On the Generalised Stochastic Petri Net Modeling of Message-Oriented Middleware Systems

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Abstract

This paper presents how to model and carry out the performance analysis of message-oriented middleware (MOM) using Generalised Stochastic Petri Net (GSPN) models. The results obtained from the Petri Net analysis are compared against ones measured in a commercial MOM. Additionally, some results are presented in order to demonstrate the flexibility and the benefits of the proposed model. This research also focuses on how to improve the MOM performance by suggesting appropriated techniques and adjustments to the MOM basic architecture. Finally, we point out some decisions usually taken by systems administrators that may have a major impact on the performance of MOM systems

Keywords — **Message-Oriented Middleware, Performance Evaluation Strategies, Petri Net Modeling**

1. Introduction

The number of middleware products available for building distributed applications is rapidly increasing. Those products are usually implemented according to open standards such as DCE (Distributed Computing Environment) [18], RM-ODP (Reference Model – Open Distributed Processing) [16] and CORBA (Common Object Request Broker Architecture) [17]. Additionally, proprietary middleware such as MQSeries (IBM), .NET (Microsoft) and RMI (Sun) have also been widely used by distributed application developers. Such variety of standards and products makes difficult a comparison between their performances. In general, it is necessary a careful analysis of the system's architecture in order to achieve high performance [1]. System administrators and researchers should rely on the use of quantitative evaluation and modelling techniques, since it is laborious to accurately predict the performance behaviour of these technologies.

The modelling and performance analysis of middleware systems is a recent research area. Tran [1] presents a performance evaluation analysis of Message-Oriented Middleware (MOM) through measurements, which focused on the IBM's MQSeries V5.2 in a test environment (*Testbed*). The authors have evaluated the impact of some factors such as buffer sizes and persistence mechanisms in variety of scenarios. Khorasani [10] presents a model for Middleware in telecommunications focusing on the performance issues. Verdickt [11] [9] proposes an extension of the traditional queue networks systems [5], namely Layered Queuing Networks (LQN), to model the performance of the Common Object Request Broker Architecture (CORBA). Abdul-Fatah [2] has implemented four different test prototypes based on the CORBA architecture, with different configurations for client-server interaction. The experiment results clearly show that there was no better choice amongst them. The authors affirm that a better solution depends on the load requirements of a particular application. Due to the difficulty to set up test environments, we consider such results as an indication to the need of analytical and simulation models for Middleware systems. Pang [3] implements a testbed in order to perform benchmarking tests of two MOM, namely TIB/RV and SonicMQ. The tests evaluated the system's capacity of message delivering, stability under high loads and resource utilization. Liu [4] proposes a model for performance analysis of middleware based on LQN and its precision has been compared against the results obtained by measurements performed using the IBM CrossWorlds InterChange Server. As far as we know, until the publication of this paper there is no related

work to PN-based modelling and evaluation of Message-Oriented Middleware.

The main objective of this work is to model and to evaluate performance behaviour of middleware systems relying on Petri Nets. Particularly, we focus the analysis on Message-Oriented Middleware (MOM) due to its vast utilization in the marketplace. In turn, the use of Petri Nets models was chosen they are well-known, widespread and suitable formalism for system performance evaluation, allow a natural modelling of various MOM elements (e.g. queues, senders and receivers application) and catch several dynamics aspects (e.g. asynchronous operation, message sizes, failures, Quality of Service (QoS) levels, capacity etc).

The remainder of this paper is organized as follows. Section 2 briefly presents theory of Generalised and Stochastic Petri Nets (GSPN). Fundamentals of Message-Oriented Middleware are described in Section 3. PN-based MOM models used in the evaluation as well as the experiments results from simulations are presented in Section 4. Finally, Section 5 presents some concluding remarks and future works.

2. Generalised Stochastic Petri Nets

Petri nets are a family of formal specification techniques that allows for a graphical, mathematical representation and have powerful methods, which allow designers to perform qualitative and quantitative analysis. Place/transition Petri nets are used to model a logical point of view of the systems, however no formal attention is given to temporal relations and constraints. GSPN is one of the most extensively adopted classes of stochastic Petri nets. A GSPN is defined by a set of places, a set of transitions, relations describing pre-conditions, post-conditions, and inhibition conditions; and a mapping from the set of places to the natural numbers describing the model's state. The set of places represents the set of resources, local states and system's variables. The set of transitions represents the set of actions. This set is divided into two subsets: the set of immediate transitions that depicts a set of irrelevant actions under the performance point of view; and the subset of timed transitions. Besides, two other functions are taken into account for representing timing and priorities. The timing function associates to each timed transition a non-negative real numbers, depicting the respective exponential transition delay (or rate). The priority function associates to each immediate transition a natural number that represents the respective transition priority level. Transitions are fired under interleaving firing semantics, a common semantics adopted even in the untimed place/transition model. However, immediate transitions have higher priority than those timed transitions.

