# Modelowanie system klastrowego z różnymi klasami klientów

Tomasz RAK

Department of Computer and Control Engineering
Rzeszow University of Technology

RZESZOW UNIVERSITY OF TECHNOLOGY

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# Table of contents

# Table of contents

# Approaches

(Chen, X., Czachórski, T., Jarabo, R., Ignacio, J., Kounev, S., Koziolek, H., Meier, P., Merseguer, J., Mironescu, I. D., Nguyen, T. B., Pant, A., Rathfelder, C., Requeno, J., Spinner, S., Zatwarnicki, K., Xiong, X., Zhou, J.)

We can not always add more and more new devices to improve performance, because the initial and maintenance cost will become too high. Power consumption depends on the load and on the number of running nodes in the cluster-based distributed Web system.

**The question:**

What is the performance of the system?

The main aim of the work was to develop models of cluster-based distributed Web system.

The related works can be divided into publications based on analysis of QN and PN models.

# Computer system (experiments) and performance model (simulations)

Workload
⇓

Configuration parameters
⇓

Computer system

⇓

Measured performance parameters

Workload model
⇓

Configuration parameters
⇓

Performance model

⇓

Calculated performance parameters (response time)

Rak, T.: Response Time Analysis of Distributed Web Systems Using QPNs. Mathematical Problems in Engineering (2015) 1–10

# Table of contents

# Multi-Layered Laboratory Environment

| Server/Parameters | Experiment |
|---|---|
| "Clients" | 10.10.10.1 |
| GlassFish AS nodes | 10.10.10.4-5 |
| Oracle DBS node | 10.10.10.2 |
| AS threads pool | 30 per node |
| DBS connections pool | 40 |
| Number of RPS | 15-60 |
| Number of clients | 500 |
| Experiment time [s] | 300 |

Application has all important functionalities for online stock trading system.
Transaction emulates a specific kind of client session.

Rak, T.: Performance Modeling Using Queueing Petri Nets. Communications in Computer and Information Science, vol. 718, Springer (2017) 321–335

# Table of contents

# My approach joins LT and PE

- Educated Guess
- Load Testing (LT)
- Performance Engineering (PE) models (provide some recommendations to realize the required performance level):
  - Performance model (used to predict performance of the system under study)
  - Availability model
  - Reliability model
  - Cost model

Rak, T., Werewka, J.: Performance analysis of interactive internet systems for a class of systems with dynamically changing offers. Lecture Notes in Computer Science, vol. 7054, Springer (2012) 109–123

# Queueing Nets and Petri Nets

## QNs – quantitative analysis

Queueing Nets have queues, scheduling disciplines and are suitable for modeling competition of equipment.

## PNs – qualitative analysis

Petri Nets have tokens representing the tasks and are suitable for modeling software.

## QPNs add queueing and time aspects to the net

Queueing Petri Nets have the advantages of QNs (e.g., evaluation of the system performance, the network efficiency) and PNs (e.g., logical assessment of the system correctness). QPNs integrate hardware and software aspects of the system behaviour into the same model.

# QNs

- Arrival process[1] e.g. Poisson, Erlang, Hyper-exponential, General
- Service process is the time which each request spends at the station e.g. Logarithmic, Chi-square, Hyper-exponential, Exponential[2]; Service times are Independent and Identically Distributed
- Scheduling strategies (queueing disciplines) e.g.: First In First Out (FIFO), Last In First Out, Last In First Out with Preempt and Resume, Round Robin with a fixed quantum, Small Quantum $\Rightarrow$ Processor Sharing (PS), Infinite Server (IS) = fixed delay[3]
- Number of servers[4]
- Number of buffers (waiting room size[5])

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[1] We analyzed closed queueing networks.

[2] We analyzed queueing systems with the exponential clients' service process.

[3] We used IS for clients station, PS for FE servers and FIFO for BE server.

[4] This model considers a single server queue.

[5] Size of the queue is infinite.

# PNs

- Set of places
- Set of transitions
- Token color function[6]
- Incidence function (routing probability[7]) assigns natural numbers to arcs (weights of arcs)
- Initial marking[8] (number of tokens)

[6] It specifies the types of tokens that can reside in the place and allow transitions to fire in different modes.

[7] **Routing of clients class $N_1$ contains all system resources in both layers. Routing of clients class $N_2$ contains only resources in FE layer.**

[8] It specifies how many tokens are contained in each place.

