Multi-class signal flow model for inter-domain traffic flows simulation

P. Haber  
Fachhochschule für Telekommunikation  
peter.haber@fh-sbg.ac.at

G. Bergholz  
Salzburg Research  
gerhard.bergholz@sz-online.de

U. Hofmann  
Salzburg Research  
Ulrich.hofmann@salzburgresearch.at

I. Miloucheva  
Salzburg Research  
ilka.miloucheva@salzburgresearch.at

Abstract

This paper is focused on the Rate and Time Continuous Fluid Simulation technology (RTC-FSIM) [Ber02a], [Ber02b] - a modular and extendable simulation technology based on differential equations paradigm realised in MATLAB and SIMULINK.

RTC-FSIM is intended to be used in INTERMON [INTERMON] project for QoS based inter-domain modelling and simulation considering priority classes to describe traffic flows in inter-domain network environment.

The RTC-FSIM modelling and simulation approach is compared with the state of the art. Special focus is the explanation of the multi-class signal fluid model and the realisation with MATLAB and SIMULINK.

The multi-class based modelling and simulation is demonstrated based on scenario for inter-domain traffic engineering.

Keywords: fluid model, simulation, rate time continuous flow, multi-class signal model, MATLAB, SIMULINK, inter-domain modelling

1. Introduction

For modelling and simulation of inter-domain issues higher abstraction level is desired as well as performant simulation technologies.

Part of the InterMON modelling and simulation environment is a novel modular Rate and Time Continuous Fluid SIMulation technology (RTC-FSIM) based on differential equations described in technical reports [Ber02a], [Ber02b], [Ber02c].

RTC-FSIM technology supports flexible layers of abstractions (border router, autonomous systems, clouds of autonomous systems, etc) using differential equations to describe continuous rate based traffic behaviour. Because the flow path decomposition represented by differential equations from node to node is a general one and is appropriate to represent any kind of queuing system, there are a variety of models based on differential equations integrated for descriptions of different kinds of queuing systems. The different kinds of models could be flexibly combined by the user depending on the selected abstraction (border router, autonomous system, etc), complexity of inter-domain systems, inter-domain routing and topology abstractions. Briefly summarised, the purpose of the InterMON RTC-FSIM technology in the InterMON project is to build inter-domain modelling and simulation environments with the following facilities:

- Large scale inter-domain modelling and simulation based on high level abstractions using the differential equation paradigm
- Efficient measurement based modelling for generation of continuous rate input models (described with mean, variance and autocorrelation function) using MATLAB with interfaces to RTC-FSIM inter-domain models implemented in SIMULINK [Simulink]. An important reason for choosing these tools to build the RTC-FSIM environment are their powerful modelling and simulation facilities combined with visualisation functionalities. Furthermore these tools support comfortable possibilities for analysis in the frequency domain.
- A modular and extendable simulation environment integrating different kinds of inter-domain simulation models (basic service model, multi-service and priority model, etc)
- Inclusion of inter-domain models describing traffic classes and priority services aimed to describe QoS issues (for instance DiffServ) in inter-domain environments (the multi-service and priority model [Ber02b]).
Currently implemented in RTC-FSIM is the general service model [Ber02a] for fluid flow approximation using an aggregate traffic model as input. The input is normal distributed continuous rate process model described with mean value, variance and autocorrelation function which is obtained by superposition of ON/OFF sources with identical distribution and autocorrelation function.

Another implemented RTC-FSIM model is the multi-service model based on priority processing [Ber02b] which could be used for simulation studies of different traffic classes such as user application traffic classes (VoIP, MPEG video) considering different priorities.

The following sections give a brief introduction into the fluid simulation and RTC-FSIM multi-class flow modelling and simulation environment. For more details on working with RTC-FSIM as well as comparison with existing modelling and simulation technologies please consider the technical reports [Ber02a], [Ber02b] and [Ber02c].

