place, arc, and place clearly. Define clearly the initial marking, any enabling function, any marking-dependent arc multiplicity function, or any marking-dependent transition rate function being used in your Petri net model.

(b) Complete the “availability” reward function below to calculate the availability of the system at 100 hours.

```c
reward_type availability()
{
    if mark("B-up") && mark("C-up")
        && mark("m-up") == 2
        return 1;
    else return 0;
}
ac_final()
{
double t=100.0;

time_value(t);
printf("Availability at %.0f hours is %f\\n", t, expected(availability));
}
```
3. (20 bonus points.) Generate the underlying Markov model for the SPN given below, assuming that the initial state is \((P_1, P_2, P_3) = (4, 0, 1)\).