# Mathematical QPN model (1)

QPN is an tuple (2), where CPN is Colored Petri Net (1).

$$CPN = (PL, TR, CF, IF, IM) \tag{1}$$

where:

- $PL = \{p_1, p_2, \ldots, p_i\}$ is a finite and non-empty set of places,
- $TR = \{t_1, t_2, \ldots, t_j\}$ is a finite and non-empty set of transitions, $PL \cap TR = \varnothing$,
- $CF$ is a color function defined from $PL \cup TR$ into finite and non-empty sets (specify the types of tokens),
- $IF^-(p, t)$ i $IF^+(p, t)$ are the backward and forward incidence functions defined on $PL \times TR$, such that $IF^-(p, t), IF^+(p, t) \in [CF(t) \longrightarrow CF(p)_{MS}], \forall (p, t) \in PL \times TR$[9] (specify the interconnections between places and transitions),
- $IM(p)$ is a initial marking funkction defined on $PL$ such that $IM(p) \in CF(p)_{MS}, \forall p \in PL$ (specify number of tokens).

[9] The subscript $MS$ denotes MultiSets. $CF(p)_{MS}$ denotes the set of all finite multisets of $CF(p)$.

# Mathematical QPN model (2)

$$QPN = (CPN, QP, FW) \tag{2}$$

where:

- $QP = (QP_1, QP_2, (q_1, \ldots, q_{|PL|}))$, where:
  - $QP_1 \subseteq PL$ is a set of timed queuing places,
  - $QP_2 \subseteq PL$ is a set of immediate queuing places, $QP_1 \cap QP_2 = \varnothing$,
  - $(q_1, \ldots, q_{|PL|})$ is an array whose entry $q_i$ denotes the description of a queue (if $p_i$ is a queuing place $q_i$ denotes the description of a queue with all colors of $CF(p_i)$ into consideration or if $p_i$ is the ordinary place $(p_i)$ equals *null*).
- $FW = (FW_1, FW_2, (w_1, \ldots, w_{|TR|}))$, where:
  - $FW_1 \subseteq TR$ is a set of timed transitions,
  - $FW_2 \subseteq TR$ is a set of immediate transitions, $FW_1 \cap FW_2 = \varnothing$, $FW_1 \cup FW_2 = TR$,
  - $(w_1, \ldots, w_{|TR|})$ is an array whose entry $w_j \in [CF(t_j) \longmapsto \mathbb{R}^+]$ such that $\forall c \in CF(t_j) : w_j(c) \in \mathbb{R}^+$ of:
    - rate of a negative exponential distribution specifying the firing delay due to color $c$, if $t_j \in FW_1$,
    - firing weight specifying the relative firing frequency due to color $c$, if $t_j \in FW_2$.

# Mathematical QPN model (3)

Based on definition (2) we define following QPN model (3) of CWS.

$$QPN = (PL, TR, CF, IF, IM, QP, FW) \tag{3}$$

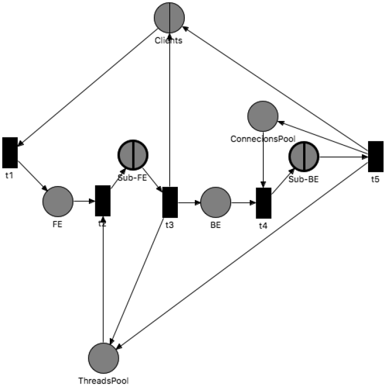
where:

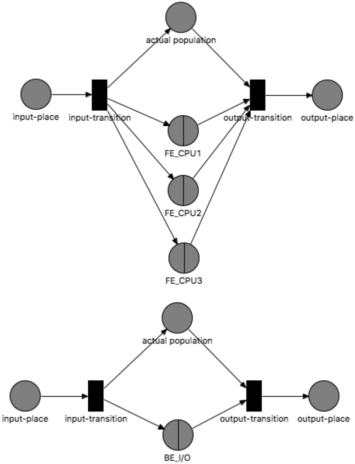
- $PL = \{FE, BE, ThreadsPool, ConnectionsPool, Clients, FE\_CPU_n, BE\_I/O\}$, where $n = \{1, 2, 3\}$,
- $TR = \{t_1, t_2, t_3, t_4, t_5\}$,
- $CF(p_i)$ for $c = \{N_1, N_2, tp, cp\}$, where:
  - $N_1$ and $N_2$ - client-classes,
  - $tp$ - threads,
  - $cp$ - connections,
- $IF^-(p, t), IF^+(p, t)$ - if $IF^-(p, t) > 0$, an arc leads from place $p$ to transition $t$ and place $p$ is called an input place of the transition, if $IF^+(p, t) > 0$, an arc leads from transition $t$ to place $p$ and place $p$ is called an output place of the transition,
- $IM(p)$ for $c = \{N_1 = 250, N_2 = 250, tp_n, cp = 40\}$, where $tp_1 = 30$, $tp_2 = 60$, $tp_3 = 90$,
- $QP =$