The paper is structured as follows. Section 2 compares RTC-FSIM with the state-of-the-art of simulation technologies. Section 3 gives introduction to signal flow modelling and simulation. Multi-class flow model of RTC-FSIM is explained in Section 4. Simulation studies are discussed in section 5. Section 6 is aimed at conclusions and outlook for further work.

2. RTC-FSIM simulation compared with state of the art

Fluid-based models of communication network traffic consider traffic behaviour in terms of rates (i.e. rate changes), rather than packet instances. The fluid model was first proposed by Anick et al. in [Ani82] to model data network traffic. Fluid modelling and simulation techniques for communication networks and services are discussed in different works ([Ahn96], [Kes96], [Kum98], [Yan99], [Liu99]).

In the fluid simulation paradigm, network traffic is modelled in terms of a (time) discrete or continuous rate based models, rather than discrete packet instances. A fluid simulator technique keeps track of the fluid rate changes at traffic sources and network nodes. An equivalent packet-level simulator would keep track of all individual packets in the network. Issues and trade of fluid simulation is addressed in [Liu99]. [Nic99] compared the performance of fluid-based and packet-based SSF models that differentiate in the generation and handling of events.

The higher level of abstraction suggests that less processing might be needed to simulate network traffic. Intuitively, this is not surprising as a large number of packets can be represented by a single fluid chunk. However, for event driven fluid simulation, a rate change event at one node triggers rate updates in all downstream nodes. More specifically, the change of one or more departure rates from a node can change the arrival rates and station state in the set of nodes directly connected to it via continuous flows, which in turn can change their departure rates and so on. Thus, a rate change in a given node can potentially ripple to all downstream nodes causing multiple rate change event processing and performance degradation due to the ripple effect [Kes96], [Liu99], [Liu01]. The ripple effect depends on the complexity of topology, node queuing mechanisms and interconnections [Liu01] as well as used simulation technique (some techniques are reported to deal efficiently with ripple effect such as time stepped event simulation [Yan98]). The rate and time continuous fluid simulator hides this performance problem behind the numerical effort for differential equation solving ([Mel02], [Gar01], [Ber02c]).

Fluid-flow models were exploited in the current research, to achieve reductions in the computational complexity of simulation runs, for powerful modelling based on rate paradigm, as for instance:

- Simulation of ATM rate based transport services ([Kes93], [Kes95], [Kes96])
- TCP fluid based flow analysis ([Bon98])
- Fluid Methods for Modelling Large, Heterogeneous Networks ([Liu99], [Liu00]).
- [Nic99], [Ros99a], [Ros99b] discuss the computation of performance measures such as end-to-end delay and loss characterization by the fluid simulations. Nicol et al. [Nic99] claim that despite the high level of abstraction of fluid models, the error of estimated measures obtained with fluid simulation is very small compared to the results of packet-level simulation. Evolution of rate and time continuous fluid modelling and simulation covering also other possible application areas is given in [Ast98].

To relate efficiency and trade off of InterMON RTC-FSIM technology (especially for the inter-domain modelling and simulation context) to known packet and fluid modelling and simulation research, a comparison table for simulation technologies is provided below. The table differentiates between:

- Source model: packet, rate discrete, rate continuous
- Simulation technique (service process): event driven, time slice driven, time continuous.
<table>
<thead>
<tr>
<th>Simulation Technique (service process) Model</th>
<th>Event based (rare, complex event Processing)</th>
<th>Time Slice driven (frequently, simple event processing)</th>
<th>Time Continuous</th>
</tr>
</thead>
<tbody>
<tr>
<td>Packet</td>
<td>For: rare Packet Arrivals, medium complex</td>
<td>For: high rate packet arrival, complex networks</td>
<td></td>
</tr>
<tr>
<td>DISCRETE Fluid Rate continuous</td>
<td>- For rare rate changes, medium complex network - ripple effect (rate change propagati on) [Nic99], [Liu01]</td>
<td>For: high Frequency of rate changes, complex - ripple effect (rate changes propagation) Time-slice driven fluid simulation scheme Time stepped fluid [Guo00]</td>
<td></td>
</tr>
<tr>
<td>Fluid Rate continuous</td>
<td>Differential Equations For high frequency of rate changes and complex networks HDCF Simulator [Mel02] Distributed hybrid simulation [Gar01] RTC-FSIM InterMON</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table 1: Efficiency and trade off of basic simulation techniques and models