3. Message-Oriented Middleware Systems - MOM

Message-oriented middleware (MOM) [8] enables communication by passing information in a message from one application to one or more applications. Two different MOMs are usually implemented: message queuing and publish/subscribe. Message queuing model provides the abstraction of a queue that can be accessed across a network. The publish/subscribe model is more elaborated as it enables a single message (sent by a publisher) to be sent to several subscribers. The interaction in the MOM model is carried as follows: a component simply gives a message to the queuing service, which takes responsibility to transmit (actually aided by the communication service) the message to another component (or components). In the publish/subscribe MOM, a component subscribes to (register interest in) a subject. Another component publishes messages to the subject and the components that have been subscribed to that subject receive the message. MOMs traditionally provides only the queuing and communication services. The queuing service manages the queue, which stores every message that must be sent from the sender to the receiver.

4. The GSPN Modeling Approach

In this section, we describe the model assumptions and provide a detailed explanation of the GSPN model that we propose for MOMs. Particularly we present a GSPN model for the IBM MQ Series v5.2, currently known as WebSphere MQ 5.3 [12]. We choose that MOM for the reason that there exists an independent performance evaluation based on measurements, as described in [1].

4.1 Model Description

The architecture of the IBM WebSphere MQ is depicted in Figure 1. The main components are the Queue Manager (QM) and the Message Control Agent (MCA). The MCA is responsible for transmitting messages between the queue managers. The communication channels (CC) interconnect several WebSphere MQ Clients or Servers. The CCs are an abstraction of the transport, network, link and physical layers. Figure 2 depicts a GSPN model of the

WebSphere MQ architecture where we identify its main components. The subsets of places and transitions identified in Figure 2 are:

- App-S – it means a sending application with average sending rate following a Poisson PDF with mean **l**.
- Queue-S – it models the main buffer at the WebSphere MQ closest to the sending application. The maximum number of messages that can be queued is modelled by the buffer size. Such system capacity is represented by the place **Size** and its initial marking **M**. Additionally, the model accounts the dropping rate. The transition **ServiceTime** represents the process of withdrawing messages from the place **Queued** (variable IID exponentially distributed with mean **1/m**).
- Network/MCA – it models the communications channel and the MCA component.
- App-R – it means a receiving application with average receiving rate following a Poisson PDF with mean $\mathbf{l}_2$;
- Queue-R – it models the main buffer at the WebSphere MQ closest to the receiving application. The service time is also a random variable IID exponentially distributed with mean $\mathbf{1/m_2}$.

It is worth stressing the quantities $\rho=\lambda/\mu$, $\rho_2=\lambda_2/\mu_2$ e $\rho_3=\lambda/\mu_2$ that define the stability condition in the sending application side, in the receiving application side and in the whole system, respectively.

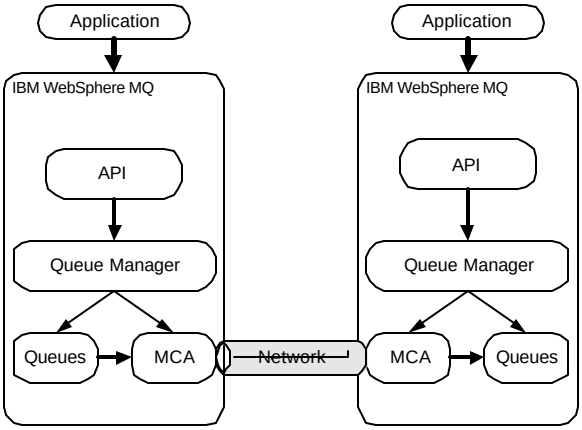

Figure 1 - IBM WebSphere MQ (MQ Series) Architecture

Some observations must be made to identify the level of correctness of the GSPN model related to the MOM's actual architectures. To do that, we compare our GSPN components and features with the test platform described in [1].

When the WebSphere MQ is configured to guarantee message delivery (persistent delivery QoS level), the queue manager and the MCA must simultaneously deal with both new messages arriving from the application and old messages buffered in the log files. In such situation, our second GSPN model (Figure 3) reproduces this persistent behaviour.

