IBIMA Publishing
Communications of International Proceedings
https://ibimapublishing.com/p-articles/46ICT/2025/4643325/
Vol. 2025 (35), Article ID 4643325

Approximation of Compressed Flows by Equivalent Stream-Based Flows in Multi-Rate Systems with Compression Mechanism*

Slawomir HANCZEWSKI, Maciej STASIAK and Joanna WEISSENBERG

Faculty of Computing and Telecommunications, Poznan University of Technology, Poznan, Poland,

Correspondence should be addressed to: Slawomir HANCZEWSKI, slawomir.hanczewski@put.poznan.pl

* Presented at the 46th IBIMA International Conference, 26-27 November 2025, Ronda, Spain

Abstract

This paper presents considerations concerning the development of an equivalent model for flows subject to compression mechanisms, namely elastic and adaptive flows. The necessity of constructing such a model stems from the fact that, during the transmission of these flows, their parameters — such as bitrate and/or transmission time, as well as the volume of the transmitted data — vary according to the instantaneous values of the compression coefficient. Accounting for these variations within the analytical model enables the development of precise tools for the analysis and dimensioning of modern IT systems like 5G networks.

Keywords: elastic and adaptive flows, compression, equivalent of compressed flows.

Introduction

An enormous volume of data is transmitted daily across telecommunication networks. Groups of packets, referred to as flows, are conveyed between data sources and their respective receivers. Diverse Quality of Service (QoS) requirements dictate that these flows may be subject to various traffic management mechanisms, such as congestion control. The operation of this specific mechanism is straightforward: in the event of network congestion or overload, the data transmission rate is limited. For elastic flows, the data transfer time is extended to ensure that all scheduled data reaches the recipient. Conversely, for adaptive flows, the limitation of the transmission rate does not entail an increase in the transfer time. Elastic flows typically correspond to data transmitted using the TCP protocol, which ensures the reliable data delivery and maintains transmission rate is limited. Adaptive flows, by contrast, are characteristic of service capable of adjusting to network congestion, allowing the service to be completed within a predefined time frame. This scenario commonly occurs in live video streaming, where, under network overload, the codec may be modified to reduce the required transmission bitrate.

From the perspective of a network operator, network maintenance and optimisation are complex tasks, commensurate with the diversity of traffic carried across the network. These processes would not be feasible without dedicated tools based on analytical or simulation modelling. Both approaches have distinct advantages and limitations. Simulation models, though generally easier to construct, tend to demand greater computational resources and time than analytical models. Analytical models, in turn, are often challenging to parameterise (particularly in the case of complex systems) so as to reflect real-world conditions accurately. Despite this limitation, analytical models are widely and successfully applied in network design and optimisation (Moscholios and Logothetis, 2019).

Cite this Article as: Slawomir HANCZEWSKI, Maciej STASIAK and Joanna WEISSENBERG, Vol. 2025 (35) "Approximation of Compressed Flows by Equivalent Stream-Based Flows in Multi-Rate Systems with Compression Mechanism " Communications of International Proceedings, Vol. 2025 (35), Article ID 4643325, https://doi.org/10.5171/2025.4643325

A key element of any analytical model is the mathematical description of the flow properties within the considered system. In the classical Erlang-based approach, an infinite number of traffic sources, a Poisson arrival stream (of flows/calls), and an exponential service time (with a constant parameter $\mu_{i,u}$) are assumed. In the case of elastic flows, this parameter is not constant; its instantaneous value is a function of the current compression factor (or congestion control factor). Conversely, for adaptive flows, the data transmission time remains unchanged, which results in a reduction in the amount of data transmitted (compared to the initially assumed volume), consequently leading to the degradation of QoS parameters. Therefore, the classical approach to analyzing systems with elastic and adaptive flows is burdened with a certain error which, when the compression factor is limited, can be neglected (as demonstrated by a number of studies, e.g. (Hanczewski et al., 2018), (Bonald and Roberts, 2012), (Racz et al., 2002) and (Stamatelos and Koukoulidis, 1997). However, to eliminate this error, an equivalent model for elastic and adaptive flows must be found, one that possesses a constant parameter $\mu_{i,u}$. According to the concept adopted in this paper, it is assumed that it is possible to replace the elastic and adaptive flow in the system analysis process with its stream equivalent that has an appropriately re-calculated parameter $\mu_{i,u}$.