The RTC-FSIM environment as seen in the table is focussed on a high level of abstraction i.e. continuous rate modelling, which is also the background for simple and efficient modelling of large complex inter-domain infrastructures. RTC-FSIM efficiency depends on the computational complexity of solving differential equations, which is considering the complexity of inter-domain node models, their complexity of interconnections and topology.

RTC-FSIM is based on one modelling and simulation paradigm, i.e. differential equations, in order to have a simple (rate based) modelling and simulation approach for QoS studies in a large scale network (considering traffic classes with their priorities). The differential equation paradigm of the basic model is similar to the continuous flow model (CFM) used in the Hybrid Discrete Continuous Flow (HDCF) simulator [Mel02]. HDCF is aimed at integrated discrete packet and continuous flow simulation.

While RTC-FSIM is intended to provide the continuous rate abstraction for traffic behaviour in large scale networks, hybrid packet and fluid simulation are aimed at different abstraction levels. For instance, hybrid packet and fluid simulation in Project Maya (i.e. Next Generation modelling and simulation tools) integrates packet level simulation for subnets and fluid for heterogeneous large scale abstraction.

The distributed hybrid simulation concept for transient and stationary performance evaluation of large scale telecommunication networks proposed by the ESPRIT project STAR [Gar01], combines queuing theory models and packet based simulation in a global decomposed traffic modelling environment. The difference to the RTC-FSIM basic model and HDCF differential paradigm is that the differential equation in the [Gar01] model describes the mean and not the actual buffer occupation.

3. General concepts of signal flow modelling and simulation

3.1. Service station

In an elementary queuing system the use of the fluid model results in the following random processes:

\[ A(t) = \text{arrival rate process}, \]
\[ B(t) = \text{service rate process}, \]
\[ D(t) = \text{departure rate process}, \]
\[ Z(t), \text{the inner system state, which is interpreted as the length of the queue}. \]
The simulation must model the implementation of the random processes (see Figure 1) and their interrelationship. For the implementation of these processes $a(t)$, $b(t)$, $z(t)$ and $d(t)$ will be used. The arrival rate and the service rate process are combined under the term **defining process** and the state process and the departure rate process are combined under the name **derived process**.

### 3.2. Arrival rate process

The arrival rate process is a superposition of ON/OFF processes.

Figure 2 represents a packet-oriented event time line with four ON-Phases. Only the transitions between ON and OFF are monitored. This means that the events between the ON/OFF processes, which are packet arrival times, could be ignored.

For the events of the ON phase, the continuous flow model with the flow rate $\lambda$ is used. It can be now assumed that the arrival rate $\lambda$ is constant between the OFF phases and that the lengths of the ON and OFF phases $\Theta_{\text{on}}$ and $\Theta_{\text{off}}$ are exponentially distributed.

### 3.3 Signal Flow Model

As an alternative to the event-driven flow model, the **signal flow model** is used in this work. This term originated because all processes in this model are recognized as signals.

The terms process and signal are synonymous and thus, Process $a(t)$ can be called the Arrival Signal.

The advantage of signal orientation is substantial simplification. This simplification is achieved by renouncing the event-oriented simulation structure and its synchronous time-discrete sampling of all signals.
4. Multi-class flow model

4.1. Example of a multi-class service network

A service network consisting of M number of serving stations designated by Bi (i=1, 2,...,M) will now be conceptualized. Figure 3 shows an example with M=4, assuming that all of them are queuing systems. The link between the communication paths P1, P2, P3, and P4 and the sources Q1, Q2, Q3, and Q4 and the destinations S1, S2, S3, and S4 (see Figure 3) are depicted.

