Home access network model specifications

IZABELA KRBILOVÁ, VLADIMÍR HOTTMAR, BOHUMIL ADAMEC

Department of Control and Information Systems, Department of Telecommunications and Multimedia, University of Žilina, Slovakia

{krbilova, hottmar, adamec}@uniza.sk

Keywords: residential gateway, stated equations, time-dependent probabilities, particular request, service time, peripherals

The paper investigates a home network configuration consisting of residential gateway RG and a number of intelligent peripheral devices capable of autonomous activity. A queuing model is built by means of bulk service in a closed circuit which circulates constant number of requests. Performance and time characteristics of peripherals communicating with residential gateway are determined. The presented results illustrate mutual dependence of the number of network peripherals and time characteristics determining operation of the network.

1. Introduction

Modern broadband *home networks* are expected to provide all new integrated multimedia services with added value (video on demand, latest news on demand, teleshopping, distance learning) along with securing, controlling and automatization of the household. The development of the digital households in the past was hindered by the lack of modern broadband technologies for access and home networks.

Nowadays, however, the innovations of broadband access technologies and the considerable investments in access networks infrastructure have eliminated the restrictions. In spite of the fact that advanced wireless and wireline technologies designed for home networks show clearly that all major technical problems concerning implementation of the networks have been overcome, distribution of integrated multimedia services among large numbers of users is still limited mostly due to separation of home networks. Residential gateway is an essential element of a modern home network. It is the access and concentration point which switches the functions for telecommunication and general data traffic, distribution of entertainment services for homes and controlling and management of various electric and electronic devices.

For the purposes of this article we will assume a home network configuration consisting of residential gateway RG and n intelligent peripheral devices PD capable of *autonomous activity*. *Fig. 1* shows one of the possible variants of home access network utilizing current technologies [8,9,19,11].

Fig. 2 shows communications among some peripheral devices within the home network. It is apparent that the busiest and thus crucial node is residential gateway.

