Analysis of the Access Protocol for a multiservice LAN

V. Pallios, T. Antonakopoulos and V. Makios

First European Conference on Information Technology for Organisational Systems - EURINFO '88

ATHENS, MAY 1988

Information Technology for Organisational Systems
H.-J. Bullinger et al. (Editors)
Elsevier Science Publishers B.V. (North-Holland)
© ECSC-EAEC-EEC, Brussels-Luxembourg, 1988

ANALYSIS OF THE ACCESS PROTOCOL FOR A MULTISERVICE LAN

V.Pallios M.Eng., T.Antonakopoulos D.Eng., V.Makios Ph.D.

University of Patras, Laboratory of Electromagnetics, Patras, Greece.

This paper presents a methodology for the analysis of a hybrid switching system. Hybrid switching enables both circuit-and packet-switched services to be provided in the same communication network. The proposed hybrid protocol is based on an asynchronous dynamic TDM technique. The formulae for the average queue length for the stream traffic and the average queue length and delay for the bursty traffic are computed. These formulae can be applied to study alternative system operations under specific real assumptions for performance analysis purposes.

1. INTRODUCTION

The needs of large enterprises and the "office automation" forsee the intergration of very different communications in one network [1]. The required services within such a network could be of the stream type (e.g. with the constraint of the real time) such as moving video, high resolution graphics, voice and interactive data and of the bursty type (e.g. with the constraint of loss of data) such as CAD and CAM, scientific computation, data bases etc. The proliferation of such services has emerged the LANs which actually digitally allocate the resources required by the network users acting as a digital switch where the switching functions are pervasively distributed throughout the network which has the required "intelligence" to do it [2].

Recent advances in computing technology enable communication networks to provide sophisticated switching techniques which allow better utilization of transmission facilities. The needs of the application environment of the multiservice LAN indicate that the stream traffic except voice will be the most critical part of the total traffic in such a LAN. The merger of these traffics has necessitated extensive investigations into hybrid switching systems which enable simultaneous circuit and packet switching. The hybrid switching technique has numerous advantages which are discussed in many papers [3], [4], [5].

The hybrid link is a digital multiplex structure which enables dynamic sharing of the channel bandwidth between circuit-switched and packed-switched modes of operation. The channel is sychronously clocked and thereby partitioned into frames of fixed duration; each frame is further decomposed into time slots. The slot size is chosen in accordance with the data rate requirements of the circuit-switched services. The frame is partitioned into two distinct regions, the circuit and the packet region, and the boundary is movable so we have dynamic sharing of the channel bandwidth.

The services provided by such a hybrid protocol are summarized in table 1 where the basic characteristics of each service,required for the analysis of the protocol are included. The following sections include the formulation of the system for the analysis purposes and the methodology and the general formulae for the mean queue length for stream and packet data and the average delay for the packet data are presented.

2. HYBRID PROTOCOL DESCRIPTION

The hybrid protocol structure is shown in Fig.1. This hybrid protocol is described in general in [6] and here is presented the form that has been already implemented for a speed of 140Mb/s as it is presented in [7]. The activity on the digital channel is organized in contiguous periodic frames in the time domain; each frame being constituted by two regions, the first devoted to circuit-switched traffic and the second devoted to packet-switched traffic.

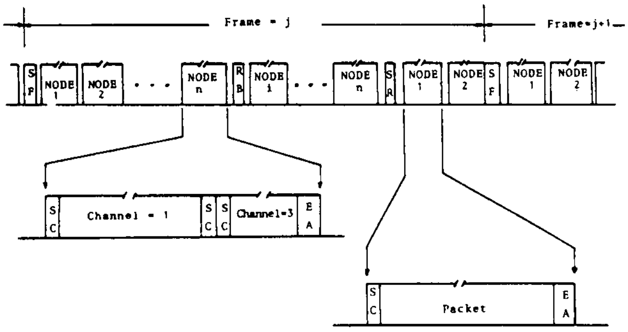


Fig.1: The hybrid protocol structure.

The beginning of a frame is marked by a Start-of-Frame (SF) flag, which has a duration of three bytes. The two regions are divided by the Region-Boundary (RB) flag which position can vary dynamically following the instantaneous circuit bandwidth demand and it also has a duration, of three bytes. The frame duration T_f pursues a trade-off between the memory required for circuit communication and the network delay on one hand, and the node processing capacity on the other. The former two items involve a frame duration as small as possible, the latter requires higher frame duration.