  $$(QP_1, QP_2, (-/M/1/IS_{Clients}, null, -/M/1/PS_{Sub-FE}, null, -/M/1/FIFO_{Sub-BE}, null, null)),$$

  where:
  - $QP_1 = \{Clients, FE\_CPU_n, BE\_I/O\}$, where $n = \{1, 2, 3\}$,
  - $QP_2 = \varnothing$,
- $FW = (FW_1, FW_2)$, where:
  - $FW_1 = \varnothing$,
  - $FW_2 = TR$,
  - $\forall c \in CF(t_j) : w_j(c) := 1$ (all transition firings are equally likely).

# Model of the system




QPN net is used to predict the system response time.

# Types of queues and tokens

Queues

| Name | Scheduling Strategy | Number Of Servers | Description |
|---|---|---|---|
| QU_Clients | IS | 1 | Client queue |
| QU_FE1 | PS | 1 | FE1 queue |
| QU_FE2 | PS | 1 | FE2 queue |
| QU_FE3 | PS | 1 | FE3 queue |
| QU_BE | FCFS | 1 | BE queue |

- Clients node (*CLIENTS* queueing place) is modeled by queueing place with Infinite Server scheduling strategy (-/M/1/IS/$\infty$ queueing system)
- Nodes of FE layer (*FE_CPU* queueing places) are modeled by queueing places with Processor Sharing scheduling strategy (-/M/1/PS/$\infty$ queueing systems)
- Node of BE layer (*BE_I/O* queueing place) is modeled by queueing place with First In First Out scheduling strategy (-/M/1/FIFO/$\infty$ queueing system)

Colors

| Name | Real Color | Description |
|---|---|---|
| N1 | | FE-BE Requests Class |
| N2 | | FE Requests Class |
| tp | | Threads |
| cp | | Connections |

- Client-classes ($N_1$, $N_2$)
- Application server threads *tp*
- Database server connections *cp*

# Input parameters of simulations (client and system)

| Parameter | One class ($N_1$) | Two classes ($N_1$ and $N_2$) |
|---|---|---|
| *Clients* queueing place | 500 | 250+250[a] |
| $X_{Clients}$ [RPS] | 15; 30; 45; 60 | 7.5 and 7.5; 15 and 15; 22.5 and 22.5; 30 and 30 |
| *ThreadsPool* place | 30; 60; 90[b] | 30; 60; 90 |
| *ConnectionsPool* place | 40[c] | 40 |
| Simulation time [s] | 300 | 300 |

[a] Each request emulates a specific type of client session with multiple round-trips over the system. Transactions are selected by the driver based on the mix (*Browse* 50%, *Purchase* 25% and *Manage* 25%). *Browse* requests are placed in FE layer and *Purchase*/*Manage* requests are placed in FE and BE layer, that why we use 50%/50% division for client-classes ($N_1$ and $N_2$).

[b] Threads for FE nodes respectively – Initial marking per node (1, 2, 3).

[c] Connections for BE node – Initial marking per node (1).

# Think time (client) and service demand (system) for two client-classes

| $(X_{Clients})_k[RPS]$ [a] | $(X_{Clients})_k[RPMS]$ [b] | $TT_k[ms]$ [c] |
|---|---|---|
| 7.5; 7.5 | 0.0075; 0.0075 | 133.33; 133.33 |
| 15; 15 | 0.015; 0.015 | 66.67; 66.67 |
| 22.5; 22.5 | 0.0225; 0.0225 | 44.44; 44.44 |
| 30; 30 | 0.03; 0.03 | 33.33; 33.33 |

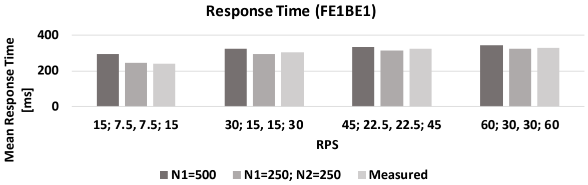
(a) *RPS* – Requests Per Second.
(b) *RPMS* – Requests Per MilliSecond.
(c) *TT* – Think Time in *Clients* queueing place.