The information comes into the service station along communication paths, is compared, and then the different traffic classes are sent off to their appropriate destinations. In our example we have service stations B1 and B4, each with two classes, and service stations B2 and B3, each with three classes. For every class Kij (i=1,2,...,M; j=1,2,...,Ki) in the service station Bi, there is an arrival rate signal $a_{ij}(t)$, a service rate signal $b_{ij}(t)$, a state signal $z_{ij}(t)$, and a departure rate signal $d_{ij}(t)$.

For the multi-class service stations, two service disciplines can be defined:
- service without priorities
- service with priorities

For the service without priorities, the communication classes are handled equally. Processor sharing is being used here, because it is necessary to compare only the various communication classes and their paths. For the service with priorities, the communication classes are prioritized and processed accordingly.

The ON/OFF arrival processes can be implemented with the help of MATLAB. The MATLAB function for the generation of the ON/OFF processes will now be described in greater detail.

4.2. Model of the ON/OFF Arrival Process

For the simulation of the arrival processes, the ON/OFF phases are shown. Implementation is using MATLAB.

![Figure 4: The generation of the event flow of an ON/OFF process in MATLAB, the transformation to SIMULINK and the resulting signal.](image)

The two values of the arrival process are processes by SIMULINK. In Figure 4, a model is given of the generation of the event flow of the ON/OFF processes in MATLAB and then the transformation to an arrival signal in SIMULINK.

4.3. State and Departure Model of Multi-class service station

In [Ber02a], an elementary waiting-loss system (a service system with a service station) with communication classes is shown. Mathematical formulas for a state model, a departure rate model, and a loss rate model of the waiting-loss system are shown. It is now possible to derive a formula for each communication class by using a single waiting room.

The loss rate model is no longer necessary because the waiting system allows the state model to simplify the process.

The formulas for the state model of the class Kij in the station Bi now is as follows:

$$\frac{dz_{ij}(t)}{dt} = \begin{cases} 
0 & \text{if } z_{ij}(t)=0 \text{ and } (a_{ij}(t)-b_{ij}(t)) \leq 0 \\
\frac{dz_{ij}(t)}{dt} & \text{else} 
\end{cases} \quad (i=1,...,M; j=1,...,K_i) (1)$$

The formula for the departure rate model of the class Kij in the station Bi now has the following form:
In Figure 5, the signal flow chart for the formulas, which are derived from the implementation of SIMULINK, are given. Instead of the condition $z_{ij}(t)=0$, $z_{ij}(t) < 0$ is now used. Theoretically, there are no changes to the results; however, practically a more precise result is achieved as long as $a_{ij}$ and $b_{ij}$ are real numbers.

\[
\begin{align*}
    d_{ij}(t) &= \begin{cases} 
        \min \{a_{ij}, b_{ij}(t)\} & \text{if } z_{ij}(t) = 0 \\
        b_{ij}(t) & \text{if } z_{ij}(t) > 0 
    \end{cases} \\
    \text{for } i = 1, 2, \ldots, M; j = 1, 2, \ldots, K.
\end{align*}
\]  

(2)

In Figure 5, the signal flow chart for the formulas, which are derived from the implementation of SIMULINK, are given. Instead of the condition $z_{ij}(t)=0$, $z_{ij}(t) \leq 0$ is now used. Theoretically, there are no changes to the results; however, practically a more precise result is achieved as long as $a_{ij}$ and $b_{ij}$ are real numbers.

**Figure 5: A signal flow chart of the state model.**

With the help of the formula in (1),

\[
A_y = z_y \leq 0
\]

\[
B_y = ((a_y - b_y) \leq 0)
\]

\[
C_y = A_y \text{ and } B_y
\]

\[
H_y = \begin{cases} 
    0 & \text{if } C_y > 0 \\
    a_y - b_y & \text{else}
\end{cases}
\]

the above relations for the signal flow chart are designated.

**Figure 6: Signal flow chart of the departure rate model**

In Figure 6, a signal flow chart of the departure rate model is given, which is evolved from formula (2). In every station model for every class $K_{ij}$, the state rate model and the departure rate model must be used. For a better overview, the models are combined in Figure 7.