The system capacity devoted to the circuit-switched traffic is handled in such a way that each information flow is provided with a slot having a length proportional to the service bit-rate, also each slot carries only user information and no overhead. Every frame includes one and only one Circuit Region whereas may include a variable (integer or not) number of Packet Rounds. The worst case is a frame with the circuit region only and the RB flag. As a consequence an explicit Start-of-Packet-Round (SR) flag is used which is also three bytes long. Therefore, if a round cannot be completed during a single frame, it must be resumed in the successive frame starting from the exact point at which it was interrupted.

The nodes of the network are numbered in accordance with their physical position on the bus; node number 1 is the farthest one; each node knows its position number and the permitted maximum number (N) of nodes and it access the bus in ordered sequence according to the above numeration. The T_a time is fixed and includes both the time required for the node to sense its right of access and the time required to access the channel. Each node in both frame regions denotes the end of 1 its activity by the End-of-Activity (EA) flag which is also three bytes long. Therefore if the channel speed is C $^b/s$ the duration of the frame delimeters T_D is:

$$T_D = \frac{24}{C} \text{ sec.}$$

3. SYSTEM FORMULATION

According to the table 1, the users deliver messages to a node with a Poisson distribution of arrivals, with the exception of the videoconference service. It is therefore reasonable to assume that each node appears to the hybrid channel as a sum of Poisson arrivals or as a Poisson arrival source with an arrival rate, the sum of the individual arrival rates [11]. The Bernouli distribution of the videoconference message arrivals as a special case of the binomial distribution fullfils the required condition [8], [9] in order to be considered as a Poisson distribution. From Table 1 the arrival rate p for the Bernoulli distribution is p<<1 therefore it can be a Poisson distribution of the form:

$$P_k(t) = e^{-pt} \frac{(pt)^k}{k!} \qquad (1)$$

TABLE 1: The services provided by the LAN.

CLASS OF SERVICE	SERVICE DESCRIPTION	SOURCE TYPE	BIT-RATE (kbit/s)	HOLDING-TIME AVERAGE (s)	HOLDING-TIME DISTRIBUTION	CALL-ARRIVAL AVERAGE RATE (call/s)	CALL-ARRIVAL DISTRIBUTION
0: TELEPHONE	TELEPHONY	STREAM	64	120	EXP	2.7E-3	POISSON
1: LOW-SPEED DATA	TEXT TERMINALS LOW-SPEED FAX VIDEOTEX INTERACTIVE DATA DISTRIBUTED PROCESSING	PACKET	≤9.6 ≤9.6 ≤1.2 ≤4.8 ≤9.6	120	EXP	1.25E-3	POISSON
2: MEDIUM-SPEED DATA	HIGH-SPEED FAX MEDIUM HOST PRINTERS	PACKET	≤64 ≤64 ≤19.2	120	EXP	1.25E-3	POISSON
3: HIGH-SPEED DATA	MAINFRAME DATA BASE LASER PRINTER GRAPHICS	PACKET	≥1,000 ≥1,000 ≥1,000 ≥500	7200	EXP	0.1E-3	BERNOULLI
4: HIGH RES. GRAPHICS AND COMPR. DIGITAL VIDEO	DESK-TOP VIDEOTEL. VIDEO-CONFERENCE HIGH RES. GRAPHICS	STREAM	2,000 2,000 ≥8,000	2	CONST.	25E-3	POISSON

The holding time of the messages from the users is shown from table 1 to follow an exponential distribution except for the high resolution graphics. Since high resolution graphics require a high throughout in practice they are serviced by an individual node of the network. Therefore for the rest of the nodes we can assume that they appear to the hybrid protocol as sources of messages with a holding time of the exponential form with parameter λ_n. In the presented analysis, we consider that each message from the node is constituted from data units, where a data unit is one byte, and the number of data units per message follows a geometrical distribution with parameter P_d. Therefore the average length of a message is $\bar{l}=1/\lambda_n$ and the average number of data units in a message is $\bar{D}=1/P_d$. The duration of a data unit is $T_d=\frac{8}{C}$ and therefore holds that

$$\bar{D} = \frac{\bar{l}}{T_d} \rightarrow P_d = \frac{8\lambda_n}{C} \qquad (2)$$

The holding time for the high resolution graphics is a constant distribution therefore is constituted of a constant number of user data units Φ. The node that provides the high resolution graphics service appears to the hybrid channel as a source with Poisson arrivals of messages, and each message has a constant distribution of the number of data units with parameter $m = \frac{\Phi C}{8}$.
The following section presents the analysis of the circuit and packet regions separately based on the above formulation.

