Rate-Based Flow Control Model in Group Communication *

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Akihito Iguchi, Makoto Takizawa, and Takayuki Tachikawa †
Tokyo Denki University ‡
e-mail{igu, taki, tachi}@takilab.k.dendai.ac.jp

1 Introduction

The information system is composed of multiple computers interconnected by the high-speed communication networks. The transmission speed of the network is faster than the processing speed of the process. The process p_i loses messages if the messages arrive at p_i faster than the processing speed of p_i. Kinds of high-speed communication protocols like XTP [1] are discussed so far. These papers discuss how to adjust the transmission rate of the sender so that the receivers could receive all the messages sent by the sender. In distributed applications like groupwares, a group G of multiple processes $p_1, \ldots, p_n$ are cooperated by exchanging messages with each other in the high-speed network. Here, each process p_i not only sends messages to multiple processes but also receives messages from multiple processes in the group. In the multimedia applications, the processes exchange multiple streams of data like voice streams and image streams in the group. In this paper, we present a general model where each process sends and receives multiple streams which are interrelated in the group G. We discuss how to allocate the transmission rates of multiple streams to the processes in the group G so that the constraints on the streams are satisfied.

2 System Model

2.1 System configuration

The distributed application is realized by the cooperation of multiple processes p_1, ..., p_n (*group* $G = \{p_1, \ldots, p_n\}$). In this paper, we assume that the processes are interconnected by the highspeed one-to-one channels. G is logically considered to support every pair of processes p_i and p_j with a reliable, bidirectional communication channel $\langle p_i, p_j \rangle$. Every pair of channels $\langle p_i, p_j \rangle$ and $\langle p_h, p_l \rangle$ are independent. That is the traffic in $\langle p_i, p_j \rangle$ are not influenced by $\langle p_h, p_l \rangle$. A unit of data transmitted between the processes is referred to as a *stream*, e.g. video stream and image stream. A *message* is a unit of data transmission in the network. p_i decomposes a data of stream from the application to a sequence of smaller messages and sends them to the network.

2.2 Massage rates

Each process p_i in the group G receives messages if the messages arrive at p_i at a slower rate than p_i could receive. Here, let $maxRR_i(t)$ be a maximum receipt rate of p_i at time t. We assume that $maxRR_i(t)$ is an invariant constant $maxRR_i$. If the messages arrive at p_i at a slower rate than $maxRR_i$, p_i can receive all the messages. Let $RR_i(t)$ be a receipt rate of p_i at time t. $TR_i(t)$ denotes a transmission rate of p_i at time t. That is, p_i sends $TR_i(t)$ messages per a time unit at t. Let $maxTR_i$ be a maximum transmission rate of p_i. Each message is destined to the destination processes, not necessarly all the processes in G. Among $TR_i(t)$ messages, p_i sends $TR_{ij}(t)$ messages to p_j at t. $TR_i(t) = TR_{i1}(t) + \ldots + TR_{in}(t)$. Here, $TR_i(t) \leq maxTR_i$. p_i receives messages from p_1, ..., p_n while sending messages to the processes in G. Here, let δ_{ij} denote propagation delay from a process p_i to p_j. Assume that $\delta_{ij} = \delta_{ji}$ for every pair of the processes p_i and p_j in G and δ_{ij} is time-invariant. p_i receives messages at time t which p_j has sent to p_i at $t-\delta_{ij}$. Hence, $TR_{i1}(t-\delta_{i1}) + \ldots + TR_{in}(t-\delta_{in})$ messages arrive at p_i at t[Figure1]. Let $AR_i(t)$ be an *arrival* rate of p_i at t which is given as follows: $AR_i(t) = AR_{i1}(t) + \cdots + AR_{in}(t)$, $AR_{ij}(t) = TR_{ij}(t - \delta_{ij})$. $AR_{ij}(t)$ is an arrival rate of messages arrived from p_j to p_i at t. If $AR_i(t) \leq maxRR_i$, p_i receives all the messages sent to p_i from the processes in G. That is, $RR_i(t) = AR_i(t)$. Otherwise, p_i loses some of the messages due to the buffer overrun.

In this paper, we assume that if $AR_i(t) > maxRR_i$, $AR_i(t) - maxRR_i$ messages per a unit time are lost by p_i at time t. That is, each p_i can receive $maxRR_i$ messages at every time t even if more messages than p_i could receive arrive at p_i. Let $L_i(t)$ denote a *loss* rate of p_i at time t, showing how many messages per in a time unit are lost by p_k. If $L_i < maxRR_i$, $L_i(t) = 0$. If $L_i(t) > 0$, $L_i(t)$ messages are lost by p_i at t and $RR_i(t) = maxRR_i$. Each p_i receives messages from $p_i, \ldots, p_n$ at the rate $RR_i(t)$ at time t as presented here. $RR_{ij}(t)$ is a receipt rate of messages from p_j to p_i. $RR_i(t) = RR_{i1}(t) + \cdots + RR_{in}(t)$.