The remainder of the paper is organised as follows: Section "Parametrisation of ICT Systems with Stream, Elastic and Adaptive Flows" discusses the fundamental concepts associated with flows observed in modern IT networks. Section "Algorithm for Deriving the Equivalent Stream Representation of Compressed Flows" presents the proposed algorithm for determining equivalent stream-based representations for elastic and adaptive flows. Finally, Section "Conclusions" provides a brief summary of the paper.

Parametrisation of ICT systems with stream, elastic and adaptive flows

In the analysis of contemporary telecommunication systems, traffic theory remains a fundamental tool for describing shared resources among different service classes characterised by diverse quality requirements. In multiservice systems featuring a compression mechanism, which encompasses both constant bit rate transmissions and services with variable bandwidth requirements, a unified approach is necessary to quantitatively map the system's behaviour under changing load conditions.

Let us, therefore, consider a system with capacity C_r, expressed in Allocation Units (AUs). In multiservice systems with a compression mechanism, dynamic regulation of the number of allocated/occupied resources is permitted, depending on the current system occupancy state. For this purpose, a compression factor $\xi(n_s, n_c) \in [\xi_{max}, 1]$ is introduced, which defines the degree of throughput (number of resources) reduction relative to the nominal value. A value of $\xi(n_s, n_c) = 1$ denotes no compression, while $\xi(n_s, n_c) = \xi_{max}$ corresponds to the maximum permissible compression level, where n_s defines the number of resources occupied by stream flows, and n_c the number of resources occupied by flows subject to the compression mechanism. From an analytical perspective, the system capacity for flows subject to the compression mechanism can be extended to the so-called analytical capacity:

$$C_v = \frac{C_r}{\xi_{max}}. \quad (1)$$

The value C_v does not represent the physical system capacity; rather, it reflects the boundary case in which all flows undergo maximum compression, thus allowing the system to service the largest number of flows at the minimum unit throughput (resource requirement) by the compressed flows.

Flows offered to the system are described by three fundamental parameters: arrival intensity $\lambda_{i,u}$, mean service intensity $\mu_{i,u}$ and the number of requested resources $c_{i,u}$, where the index i denotes the traffic class (flow/flow class) number and u its type ($u \in \{s - \text{stream flow}, e - \text{elastic flow}, a - \text{adaptive flow}\}$). These parameters define the characteristics of the flow classes in a nominal sense. The influence of the load level and the compression mechanism on resource utilisation and the quality of served flow classes results from the adopted resource allocation rule (expressed in AUs).

To reflect the influence of the system occupancy state on the traffic parameters of individual flow class, the parameters $c_{i,u}$ and $\mu_{i,u}$ are treated as functions of the system occupancy state (n_s, n_c).

For stream traffic flows, the parameters remain constant throughout the duration of the connection, which corresponds to services with guaranteed throughput and quality of service:

$$c_{i,s}(n_s, n_c) = c_{i,s} \text{ and } \mu_{i,s}(n_s, n_c) = \mu_{i,s}. \quad (2)$$

The dependence on the system occupancy state for stream flows occurs only at the stage of accepting a new flow, when the number of free allocation units is insufficient to service it. In this case, the flow is lost.

For elastic flows, the number of occupied resources (allocation units) and the service intensity can be represented using functions of the current system occupancy state. When the total system occupancy exceeds the capacity C_r, the compression mechanism is activated, which responds to the fluctuating changes in system occupancy level in the following manner:

$$c_{i,e}(n_s, n_c) = c_{i,e}\xi(n_s, n_c) \text{ and } \mu_{i,e}(n_s, n_c) = \mu_{i,e}\xi(n_s, n_c), \quad (3)$$

where the compression function $\xi(n_s, n_c)$ can be written as follows:

$$\xi(n_s, n_c) = \begin{cases} 1, & 0 \le n_s + n_c \le C_r, \\ \frac{C_r - n_s}{n_c}, & C_r < n_s + n_c \le C_v. \end{cases} \quad (4)$$

The increase in system load leads to a decrease in the number of allocation units assigned to elastic flows and to an extension of their service time, while a decrease in system load results in the inverse effect.