This model can also be used for every communication class $K_{ij}$, with or without priorities for the service disciplines.

**Figure 7: Overview of the signal flow chart for the state and departure rate model**

### 4.4 Service rate model for a multi-class service station

#### 4.4.1. Model of the operative service rate for a single-class service station

In contrast to the single-class model, the signals $b_{ij}(t)$ in (1) and (2) can not be replaced with the given service rate $b_i$ of the respective Station $B_i$, rather the interrelationship between the given service rate $b_i$ must be established.

For the operative service rate $b_{wi}$ of the station $B_i$ the following formula is introduced:

\[
b_{wi}(t) = \sum_{j=1}^{K} b_{ij}(t) \quad (z)
\]

The value $b_{ij}(t)$ is called the operative service rate of the class $K_{ij}$. In a single-class system, then in (z):

\[
b_{wi}(t) = b_{i1}(t)
\]

The operative service rate in this case is:
Even though (1) and (2) in a single-class model from b\textsubscript{i} is sufficient, in this case the use of operative service rate b\textsubscript{i} is also correct.

The individual communication class K\textsubscript{ij} of the service station Bi is now being viewed under the condition that each class will be maintained by an individual service station. In other words, each communication station will be handled like a single-class model. In this case, the signals E\textsubscript{ij} and G\textsubscript{ij} can be represented with the following formulas:

\[
E_{ij}(t) = \begin{cases} 
0 & \text{if } (z_j(t) = 0) \text{ and } (a_j(t) = 0) \\
1 & \text{if } (z_j(t) > 0) \text{ or } ((z_j(t) = 0) \text{ and } (a_j(t) > 0))
\end{cases}
\]

\[
G_{ij}(t) = \begin{cases} 
0 & \text{if } (z_j(t) = 0) \text{ and } (a_j(t) = 0) \\
1 & \text{if } (z_j(t) > 0) \text{ or } ((z_j(t) = 0) \text{ and } (a_j(t) > 0))
\end{cases}
\]

These relations can now be implemented into a signal flow chart (see Figure 8):

![Figure 8: Model for the Evaluation of E_{ij} and G_{ij}](image)

Therefore, in this case, under the condition E\textsubscript{ij}(t), the service rate b\textsubscript{i} is unoperated and under the condition G\textsubscript{ij}(t) the service rate b\textsubscript{i} is completely operational.

Figure 9 shows an example of three communication classes on a single time line, in which the condition E\textsubscript{ij} and G\textsubscript{ij} are depicted.

4.4.2. Service rate model for a multi-class service station with priorities

On the basis of a service discipline model with priorities, a model with K\textsubscript{i} communication classes for the service station Bi could be established as a general approach for the operational service rate of the different communication classes.

In this case, the communication class is also a priority class. For K\textsubscript{i} each priority class of the service station Bi, the following formula is used:

\[
A_g = (z_j \leq 0) \\
B_g = (a_j \leq 0) \\
C_g = z_j > 0 \\
D_g = a_j > 0 \\
E_{ij} = A_{ij} \text{ and } B_{ij} \\
F_{ij} = A_{ij} \text{ and } D_{ij} \\
G_{ij} = C_{ij} \text{ or } F_{ij}
\]
In Figure 9, the sections are given in which the condition $H_{ij}$ is valid. It is shown in the following example with three classes:

$$H_{i1} = G_{i1}$$
$$H_{i2} = G_{i2} \text{ and } E_{i1}$$
$$H_{i3} = G_{i3} \text{ and } E_{i1} \text{ and } E_{i2}$$

In general, for one service station of $K_i$ priority classes, the following results are achieved:

$$H_{i,j} = G_{i,j} \text{ if } j = 1$$
$$H_{i,j} = G_{i,j} \text{ and } E_{i1} \text{ and } E_{i2} \text{ and } ... \text{ } E_{i,j-1} \text{ if } 1 < j \leq K_i$$

In this formula, the calculation time can be formulated using the following logical operations:

$$Q_{K_i} = \sum_{i=0}^{K_i} (i - 1)$$

$$Q_{K_i} = K_i^2 / 2$$

The calculation time increases quadratic ally for each service station with priorities by the number of priority classes $K_i$.