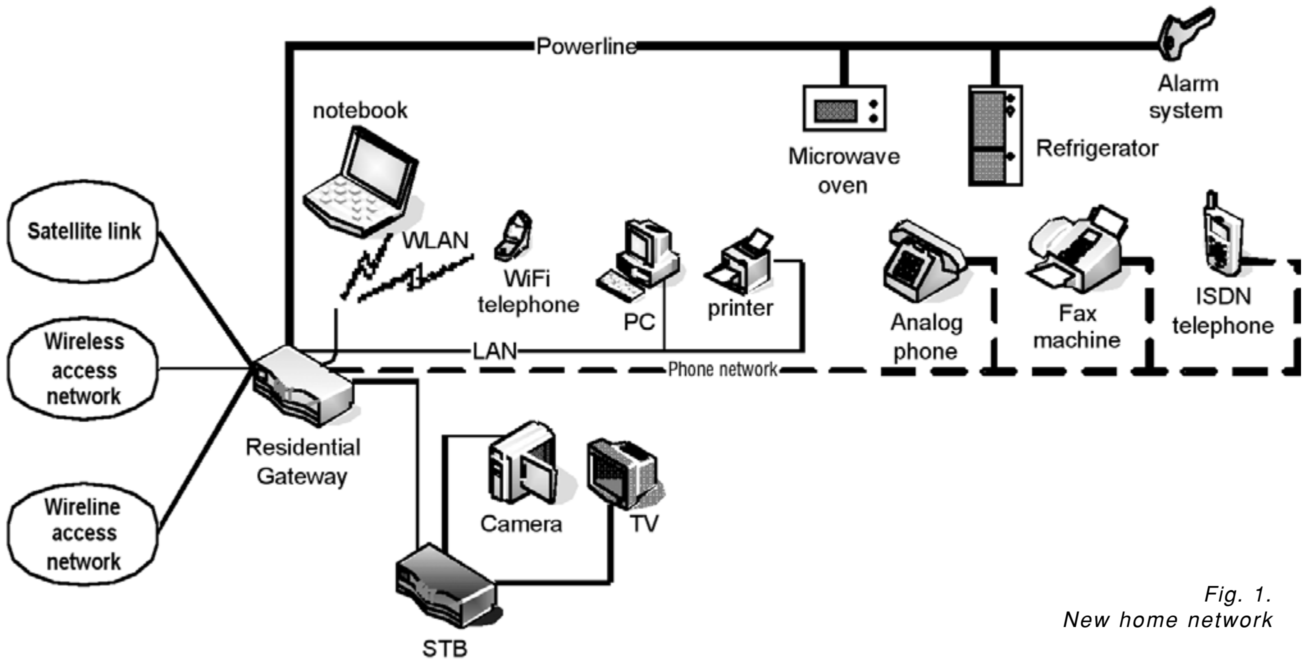

Fig. 1. New home network

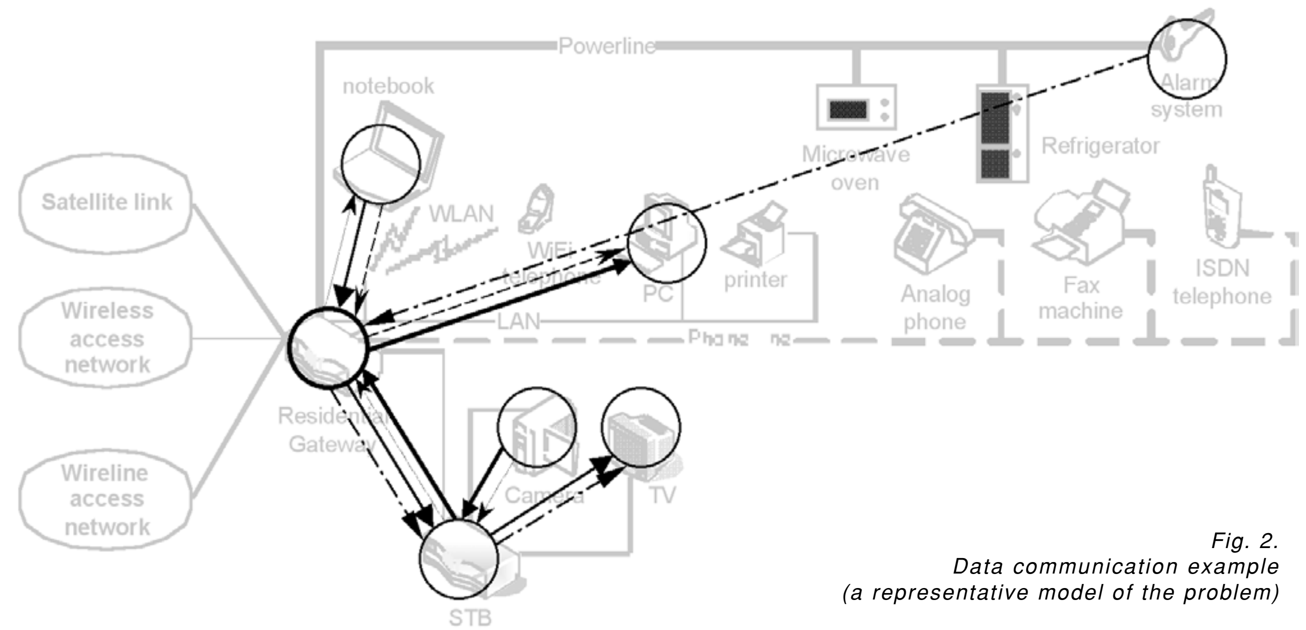

Fig. 2. Data communication example (a representative model of the problem)

Let peripheral devices P_1 *to* P_n communicate with residential gateway based on the principle of requests and responses. Unless the gateway is busy communicating with one of the peripherals or with its own activity, it is able to receive a demand and respond to it. If one of the peripherals requests communication with residential gateway when it is busy, it will transmit the demand and it will be ordered in queue. If one of the peripherals P_1 *to* P_n finished its communication with residential gateway, it will either perform its autonomous activity (being out of the system) and thus it becomes a potential source of demands or it repeatedly requests communication with the residential gateway and enters the system and queues up in case the residential gateway is busy.

These peripherals will be recognized as out of system peripherals. The sequence of peripherals requesting communication will result from the sequence they entered the system. There is no priority scheme, the first-in first-out rule can be used. As soon as the residential gateway is free, it will respond to the first peripheral in the queue. The described model clearly shows the interdependence of residential gateway load and the number of requested operations, where the number of the requests is equal to the number of peripherals. The number of the peripherals in and out of the system is *n*, so the system is finite and it is a closed unit. In the next section we will analyze the suggested problem and calculate the quantities and time characteristics of the system based on the model of bulk service [1,2,6,7].