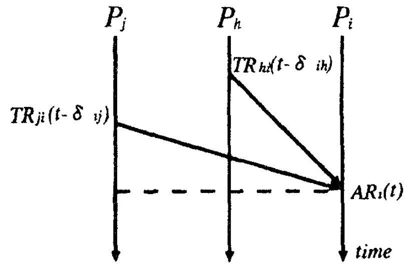

Figure 1: Arrival rate

If $AR_{ij}(t) > RR_{ij}(t)$, p_i lose $AR_{ij}(t) - RR_{ij}(t)$ messages at t. Let $L_{ij}(t)$ denote a rate of messages which p_i loses from p_j. $L_{ij}(t) = AR_{ij}(t) - RR_{ij}(t)$. Even if $AR_i(t) < maxRR_i$, $L_{ij}(t)$ may not be zero. For example, p_i controls the receipt rate of message from p_j so that $RR_{ij}(t) \leq maxRR_{ij}$ for some constant $maxRR_{ij}$. Hence, $L_i(t)$ is given as follows: $L_i(t) = L_{i1}(t) +, \cdots, + L_{in}(t)$.

Let $maxRR$ be $maxRR_1 + \ldots + maxRR_n$. $maxRR$ is named a *total capacity* of the system. Let $totalAR(t)$ be a *total arrival* rate of the system at t. $totalAR(t)$ shows the amount of messages which are arriving at the processes at t. Let $totalRR(t)$ be a *total receipt* rate of the system at t. $totalRR(t)$ shows the *through-*

*グループ通信における送信率割り当て方式
†井口 昭人, 滝沢 誠, 立川 敬行
‡東京電機大学

put of the system at t. Here, $totalRR(t) \leq maxRR$ and $totalRR(t) \leq totalAR(t)$. The *efficiency* $E(t)$ of the system at t is defined to be $totalRR(t)$ / $totalAR(t)$.

2.3 Stream rates

Each process p_i in the group G sends multiple streams S_i^1, ..., $S_i^{k_i}$ ($k_i \geq 1$) at the same time. Messages decomposed from each stream S_i^h are transmitted to the destinations in the group G at some rate $TR_i^h(t)$ ($h = 1,\ldots,k_i$). $TR_{ij}(t) = TR_{ij}^1(t) + \cdots + TR_{ij}^{k_i}(t)$. Here, $TR_{ij}^h(t)$=0 if S_i^h is not sent to p_j. $AR_{ji}^h(t) = TR_{ij}^h(t - \delta_{ij})$ which is the arrival rate of S_i^k from p_i to p_j. Let $RR_{ji}^h(t)$ denote a receipt rate of messages of S_i^h which p_j receives from p_i. Let $L_{ij}^h(t)$ be a rate of messages in S_j^h which p_i loses from p_j.

2.4 Fairness

First, let us consider the transmission rates of the processes. Suppose that p_i and p_j would send messages in the network. Suppose that there are two systems T_1 and T_2, which support the group G of the processes p_1, ..., p_n with different rate-based flow control strategies. Let $TR_i^{(k)}(t)$ be a transmission rate of p_i by the system T_k at time t. T_1 is defined to be more *fair* than T_2 on the transmission rates of p_i and p_j at t iff $|TR_i^{(1)}(t)$ - $TR_j^{(1)}(t)| \leq |TR_i^{(2)}(t)$ - $TR_j^{(2)}(t)|$. Here, let $VTR^{(k)}(t)$ be the variance of $TR_1^{(k)}(t)$, ..., $TR_n^{(k)}(t)$ in a system T_k.

[Definition] T_1 is more *fair* than T_2 on the transmission rate iff $VTR^{(1)}(t) \leq VTR^{(2)}(t)$. □

The fairness of the receipt rate and the loss rate can be defined similarly to the transmission rate. Here, let $VRR^{(k)}(t)$ and $VL^{(k)}(t)$ be the variances of the receipt rates and the loss rate of the processes in the system T_k at time t.