4. HYBRID PROTOCOL ANALYSIS

In this section it will be presented the calculation for the average queue of each node for the circuit and packet regions. Following the formula for the calculation of the average duration of the circuit and packet regions could be given and their relation to the frame duration T_f. Finally a formula for the average delay of the packets will be given under the assumption of non-blocking for the circuit-switched data (see Appendix).

4.1. The circuit region

An incoming circuit-switched message, which arrives at an arbitrary instant during a frame, is buffered in a "gating" queue until the start of the next frame; therefore each node delivers to the channel during the circuit-region of the current frame the messages gated during the previous frame. Therefore we imbed a Markov chain at the end of each frame considering departure epochs. Then if $A(z,T_f)$ is the z-transform of the r.v. of data units in the (o,T_f) and $M(z)$ is the z-transform of the r.v. of number of data units in a message, we have, assuming that a steady state solution exists, that the generating function of the distribution of the number of messages in the queue is $\boxed{10}$:

$$P(z) = \frac{(1-\rho)(1-z)A(z)}{A(z)-z} \tag{3}$$

and the average number of data units is:

$$\bar{q}_1 = \frac{\lambda T_f}{1-P} \tag{4}$$

for Poisson sources with parameter λ and geometrical distribution of data units with parameter P and

$$\bar{q}_2 = T_f \, \frac{\lambda m(m+1)-T_f(\lambda m)^2}{2(1-T_f \lambda m)} \tag{5}$$

for Poisson sources with parameter λ and constant distribution of data units with parameter m. Therefore in the steady state assuming that we have n_1 nodes with videoconference, n_2 nodes with high resolution graphics and n_3 nodes with the other categories of circuit-switched messages we have that the average number of data units of the circuit region, including the required protocol delimeters and also assuming that every node has messages to deliver is given by:

$$\bar{q}_s = T_f \left[\sum_{i=1}^{n_1} \frac{P_i}{1-P_{d,i}} + \sum_{i=1}^{n_3} \frac{\lambda_i}{1-P_i} + \sum_{i=1}^{n_2} \frac{\lambda_i m_i(m_i+1)-T_f(\lambda_i m_i)^2}{2(1-T_f \lambda_i m_i)} \right] \tag{6}$$

where $n_1+n_2+n_3=N$ the total number of nodes.

4.2. The packet region

An incoming packet-switched message, which arrives at an arbitrary instant during a frame is buffered in a node-queue until the node gains access to the packet region of the current frame, then each node delivers one packet. When each node has delivered one packet a round is formed and a new round begins following the same procedure. The number of data units per packet is d, therefore the packet length is $P_L=dT_d$. We consider an M/M/1 model for the queues in the packet region, then in the steady-state solution we assume that each node has at least one packet per round to deliver to the channel. This assumption implies that $\lambda \geq \mu$ where λ is the parameter for the Poisson arrival process and μ is the parameter for the exponential service time for a network node during the packet region. The duration of a round under these assumption is given by $T_R=NP_L$ where N is the number of the network nodes.

During the packet region of a frame the evolution of rounds depends on the relation of:

1) The duration of the circuit region (the average length $\bar{X}$ is calculated through Eq.6 and the channel rate).
2) The round duration T_R.
3) The duration of the frame T_f.