In Figure 10, the three-class service rate model with priorities is transferred to the signal flow chart. Therefore, for the three elements $E_{ij}$ $G_{ij}$ ($i=1,2,3$), the sub models from Figure 8 are used. Also with that, other multi-class service rate models can be built. For the demonstration example in Figure 3 two two-class models and two three-class models are needed.

### 4.4.3. Multi-class service class model for a system without priorities

#### Two-class model

The two-class model without priorities for the station $B_i$ will now be depicted. In the two-class model without priorities the operative service rates of the two classes now have only the values 0, $b_i / 2$ or $b_i$. Under these conditions, the following formula can be used.

$$b_{i1} = \begin{cases} b_i & \text{if } H_{i11} \\ b_i / 2 & \text{if } H_{i12} \\ 0 & \text{else} \end{cases} \quad (3)$$

The same approach can be used for the operative service rate of the class $K_i$:

$$b_{i2} = \begin{cases} b_i & \text{if } H_{i21} \\ b_i / 2 & \text{if } H_{i22} \\ 0 & \text{else} \end{cases} \quad (4)$$

In Figure 11, the time lines with the conditions $E_{ij}$ and $G_{ij}$ are depicted. From these, the conditions $H_{ij}(i=1,2; r=1,2)$ are derived:

$$H_{i1} = G_{i1} \text{ and } E_{i2}$$
$$H_{i2} = G_{i2} \text{ and } G_{i1}$$
$$H_{r1} = G_{r1} \text{ and } E_{r1}$$
$$H_{r2} = H_{r12}$$

These conditions can also be seen in Figure 11.
Three-class model

The relationships of the operative service rates of the three-class model without priorities of a service station $B_i$ can be established.

In this case, the following approach for the operative service rate of the three communication classes:

$$b_{ni} = \begin{cases} b_i & \text{if } H_{n1i} \\ b_i/2 & \text{if } H_{n2i} \\ b_i/3 & \text{if } H_{n3i} \\ 0 & \text{else} \end{cases}$$

(6)

$$b_{nti} = \begin{cases} b_i & \text{if } H_{n1t} \\ b_i/2 & \text{if } H_{n2t} \\ b_i/3 & \text{if } H_{n3t} \\ 0 & \text{else} \end{cases}$$

(7)

$$b_{nj} = \begin{cases} b_i & \text{if } H_{nj} \\ b_i/2 & \text{if } H_{n2j} \\ b_i/3 & \text{if } H_{n3j} \\ 0 & \text{else} \end{cases}$$

(7)

In Figure 12, the three-class model without priorities with the following conditions $G_{ij}$, $E_{ij}$, and $H_{ij}$ is shown. Based on this, the following formulas are derived:

$$H_{i11} = G_{i1} and E_{i1} and E_{i3}$$

$$H_{i12} = (G_{i1} and G_{i2} and E_{i3}) or (G_{i3} and G_{i3} and E_{i2})$$

$$H_{i21} = G_{i1} and G_{i2} and G_{i3}$$

$$H_{i31} = G_{i2} and E_{i1} and E_{i3}$$

$$H_{i22} = G_{i1} and G_{i1} and E_{i2} or (G_{i2} and G_{i3} and E_{i2})$$

$$H_{i32} = H_{i33}$$

General Multi-class model

For the general multi-class model with $K_i$ communication classes, it is possible to use the following formula to find the operative service rate:

$$b_y = \begin{cases} b_i & \text{if } H_{yj} \\ b_i/2 & \text{if } H_{y2j} \\ b_i/3 & \text{if } H_{y3j} \\ 0 & \text{else} \end{cases} \quad (j = 1,2,\ldots,K_i)$$