MOMs usually offer three QoS levels in their architectures: Non-Persistent (NP), Persistent (P) and Transactional (T). Accordingly, it is feasible to evaluate all three schemes using GSPN models. In this work we analysed the NP and P cases.

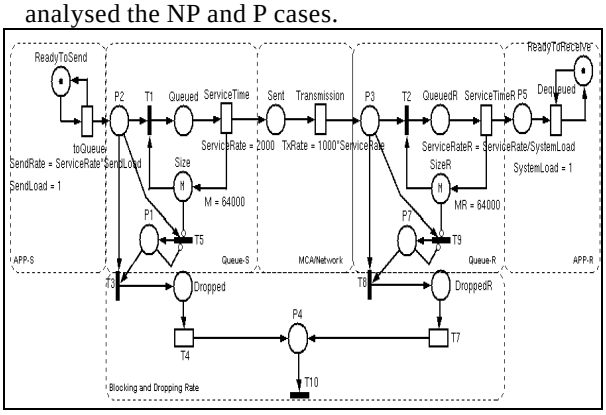

Figure 2. GSPN Base Model of the MQ Series

Capacity of the receiver, comprising the queue's processing rate and the number of threads, has a direct effect on MOM's performance. In a GSPN model, it is possible to include multiple threads in the receiver through two strategies: the first one is represented by *k* concurrent stochastic transitions to take messages out the main receiver buffer. The quantity *k* represents the number of threads available to perform a respective job. The second possible scheme could define an Infinite Server Semantic (ISS) or a K-Server Semantic (KSS) for the transition that takes messages out of the queue.

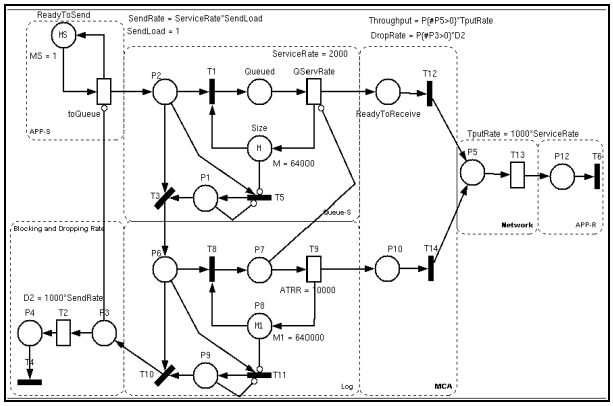

Figure 3 – Basic persistent GSPN model of the IBM WebSphere MQ

Finally, associated to persistent capability of MOM, some results presented in [1] showed that scenarios with persistence had poor performance, since messages have to be recorded to and read from disk, which access times is typically slower than that in random

access memories. A persistent scheme can be implemented in a GSPN model by inhibiting the timed transition in the main buffer as long as exists messages in the persistent log area, as depicted in Figure 4.

In the computer architecture field, access time is the average time interval between a storage peripheral device (e.g., disk drive or semiconductor memory) receiving a request to read or write a certain location and returning the value read or completing a write. So the ratio between access time in the main buffer and in the log buffer could be taken into account to set the weights for the timed transitions. We name this ratio as Access Time Ratio (ATR). Furthermore, this work suggests an alternative for improving the effective utilization of the system. This work proposes messages in the log buffer to be queued up in the main buffer area once again, as depicted in the transition **T9** in Figure 4.

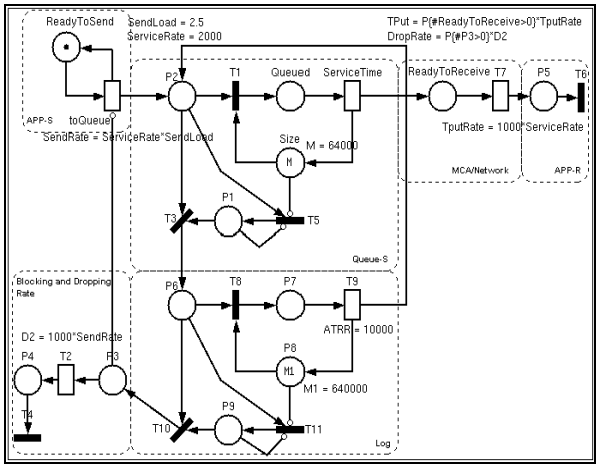

Figure 4 – Alternative GSPN Model

4.2 Simulation Results

In the previous section we presented three GSPN models for MOMs. The first one is the basic model (Figure 2) and the others are able to handle persistent messages delivery (Figure 3 and Figure 4). The second model is capable to reproduce the experiments results conducted in [1]. The alternative proposed model suggests a potential modification in the MOM's components in order to improve the overall performance behaviour. Hence, the experiments carried out using our models aim to analyse the performance behaviour of MOMs under different workload conditions and parameterizations of their constituents.