Then we can distinguish two major procedures for the evolution of rounds. In the case where the duration of the packet region is greater than the duration of a round, the arbitrary round under consideration can be completed inside the current frame with a probability P_1 or it is going to be completed inside the next frame with probability $1-P_1$. Therefore in this case we have two different time intervals during which new messages are arriving. In the second case, where the duration of the packet region is less than the duration of a round, the round will be completed after k frames. Under this formulation we can imbed a Markov chain at the end of each round considering departure epochs. Therefore for the j frame where the i+1 round evolves one can have for the v node:

$$n_{v,1+1} = n_{v,i} - U(n_{v,i}) + \tilde{a}_{v,i+1} \tag{7}$$

where $n_{v,i+1}$ is the number of messages in the v node at the end of the i+1 round, $n_{v,i}$ is the number of messages in the v node at the end of the i round and $\tilde{a}_{v,i-1}$ is the average number of arrived messages during the i+1 round. After some mathematical manipulations we have for N identical nodes that the generating function of the distribution of the number of messages in the queue of a network node is:

$$P_v(z) = \frac{(1-\rho)(1-z)\tilde{A}_v(z)}{\tilde{A}_v(z)-1} \tag{8}$$

where $\rho = \lambda/\mu$.

If $\bar{X}$ is the average duration of the circuit region, where

$$\bar{X} = \bar{q}_s T_d + (N+1)T_a + (N+2)T_D$$

(T_a is the maximum access time for a network node), then the average duration $\bar{Y}$ of the packet region is:

$$\bar{Y} = T_f - \bar{X}$$

Therefore for:

1) $T_R \leq T_f - \bar{X}$: following Fig.2 then, if the i+1 round is completed during the j frame we have that $\tilde{A}_v(z)$ takes the form

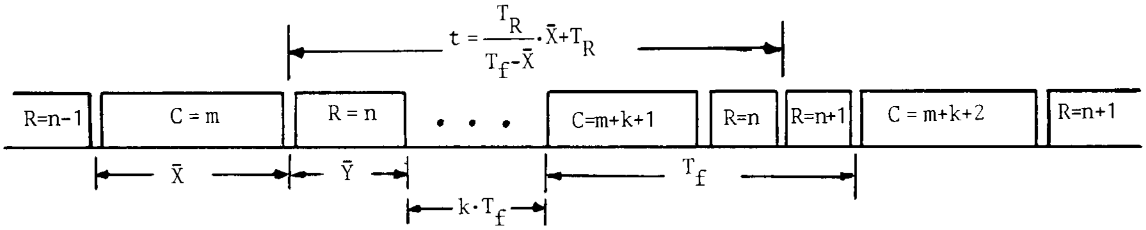
$$\tilde{A}_{v_1}(z) = \int_0^{T_R} e^{-\lambda t(1-z)} e^{-t/\mu} dt$$

$$P_1 = \frac{\left\| \left[\frac{T_R - \bar{X}}{T_R} \right] \right\| T_R}{\left(\left\| \left[\frac{T_R - \bar{X}}{T_R} \right] \right\| - 1 \right) T_R + \bar{X}} \qquad (11)$$

$$P_2 = \frac{T_R + \bar{X}}{\left(\left\| \left[\frac{T_R - \bar{X}}{T_R} \right] \right\| - 1 \right) T_R + \bar{X}} \qquad (12)$$

then using eq.(9),(10),(11) and (12) we get:

$$\tilde{A}_v(z) = P_1 \tilde{A}_{v_1}(z) + P_2 \tilde{A}_{v_2}(z) \qquad (13)$$



X: The average Circuit Region length
Y: The average Packet Region length
C: Circuit Region
T_f: The Frame duration
T_R: The average Packet Round length
R: Packet Round

Fig.2: The packet round evolution, for $T_R \leq T_f - \bar{X}$.

$$\tilde{A}_{v_1}(z) = \frac{\exp\left[- \left[(1-z) + 1/\mu \right] T_R \right] - 1}{1/\mu - \lambda(1-z)} \qquad (9)$$

and if the i+1 round is not completed during the j frame:

$$\tilde{A}_{v_2}(z) = \int_0^{T_f + T_R - \bar{Y}} e^{-\lambda t(1-z)} e^{-t/\mu} dt$$

$$\tilde{A}_{v_2}(z) = \frac{\exp\left[- \left[(1-z) + 1/\mu \right] (T_R + \bar{X}) \right] - 1}{1/\mu - \lambda(1-z)} \qquad (10)$$

The probability P_1 to have arrivals during the i+1 round according to eq.(9) is given by equation (11) and the probability P_2 to have arrivals during the i+1 round according to eq.(10) is given by equation (12), where $\| [\ ] \|$ is denoting the integer part.

(see also Appendix).