(7)

In this case, the formula $H_{il}$ will no longer be depicted. The logical operation $Q$ will be analyzed, which is necessary to calculate the operative service rate. The following formula represents the general case for a service station $B_i$:

$$Q_{K_i} = \begin{cases} 0 & \text{if } K_i < 2 \\ 2(K_i-1)^2 + K_i & \text{if } K_i = 3,4,\ldots \end{cases}$$

The analysis of this formula shows that with the increasing of the communication classes, the value will cause a rapid increase of the number of the logical operations for each service station (as seen in the sum above). The sum leads to the main increase of $Q_{K_i}$ by increasing $K_i$, each sum of the sums expressed are binomial-coefficients, with their sum equal to $2K_i-2$ as shown in the following formula:

$$Q_{K_i} \sim K_i^2 \times 2^{K_i-2}$$

It causes the sum to increase more rapidly than exponentially. It is used to handle the explosion of logical operations. Due to a large number of communication classes, this method is unsuitable for a multi-class model.
The Entirety of Two-class models

There is another method for service rate models without priorities which would reduce the number of logical operations. This method requires the analysis of the communication paths in the service networks. In each service station all of the communication classes are joined together.

Therefore the other communication paths of the service network can be joined together to form one path which results in a two-class service network. If this method is used for every communication path, the result for the number of logical operations is:

\[ Q = 4 \times M \]

There is a linear increase which is dependent on the number of service stations. A priority free model for each communication path on the service network can be confined in which each service station contains at least two communication classes. This method is suitable for one and two-class service rate models in this case.

In Figure 12 a two-class service rate model without priorities for one service station is shown.

![Figure 12: Two-class service rate model without priorities for one service station](image)

4.5 Actual Waiting Time in a Service Station

4.5.1. Actual Waiting Time in a Service Station with Priorities

In each priority class of the service station Bi, the most attention is given to the actual waiting times \( t_{wij} \) (i=1,2,...,M; j=1,2,...,Ki). For a general multi-class model, the actual waiting time can be represented as:

\[ t_{wij} = \frac{\sum_{j=1}^{K_i} z_{ij}}{b_i} \quad (i = 1,2,...,M; j = 1,2,...,K_i) \]

This approach is based on the fact that the higher and equal level queuing lengths affects the waiting time. Ki=3 leads to:

\[ t_{w1} = \frac{z_{i1}}{b_i} \]
\[ t_{w2} = \frac{z_{i2}}{b_i} \]
\[ t_{w3} = \frac{z_{i1} + z_{i2}}{b_i} \]

This formula should be considered in the implementation of the signal flow chart of the service stations with priorities.

4.5.2. Actual Waiting Time in Service Station without Priorities

Now the actual waiting time for a multi-class service station without priorities will be shown where each queue length \( z_{ij} \) influences the waiting time in every communication class.

In this case, the waiting time for all classes is equal. The actual waiting time of all classes in the station Bi is:

\[ t_{wi} = \frac{\sum_{j=1}^{K_i} z_{ij}}{b_i} \]

A two-class model:

\[ t_{wi} = \frac{z_{i1} + z_{i2}}{b_i} \]

This formula must be considered in the signal flow chart for the two-class model of the service station without priorities.
4.6 Signal flow chart for a multi-class service station

4.6.1. Signal flow chart for a two-class und three-class service station with priorities

Figure 13 shows the signal flow chart for a two-class for a service station with priorities.

The element of this signal flow chart are the service rate model and the state and departure rate model, Class 1 and Class 2 for both communication classes Ki1 and Ki2.

In this signal flow chart, the corresponding segments for the evaluation of the actual waiting time of each class must be added.

Figure 13: Signal flow chart for a two-class model

As previously used, the signal flow chart for the two-class model can also be used in a three-class model of a service station with priorities. Therefore, all sub models of the elements of the signal flow chart in Figure 14, the service rate model in Figure 10, and the classes 1,2,3 and the state and departure rate model in Figure 7 are used. Also in this signal flow chart, the corresponding segments for the evaluation of the actual service time must be added.