The distributed application has requirements on the transmission rate of messages in the group G. Let QR_{ij}^h be a transmission requirement for a stream S_i^h sent by p_i to p_j which shows how many messages of S_i^h per a time unit to be transmitted from p_i to p_j. QR_{ij} is a transmission requirement of messages sent by p_i to p_j ($QR_{ij} = QR_{ij}^1 + \cdots + QR_{ij}^{h_i}$). In addition, there is a requirement among the streams S_i^h and S_h^l. Suppose that S_i^h and S_k^l are sent to p_j. For example, applicates require that p_i receive the messages of S_i^h and S_k^l at the same rate, i.e.$QR_{ij}^h = QR_{hl}^l$. Thus, the relation among the streams $S_i^h, \ldots, S_j^l$ is represented by the relation among the receipt rates $Q_{ih}^h, \ldots, Q_{im}^l$.

3 Rate Allocation

First, p_i has to send messages of each stream S_i^h to each destination p_j so that p_j could receive all the messages. In addition, we have to consider the relations among the streams. For example, suppose that p_j and p_k send streams S_j and S_k to p_i, respectively. p_i has to receive two streams S_j and S_k in a synchronous mode if S_j and S_k are related. Thus, each process p_i has to send messages to the destination processes so as to satisfy the requirements. In this paper, we consider the following requirements: (1) Transmission rate, (2) Throughput, and (3) Synchronization.

Each process p_i sends a stream S_i^h to the destination processes in G. For each S_i^h and each destination p_j of S_i^h, there is a requirement of the transmission rate QR_i^h. p_i is required to send S_i^h to p_j at a rate $TR_i^h(t) \geq QR_i^h$. p_i has to decide $TR_i^h(t)$ so as to satisfy the following constraints: $\sum_{h=1}^{k_i} TR_i^h(t) \leq maxTR_i$, $TR_{ij}^h(t) \leq maxRR_{ji}$ for every destination process p_j. Before sending streams $S_i^1, \ldots, S_i^h$, each process p_i sends the requirement of the transmission rates $QR_{i1}^h, \ldots, QR_{in}^h$ for every S_i^h to all the processes $p_1, \ldots, p_n$ in the group G. p_i receives the transmission requirements from all the processes, i.e. $\{QR_{jh}^l | j, h = 1, \ldots, n, l = 1, \ldots, k_j\}$. If $\sum_{j=1}^n QR_{jh} \leq maxRR_h$ for every process p_h, there occurs no overrun in G. Here, each p_i sends messages to p_j at a transmission rate $TR_{ij}(t) = QR_{ij}$ and p_j receives the messages from p_i at a receipt rate $RR_{ji}(t) = QR_{ij}$. Otherwise, overrun may occur. In order to avoid the orverrun, the transmission rates of the processes are changed as follows: If $\sum_{k=1}^n QR_{kh} \leq maxRR_h$, TR_{kh} = $QR_{kh} \cdot (maxRR_h / \sum_{k=1}^n QR_{kh})$.

Some streams transmitted in the group G are interrelated. There are the following cases:

(1) A process p_i sends a steam S_i^h to the processes $p_1, \ldots, p_n$ in G. For every pair of destinations p_j and p_k of S_i^h, $TR_{ij}^h(t) = c_{jk} \times TR_{ik}^h(t)$ where c_{jk}^h is a constant.

(2) p_i receives streams from the processes $p_1, \ldots, p_n$ in G. Suppose that p_i receives a stream S_j^h from p_j and S_k^l from p_k, $RR_{ji}^h(t) = b_{jk} \times RR_{ki}^l(t)$ where b_{jk} is a constant.

In (1), if $c_{jk} = 1$, p_i sends the messages of S_i^h to every destination p_j at the same transmission rate. In (2), if $b_{jk} = 1$, p_i has to receive messages of S_j^h and S_k^l at the same receipt rate. That is, p_i receives the massages in a synchronous mode. If the overrun occurs in the receiver process, the transmission rate is decreased so as to satisfy the constraint (1) and (2).

In our system, every process p_i negotiates with the other processes before transmitting the messages of the stream. Each process p_i first sends the transmission requirement QR_i to all the processes $p_1, \ldots, p_n$ in the group G before sending the messages of a stream S_i^h. The requirement QR_i includes the rate requirement QR_{ij}^h for each destination process p_j. QR_i also includes the inter-stream requirement in from $\langle QR_{ij}^h, QR_{ik}^h, c_{jk}^h \rangle$. On receipt of the rate requirement QR_{ij} from p_j, p_j decides the maximum receipt rate $maxRR_{ji}^h$ for S_i^h.

4 Concluding Remarks

In the group communication, each process not only sends messages to multiple processes but also receives messages sent by multiple processes. In this paper, we have presented the general models of the group communication of multimedia. In addition, we have discussed how to allocate the transmission rates to the processes in the group.

References

[1] Strayer, W. T., Dempsey, B. J., and Weaver, A. C., "XTP: The Xpress Transfer Protocol(XTP)," *Addison-Wesley*, 1992.