2) $T_R > T_f - \bar{X}$: following Fig.3 the time required for i+1 round to be completed is given by:

$$t = \bar{y} + KT_f + \bar{X} + T_1$$

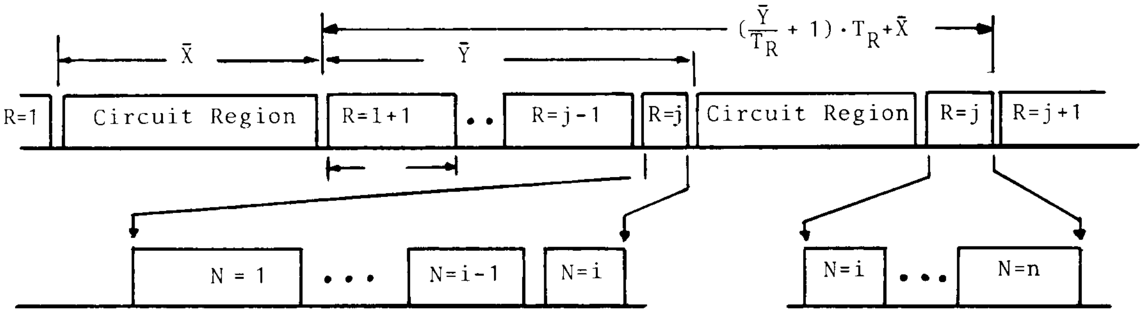
but $\quad T_1 = T_R - \bar{y}(K+1)$

and $\quad K+1 = \left\| \left[\frac{T_R}{\bar{y}} \right] \right\|$ then

$$t = \left\| \left[\frac{T_R}{T_f - \bar{X}} \right] \right\| \bar{X} + T_R \qquad (14)$$

and in this case we obtain:

$$\tilde{A}_v(z) = \int_0^{t} e^{-\lambda t(1-z)} e^{-t/\mu} dt =$$



$\bar{X}$: The average Circuit Region length T_R: The average Packet Round length
$\bar{Y}$: The average Packet Region length R: Packet Round, N: NODE

Fig.3: The packet round evolution, for $T_R > T_f-\bar{X}$.

$$= \frac{\exp\left[-\left[\lambda(1-z)+1/\mu\right]\left(\frac{T_R}{T_f-\bar{X}}\,\bar{X}+T_R\right)\right]-1}{1/\mu-\lambda(1-z)} \qquad (15)$$

5. DISCUSSION OF THE ANALYSIS

From the formulae extracted in equations (8), (13),(15) we can calculate the average number of data units in the queue of a network node for the packet-switched traffic which can be derived using the equations for the M/M/1 queue analysis of [10]. Using also Little's formula we can calculate the total delay for the packets of each network node (see Appendix).

From the analysis of the services provided through the use of this class of hybrid protocols (see Table 1) we notice that the dominant services as far as throughput is concerned are the circuit switched ones. From the description of the hybrid protocol we also notice that the performance of the protocol strongly depends on the optimum choise of the frame duration T_f with respect to the required throughput and the requirement of bounded delays for the packet-switched services. Therefore the derived formulas are the method for the analysis of the hybrid protocol performance especially when it is taken into account the required buffers for the packet traffic and the "gating" buffers for the circuit traffic. Therefore numerical results can be obtained, when the parameter values are used, either by analytical methods or by the use of simulation techniques. Important results also can be derived for the required service time and mechanism and also for the required transfer or access speeds of this mechanism to the carrier.

A further very important step under consideration is the formulation of the Poisson arrivals for both circuit and packet-switched traffic using a real scenario for the users that are serviced from each node of the network.

APPENDIX

The average queue length for the packet region is given, using eq.(8), by [10]:

$$\bar{n}_D = \left.\frac{dP_v(z)}{dz}\right|_{z=1} = \frac{2(1-\rho)\tilde{A}'_v(1)+\tilde{A}''_v(1)}{2\left[1-\tilde{A}'_v(1)\right]} \qquad (16)$$