For adaptive flows, changes in the number of occupied resources also depend on the compression level, however, the service intensity, and thus the average service duration, remains unchanged:

$$c_{i,a}(n_s, n_c) = c_{i,a}\xi(n_s, n_c) \text{ and } \mu_{i,a}(n_s, n_c) = \mu_{i,a}, \quad (5)$$

where $\xi(n_s, n_c)$ is expressed by equation (4).

These dependencies uniquely describe the influence of the system occupancy state on the effective values of the traffic parameters, differentiating the behaviour of individual flow classes.

Figure 1 presents the service process of a single elastic flow. As can be seen, the actual data transmission rate deviates from the initially assumed rate (100%). The observed changes depend on the current occupancy state. Changes in the data transmission rate necessitate an appropriate extension of the transmission time to deliver the initially assumed volume of data. Figure 2, presents the service process of a single adaptive flow. In this case, the change in transmission rate does not cause an extension of the transmission time; however, it leads to a reduction in the transmitted data volume.

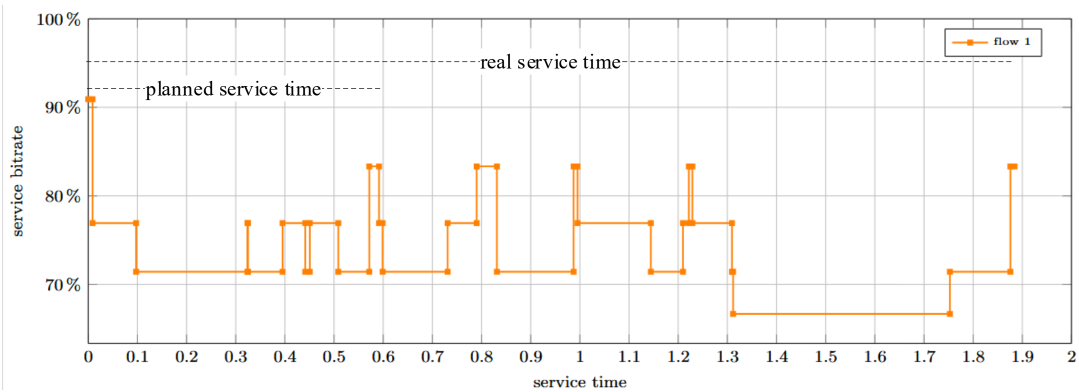

Figure 1. Changes in the transmission rate of an elastic flow

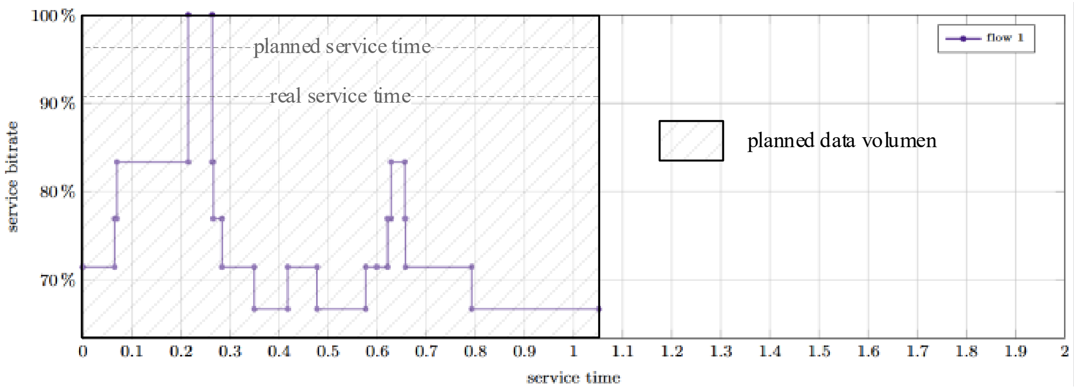

Figure 2. Changes in the transmission rate of an adaptive flow, along with a limitation of the transmitted data volume

In (Hanczewski et al., 2021), (Hanczewski et al. 2018) and (Racz et al., 2002), it was demonstrated that the inclusion of elastic flows in multiservice systems with a compression mechanism leads to service processes of an irreversible nature. This phenomenon results from fluctuations in the resource occupancy level, which directly influence the variability of the service intensity of elastic flows. Consequently, their service time becomes dependent on the instantaneous occupancy state of the system, significantly complicating classical analytical modelling and preventing the use of methods characteristic of reversible processes.