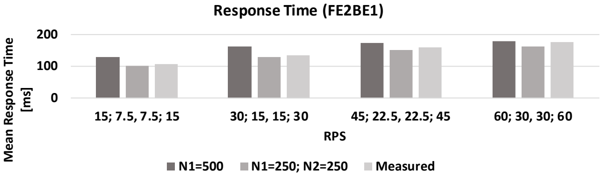
| Resource $i$ | $(X_i)_1[RPS]$ | $(X_i)_2[RPS]$ | $(X_i)_1[RPMS]$ | $(X_i)_2[RPMS]$ | $(SD_i)_k[ms]$ |
|---|---|---|---|---|---|
| $FE\_CPU_n$ | 1,400 | 1,400 | 1.4 | 1.4 | 0.714 |
| $BE\_I/O$ | 7,500 | 7,500 | 7.5 | 7.5 | 0.133 |

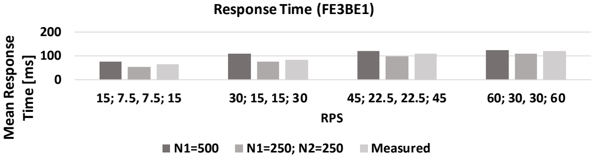
# Table of contents

# Response time

One class and two classes - one, two and three nodes in FE layer (500 clients, different RPS workload)



# Response time error

One class and two classes - one, two and three nodes in FE layer (500 clients, different RPS workload)

| Client think time [ms] | Model with one client class [ms] | Model with two client-classes [ms] | Measured [ms] | Error for one client class [%] | Error for two client-classes [%] |
|---|---|---|---|---|---|
| 133.33 and 133.33 | 291.14 | 224.58 | 241.00 | 20.63 | 6.94 |
| 66.67 and 66.67 | 323.46 | 291.87 | 303.00 | 6.55 | 3.85 |
| 44.44 and 44.44 | 334.45 | 312.62 | 321.00 | 4.16 | 2.64 |
| 33.33 and 33.33 | 340.31 | 324.71 | 330.00 | 2.98 | 1.74 |
| 133.33 and 133.33 | 128.58 | 102.11 | 106.66 | 20.55 | 4.27 |
| 66.67 and 66.67 | 162.36 | 128.44 | 135.01 | 20.26 | 4.87 |
| 44.44 and 44.44 | 173.49 | 150.63 | 159.42 | 8.83 | 5.51 |
| 33.33 and 33.33 | 178.48 | 162.33 | 175.43 | 1.74 | 7.47 |
| 133.33 and 133.33 | 76.46 | 56.23 | 65.12 | 17.41 | 13.65 |
| 66.67 and 66.67 | 110.32 | 76.78 | 85.28 | 29.36 | 9.96 |
| 44.44 and 44.44 | 121.23 | 99.38 | 110.83 | 9.38 | 10.34 |
| 33.33 and 33.33 | 126.59 | 109.76 | 120.94 | 4.68 | 9.25 |

Rak, T.: Cluster-Based Web System Models for Different Classes of Clients in QPN. Communications in Computer and Information Science, vol. 1039, Springer (2019) 347–365

# Conclusions

Convergence of simulation results with the real system results confirms correctness

- We can use this analysis to apply the modification of the system without interfering into the system construction or into software (main achievement)
- It is possible to analyze the compromise between perceived average response time and energy consumption by nodes in the system (practical value)
- The modeling approach presented in this paper differs from my previous works where it was based on QNs and Time Coloured PNs
- The modeling approach presented in this paper differs from my last work based on QPNs because the types of tokens (requests classes) were not used earlier

**Daniel A. Menascé**

"Verify and validate the models (...) a certain acceptable mergin of error (...) resource utilizations within 10%, system throughput within 10%, and response time within 20% are consideren acceptable."

# Cluster-based Web System Models for Different Classes of Clients

Thank you for your attention!



Types of customers: driver (Let's do this right now!), analyst (I will do it in the right way!), amiable (Let's do it together. Teamwork!) and expressive (I have a gut feeling about this one, let's do it!).