The performance metrics are the System's Throughput (messages per second) and the Message Dropping Rate (MDR). Results were obtained through the execution of a number of replications for each scenario in a batch mean simulation technique [7] using a well-known GSPN tool named TimeNET 3.0 [14].

Figure 5 shows the simulation results for the GSPN model with a sender's sending rate limited at 4000 mps. We fixed the receiver's receiving rate at 2000 messages per second (mps). Our model (Figure 2) reasonably represents the scenario and precisely reproduces the experimental results (in [1]). Up to the limit of 2000 mps (saturation point), the receiver's throughput increases linearly with the sender's rate. Beyond this point, messages are cumulated in the receiver's queue.

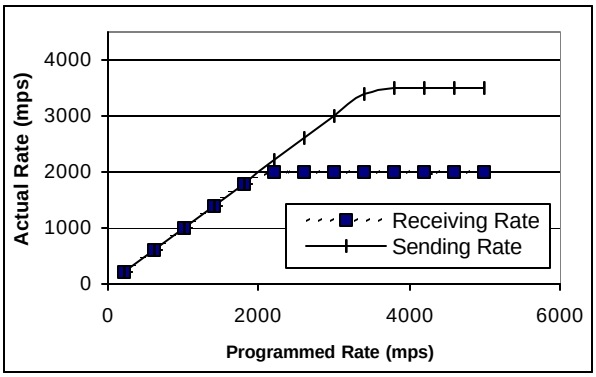

Figure 5 - Comparison of results - GSPN Vs. Testbed

Results presented in Figure 6 shows throughput and dropping rate of the non-persistent GSPN model when we vary the main buffer size (ρ = 1). We considered that tokens represent messages with 64 bytes length and sender's average sending rate is 2000 mps. It can be seen the maximum throughput and the minimum dropping rate is achieved when the available main buffer depth is around 10^5. This result supports that a correct parameterisation of MOM systems could minimize losses due to lack of system's resources.

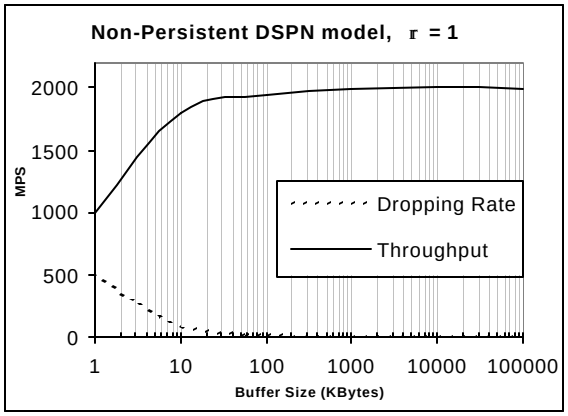

Figure 6 - Basic Non-Persistent GSPN Model

Figure 7 shows simulation results for the throughput metric in two circumstances. One curve

pertains to the MOM with the persistent feature enabled (GSPN IBM WebSphere MQ) and the other concerns to the modified persistent GSPN model. The ratio between the firing times of the transitions that represent the main and the secondary buffer corresponds to the access times ratio (ATR). As commented in [1], we also observed the throughput substantially decreases with the incorporation of messages delivery guarantees. Hence, the trade-off between higher performance and message delivery assurance is an important design issue to be considered.

Our modified GSPN model puts back a logged message in the main buffer. It also conveys the sender to postpone the arriving of new messages when the secondary buffer reaches its maximum capacity. These features allow the system to achieve its maximum capacity faster than the original persistent GSPN, because it gives higher priority to withdraw new messages and occasionally remove old messages that were put back in the main buffer.