To enable effective analysis of such systems, this paper proposes an algorithm in which elastic and adaptive flows are mapped onto equivalent stream-type flows with appropriately re-calculated parameters. This makes it possible to describe the system using a reversible service process, allowing the use of classical traffic theory tools while maintaining high consistency with the results of real systems.

Algorithm for deriving the equivalent stream representation of compressed flows

To determine the subsequent steps of the algorithm, let us consider a fragment of the Markov chain describing transitions between system occupancy states. Each transition between states corresponds to the arrival of a new flow or the completion of an existing connection. Figure shows the Markov chain describing transitions for an elastic flow of class i and Figure for an adaptive flow of class i.

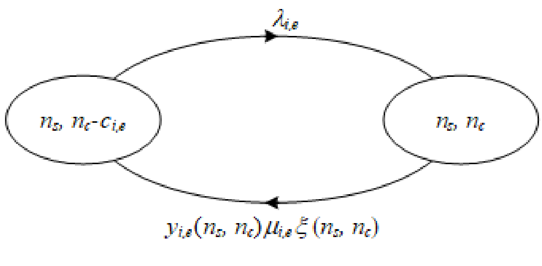

Figure 3. A fragment of the Markov chain in a multi-service system with a compression mechanism corresponding to elastic flows

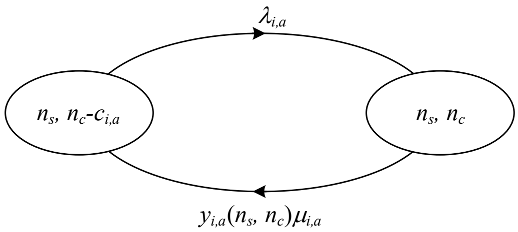

Figure 4. A fragment of the Markov chain in a multi-service system with a compression mechanism corresponding to adaptive flows

To obtain the relationships between the system states in terms of traffic, the transition intensities in the Markov chain are normalised with respect to the service intensity and scaled by the number of occupied resources. Dividing both sides of the transition equations by $\mu_{i,u}(n_s, n_c)$ and multiplying by $c_{i,u}(n_s, n_c)$, we obtain the relation:

$$\frac{\lambda_{i,u}}{\mu_{i,u}(n_s,n_c)} c_{i,u}(n_s, n_c) = A_{i,u}(n_s, n_c)\ c_{i,u}(n_s, n_c)\ , \quad (6)$$

where $A_{i,u}(n_s, n_c)$ denotes the offered traffic intensity by a flow of class i type u (in Erlangs). After performing these operations, and taking into account equations (3), (4), and (5), scaled Markov chains are obtained, presented in Figure 5 and Figure , which illustrate the relations between states in terms of traffic, i.e., taking into account the traffic intensity $A_{i,u}(n_s, n_c)$ and the number of occupied resources $c_{i,u}(n_s, n_c)$. In Figure , Figure , Figure 5 and Figure , $y_{i,u}(n_s, n_c)$ denotes the average number of Allocation Units (AUs) occupied by a single flow of class i type u in occupancy state (n_s, n_c). This quantity reflects the resource occupancy level by flows of a given class in the considered state of the Markov chain.