Figure 14: Signal flow chart for a three-class model of a service station

4.6.2. Signal flow chart for a two-class service station model without priorities

In Figure 15, a two-class service model with one service station without priorities is depicted in which the system elements were previously shown as sub models. The system elements are the service rate model (Figure 12) and the state and departure rate model (Figure 7). Moreover, the evaluation of the actual waiting time (see section 6.2) in the signal flow chart is implemented.

Figure 15: Two-class model of one service station without priorities
5. Simulation studies

5.1. Simulation of an example of a multi-class service network

An example of a signal flow chart of a simulation of a service network without priorities is given in Figure 3.

The signal flow chart of a multi-class signal network can be established hierarchical as shown in previous sections. The hierarchical structure for the models with and without priorities must be differentiated.

5.1.1. Simulation of an example of a multi-class service network with priorities

A simulation of the given example in section 2 of a multi-class service network will now be given, showing the service discipline has priorities.

Figure 16 a hierarchical structure for a simulation of a multi-class service network with priorities is given for the example above.

5.1.2. Simulation of a two-class model without priorities

Because of the essential reductions needed for the calculation time of a two-class model for a service network without priorities, the multi-class service model will no longer be considered.

Figure 18 shows the simulation for a two-class service network without priorities.
In Figure 18, an example of a demonstration for the hierarchical construction of a network model without priorities is given. Figure 19 shows the signal flow chart for the net model without priorities, in which four service stations are the elements for the signal flow chart.

5.2. Practical scenarios for inter-domain traffic engineering

The inter-domain traffic engineering is aimed at optimisation of inter-domain resources for different traffic classes considering their priorities. The purpose of this scenario is to study how different kinds of flows interact and influence each other depending on the different class priority. We use the two class simulation model. The inputs are two ON/OFF arrival processes – one describing real time input process like VoIP and the other bursty file transfer traffic. For the arrival process, the exponential distribution of the ON/OFF phases, which has a mean value duration $T_{on}$ and $T_{off}$ and a constant arrival rate $\lambda$ for the ON phase could be obtained from real world measurements.

We set different priorities for flow processing (dependent on the QoS requirements or policies) and want to see the behaviour of the two flows, i.e.
- waiting times
- departure process models.

The input processes are shown in the following figures:

Figure 20: Arrival process K1 (priority real time flow)

Figure 21: Arrival process K2 (non priority bursty flow)

For the output processes, the mean values $T_{w1j}$ and variances $V_{wij}$ of the waiting times were derived. The mean waiting time is given by the mean value formation from MATLAB with the standard function `mean` and the standard deviation of the waiting time with the standard function `var`. The following figure summarises the results of the simulation study, for the real time flow K1 (prioritised) and bursty flow K2 (not prioritised) the modelling statistics – arrival, waiting time and departure model. We see the strong dependency of the departure flow model from the selected priority.

Departure model of flow K1 is very similar to the arrival model, because the flow is processed immediately, where flow K2 departure model is different from the arrival due to the waiting at the processing node.
The greater waiting times of K2 are shown in figure 23.

The models of the departure processes (figure 24, figure 25) show that the priority processing preserves the real time flow model, where the bursty traffic is shaped due the non priority processing and longer waiting times.
6. Conclusion and further work

In this paper, the RTC-FSIM technology especially the multi-class flow model are presented.

A simple scenario was shown to illustrate the multi-class simulation model based on different traffic classes.

The RTC-FSIM simulator is intended to be used in the framework of INTERMON [INTERMON] project.

Further work is:
- measurement based simulation using real world traffic traces and their modelling as input for RTC-FSIM simulator
- enhancement of RTC-FSIM simulator statistics
- simulation based on practical scenarios in the area of capacity planning and traffic engineering
- integration in the INTERMON toolkit.

7. References


[Simulink] [www.sciencesoftware.com/simulink.asp](www.sciencesoftware.com/simulink.asp)