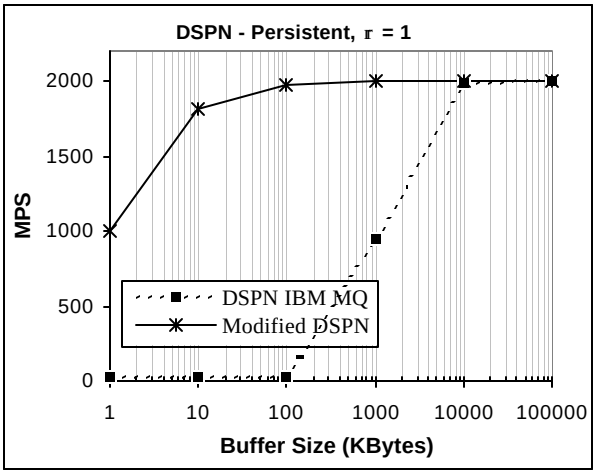

Figure 7 - Throughput - Persistent GSPN Models

Results previously presented use an ATR around 10^5. The following results show the effect of this factor in the metrics. Figure 8 validates our first impression that the ATR factor has no influence on throughput in a stability region ($\rho < 1$), since there will be rare occurrences of dropped messages to the log buffer. On the other hand, one should notice that in an extreme high workload ($\rho = 2.5$), the throughput only reaches its maximum if the ATR is around few units.

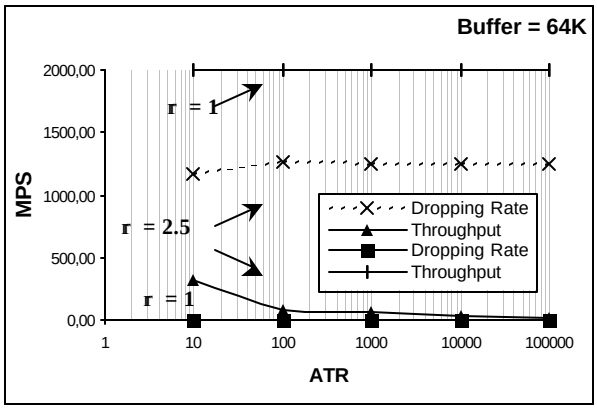

Figure 8 - Impact of ATR on Throughput and Dropping Rate, r = 1

Figure 9 shows the performance behaviour of the persistent GSPN model when we vary the workload. In this simulation, we considered a buffer size with capacity tuned by the previous results, i.e., around 10^5. In both curves, one should notice that throughput increases as the workload does and the absence of dropping messages, up to the stability limit. As the workload grows, the system's throughput drastically decreases and the dropping rate exponentially increases. In the case of a lower ATR, slower decreasing throughput is apparent.

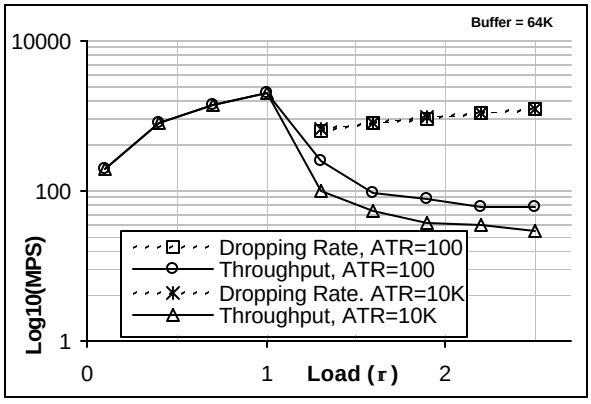

Figure 9 – Persistent GSPN Model, Throughput and Dropping Rate vs. Workload, Buffer = 64K

5. Concluding Remarks and Further Developments

Middleware has a large diversity of features such as price, complexity, flexibility, and performance, where in each target application, different aspects are more important than others. The process of choosing the correct middleware technology refers first in deciding which qualities have more significance for applications

[15]. However, a common requirement for almost all applications is the performance behaviour. Although several ways of evaluating the performance of Middleware are available, most scientific research papers in this area are mainly based on measurements in test environments. The main disadvantage of this approach is related to test scalability. Thus, the search for simulation and analytical models that allows complex system's performance behaviour reproduction has been received increasingly attention by the distributed systems scientific community.

In this paper Message-Oriented Middleware (MOM) was evaluated through Generalised and Stochastic Petri Nets (GSPN) based modelling. The model's accuracy could be evaluated through comparisons with measurements performed in a real test measurement environment. The GSPN model demonstrated to be very accurate and succeed in catching the main performance characteristics of a real MOM. Moreover, some performance analysis could be extended to verify the behaviour of some metrics while changing different factors and their respective levels. In general, results presented the ability of modelling and flexibility in evaluating MOM using GSPN.

The MOM's GSPN-based model is suitable to possible extensions, some of which are currently in progress. Hence, additional performance evaluation can be made in future works. One of them refers to the introduction of threads in the sender or receiver side.

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