From eq.(9),(10) we obtain for $T_R \lesssim T_f-\bar{X}$ the first and second derivatives for $\tilde{A}_v(z)$ at z=1:

$$\tilde{A}'_{v_1}(1) = \lambda\mu^2\left[\left(\frac{T_R}{\mu}-1\right)\cdot\exp\left(-\frac{T_R}{\mu}\right)-1\right] \qquad (17)$$

and

$$\tilde{A}''_{v_1}(1)=\lambda^2\mu^3\left[\left[\left(\frac{T_R}{\mu}-1\right)^2+1\right]\cdot\exp\left(-\frac{T_R}{\mu}\right)+2\right] \qquad (18)$$

$$\tilde{A}'_{v_2}(1)=\lambda\mu^2\left[\left(\frac{T_f+T_R-\bar{Y}}{\mu}-1\right)\cdot \right.$$
$$\left.\cdot\exp\left(-\frac{T_f+T_R-\bar{Y}}{\mu}\right)-1\right] \qquad (19)$$

and

$$\tilde{A}''_{v_2}(1)=\lambda^2\mu^3\left[\left[\left(\frac{T_f+T_R-\bar{Y}}{\mu}-1\right)^2+1\right]\cdot\right.$$
$$\left.\cdot\exp\left(-\frac{T_f+T_R-\bar{Y}}{\mu}\right)+2\right] \qquad (20)$$

From eq.(15) we obtain for $T_R > T_f - \bar{X}$ the first and second derivatives for $\tilde{A}_v(z)$ at z=1:

$$\tilde{A}'_v(1) = \lambda\mu^2 \left[\left(\frac{\left\|\left\lceil \frac{T_R}{Y} \right\rceil\right\| \bar{X}+T_R}{\mu} - 1 \right) \cdot \exp\left(- \frac{\left\|\left\lceil \frac{T_R}{\bar{Y}} \right\rceil\right\| \bar{X}+T_R}{\mu} \right) - 1 \right] \qquad (21)$$

and

$$\tilde{A}''_v(1) = \lambda^2\mu^3 \left[\left[\left(\frac{\left\|\left\lceil \frac{T_R}{\bar{Y}} \right\rceil\right\| \bar{X}+T_R}{\mu} - 1 \right)^2 + 1 \right] \cdot \exp\left(- \frac{\left\|\left\lceil \frac{T_R}{\bar{Y}} \right\rceil\right\| \bar{X}+T_R}{\mu} \right) + 2 \right] \qquad (22)$$

The mean delay is obtained by the Pollaczek-Khinchin formula [10]:

$$\bar{d} = \frac{\bar{n}_D}{\lambda} \qquad (23)$$

ACKNOWLEDGEMENTS

The authors would like to thank Dr. S. Koubias for the helpful discussions on this analysis. This work, was carried out as a part of the work in the Laboratory of Electromagnetics for the ESPRIT project LION 169.

REFERENCES

[1] Corsi, N., Luvison, A. and Moncalvo, A.: "Perspectives on wideband local area communication networks". Proc. IEEE ICC'84, p.p.622-625, May 1984.

[2] Tobaggi, F., Borgonovo, F., Fratta, L.: "Expressnet: A High Performance Integrated Services Local Area Network", IEEE Journal on Selected Area on Communications, Vol. SAC-1, No.5, November 1983.

[3] Gitman, I. and Frank, H.: "Economic analysis of integrated voice and data networks: A case study "Proc.IEEE, Vol.66, pp.1549-1570, Nov. 1978.

[4] Rudin, H.: "Studies on the integration of circuit and packet switching" in Proc. Int. Conf. Communications (Toronto,Canada), June 1978.

[5] Ross, M., Tabbot A. and Waite, J.: "Design approaches and performance criteria for integrated voice and data switching" Proc. IEEE, Vol.65, Sept.1977.

[6] ESPRIT Project 169 "Local Wideband Communication System", Pilot Phase Report, Sep. 1984.

[7] Pallios, V., Antonakopoulos T. and Makios, V.: "Architecture and Implementation of the Access Mechanism for a bus-structured Multiservice LAN" submitted for pulbication to the 8th International Conference on Distribu Computing Systems, June 1988.

[8] Davenport, W.B.: "Probability and random processes: an introduction for applied scientists and engineers", McGraw-Hill 1970.

[9] Papoulis, A.: "Probability, Random Variables and Stochastic Processes", McGraw-Hill 1984.

[10] Hayes, J.: "Modelling and Analysis of Computer Communications Networks" Plenum Press 1986.

[11] Kleinrock, L.: "Queueing Systems" Vol. I, II, John Wiley & Sons, 1974.