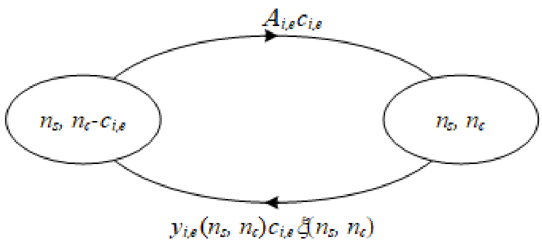

Figure 5. A scaled fragment of the Markov chain in a multi-service system with a compression mechanism corresponding to elastic flows

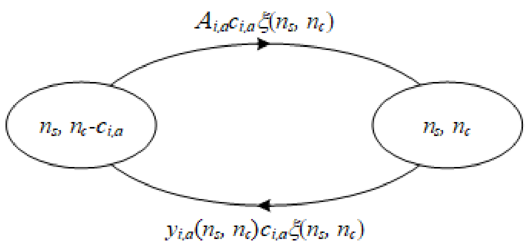

Figure 6. A scaled fragment of the Markov chain in a multi-service system with a compression mechanism corresponding to adaptive flows

Based on the state diagrams presented in Figure 5 and Figure , the local balance equations for Markov processes can be written as:

$$A_{i,e}c_{i,e}P(n_s, n_c - c_{i,e}) = y_{i,e}(n_s, n_c)c_{i,e}\xi_{i,e}(n_s, n_c)P(n_s, n_c), \quad (7)$$

$$A_{i,a}c_{i,a}\xi_{i,a}(n_s,n_c)P(n_s,n_c-c_{i,a}) = y_{i,a}(n_s,n_c)c_{i,a}\xi_{i,a}(n_s,n_c)P(n_s,n_c), \quad (8)$$

where the probability distribution $P(n_s,n_c)$ was determined in article (Hanczewski et al. 2025).

Based on the analysis of the scaled Markov chains, an approximation algorithm for replacing compressed traffic with its equivalent stream form was developed. The algorithm enables the determination of approximate values for equivalent parameters, ensuring the preservation of the load proportions and resource utilization structure characteristic of a system with a compression mechanism. This allows for the application of classical traffic theory methods to assess the performance of multiservice systems servicing elastic, adaptive, and stream traffic.

The subsequent steps of the algorithm are presented below.

1. Determination of the mean number of elastic and adaptive flows of class i served in state (n_s,n_c):

$$y_{i,e}(n_s,n_c) = \frac{A_{i,e}P(n_s,n_c-c_{i,e})}{P(n_s,n_c)\xi_{i,e}(n_s,n_c)}, \quad (9)$$

$$y_{i,a}(n_s,n_c) = \frac{A_{i,a}P(n_s,n_c-c_{i,a})}{P(n_s,n_c)}. \quad (10)$$

2. Determination of the probability of service completion for elastic and adaptive flows of class i in occupancy state (n_s,n_c).
   In state (n_s,n_c), two types of elementary events are possible for each flow class: the arrival of a new flow or the completion of an existing active connection. The probability of service completion for flow class i in a given state is determined by the share of effectively served flows of that class in the total stream of events of that class in the considered occupancy state. These probabilities for elastic and adaptive flow classes, respectively, can be written as follows:

$$\Pi_{i,e}(n_s,n_c) = \frac{y_{i,e}(n_s,n_c)\xi(n_s,n_c)}{A_{i,e}+y_{i,e}(n_s,n_c)\xi(n_s,n_c)}, \quad (11)$$

$$\Pi_{i,a}(n_s,n_c) = \frac{y_{i,a}(n_s,n_c)\xi(n_s,n_c)}{A_{i,a}\xi(n_s,n_c)+y_{i,a}(n_s,n_c)\xi(n_s,n_c)}. \quad (12)$$

3. Determination of mean number of serviced elastic and adaptive flows of class i in occupancy state (n_s,n_c).
   The mean (expected) number of serviced elastic and adaptive flows of class i can be expressed by the formulas:

$$z_{i,e}(n_s,n_c) = y_{i,e}(n_s,n_c)\Pi_{i,e}(n_s,n_c), \quad (13)$$

$$z_{i,a}(n_s,n_c) = y_{i,a}(n_s,n_c)\Pi_{i,a}(n_s,n_c). \quad (14)$$

Based on the determined values of parameters $z_{i,u}(n_s,n_c)$ and the probability distribution $P(n_s,n_c)$ the equivalent stream flow approximating the elastic and adaptive flows can be determined. Equivalent parameters are determined as weighted averages based on the frequency of occurrence of individual states:

4. Determination of equivalent elastic flow:
   Service intensity of elastic flow of class i:

$$\mu_{i,e}^{eq} = \frac{\sum_{(n_s,n_c)}\mu_{i,e}\xi(n_s,n_c)z_{i,e}(n_s,n_c)P(n_s,n_c)}{\sum_{(n_s,n_c)}z_{i,e}(n_s,n_c)}. \quad (15)$$

   Number of requested resources expressed in AUs by elastic flow of class i:

$$c_{i,e}^{eq} = \frac{\sum_{(n_s,n_c)}c_{i,e}\xi(n_s,n_c)z_{i,e}(n_s,n_c)P(n_s,n_c)}{\sum_{(n_s,n_c)}z_{i,e}(n_s,n_c)}. \quad (16)$$

   Mean traffic intensity of elastic flow of class i:

$$A_{i,e}^{eq} = \frac{\lambda_{i,e}}{\mu_{i,e}^{eq}}. \tag{17}$$

5. Determination of equivalent adaptive flow:
   Service intensity of adaptive flow of class i:

$$\mu_{i,a}^{eq} = \mu_{i,a}. \tag{18}$$

Number of requested resources expressed in AUs by adaptive flow of class i:

$$c_{i,a}^{eq} = \frac{\sum_{(n_s,n_c)} c_{i,a}\xi(n_s,n_c) z_{i,a}(n_s,n_c) P(n_s,n_c)}{\sum_{(n_s,n_c)} z_{i,a}(n_s,n_c)}. \tag{19}$$

Mean traffic intensity of adaptive flow of class i:

$$A_{i,a}^{eq} = A_{i,a}. \tag{20}$$

Conclusions

This paper presented a method for determining equivalent parameters for elastic and adaptive flows in telecommunication systems with a compression mechanism. The developed algorithm enables the replacement of actual compressed traffic with its equivalent stream counterpart, whose parameters, such as service intensity, number of occupied resources, and traffic intensity, reflect the averaged properties of the actual service process across different system occupancy states.

The use of equivalent values allows for the simplification of multiservice system analysis without losing consistency with the actual nature of the processes occurring in the system.

The obtained dependencies form the basis for developing analytical models that enable the assessment of quality of service and resource utilisation efficiency in systems servicing variable-bit-rate flows.

Acknowledgment

This research is funded by the Ministry of Science and Higher Education: Grant 0313/SBAD/1311

References

- Hanczewski, S., Stasiak, M., Weissenberg, J. and Weissenberg, M. (2025) ‘Modeling of Heterogeneous 5G Network Slice for Smart Real-Time Railway Communications,’ IEEE Transactions on Network and Service Management, vol. 22, no. 3, pp. 2534-2545
- Hanczewski, S., Stasiak, M. and Weissenberg, J. (2021) ‘A Model of a System With Stream and Elastic Traffic,’ IEEE Access, vol. 9, pp. 7789-7796
- Racz, F., Gero, B. and Fodor, G (2002), ‘Flow level performance analysis of a multi-service system supporting elastic and adaptive services,’ Performance Evaluation, Volume 49, Issues 1–4, pp. 451-469.
- Bonald, T. and Roberts, J.W. (2012) ‘Internet and the Erlang formula,’ ACM SIGCOMM Computer Communication Review. 42, 1, pp 23–30.
- Stamatelos, G. M. and Koukoulidis, V. N. (1997), ‘Reservation-based bandwidth allocation in a radio ATM network,’ IEEE/ACM Transactions on Networking, vol. 5, no. 3, pp. 420–428.
- Hanczewski, S., Stasiak, M. and Weissenberg, J. (2018), ‘Queueing model of a multi-service system with elastic and adaptive traffic,’ Computer Network, vol. 147, pp. 146–161.
- Moscholios, I.D. and Logothetis, M. D. (2019) Efficient Multirate Teletraffic Loss Models Beyond Erlang, Wiley-IEEE Press,