2. Quantification and modelling of the system

According to the above discussion we will analyse characteristics and calculate parameters of a closed system [2,4,5]. For this purpose we will introduce the following assumptions:

- One of the first things we have to deal with is to define the flow of requests entering the system. We assume that the returns of the requests into the system correspond to Poisson elementary flow of requests with exponential distribution of their arrival intervals. General distribution is assumed for a given service interval of the residential gateway.
- Let P_1 *to* P_n be the requests demanding communication from the residential gateway. *N* requests hence circulate in the system. Let λ be the parameter of a random variable with exponential division. $1/\lambda$ is hence average interval of residential gateway response to the request (e.g. the interval of the response transferred to the peripheral P_i) until the request (of peripheral P_i) returns back to the system.
- Let the service time of the residential gateway *t* be a continuous random variable with mean value τ and general distribution. If the density of service time probability is *g(t)*, the mean value of the service time can be calculated by the relation:

$$\tau = \frac{1}{\mu} = \int_0^\infty t \cdot g(t) dt , \tag{1}$$

where μ is the mean value of service time.

Communication regime between residential gateway and peripherals defined in this way will be modelled through the system of a bulk service and in compliance with Kendall's designation we will define it as *closed QS with constant number of requests M/G/1/FIFO*. As already stated, according to the theory of bulk service, individual peripherals present requests communicating with the system.

Operational time P_i of each peripheral in the network consists of three phases that change [2,3]:

a) time interval of the request outside the system;

b) waiting time of the request – peripheral P_i in the service system requesting a response from the residential gateway;
c) service time of the residential gateway.

In the following we will examine circulation of the requests in the system. Let N be the average number of returns of a request into the system in a time interval. Let W be the average waiting time of a request in the queue. Then the equation

$$N\left(1/\lambda + W + \tau\right) = 1 \qquad (2)$$

denotes the mean value of service duration supposing a request by mean values [1,2,3]. In order to determine variables N and W in the relation 2) it is necessary to define times of relieving and occupying the gateway. Work time of the residential gateway involves two alternating intervals; occupying the residential gateway and relieving the gateway. As the system contains n requests, mean value of occupying the gateway is product $nN\tau$. We will now focus on the average time of relieving the gateway. Let p_k be the conditional probability of the fact that only one request will enter the system assuming that the system contains k requests. Average number of intervals when the gateway is unoccupied equals the product nNp_0, where p_0 is the probability of empty system.

If all the requests (peripherals P_1 *to* P_n) are out of the system at the moment, the probability of the assumption that after a time interval t all the requests will remain out of the system is $e^{-\lambda nt}$ and the probability of the assumption that a request will enter the system in a time interval $(t+\Delta t)$ je $\lambda n\Delta t + o(\Delta t)$ where (Δt) is a function converging to zero faster than linear [1-3].

The probability that the interval of not occupying the residential gateway will finish between $o(\Delta t)$ is $e^{-\lambda nt}\lambda n\Delta t + o(\Delta t)$ and average interval time of unoccupied gateway will be:

$$\int_0^\infty te^{-\lambda nt}\lambda n dt = \frac{1}{\lambda n}. \qquad (3)$$

The sum of all intervals of unoccupied gateway is given by the relation

$$nNp_0\frac{1}{\lambda . n} = N\frac{p_0}{\lambda}. \qquad (4)$$

Considering the relation (4) and the given average time of occupying the residential gateway ($nN\tau$) we get

$$N\left[n\tau + \frac{p_0}{\lambda}\right] = 1. \qquad (5)$$

Applying the relations (1) and (5) for average waiting time of a request in the queue W we obtain

$$W = (n-1)\tau - \frac{1-p_0}{\lambda}. \qquad (6)$$

In the following section we will examine a condition of the system where service time of the gateway will be interrupted by other request(s) entering the system. Let us consider two time instants t_1 and t_2. t_1 is the time when the request left the system. We assume that at the time t_1 the system still contains r requests and t_2 represents departure time of another request from the system and hence the system contains $r-1$ requests.

Time interval t_2-t_1 is the service time of a request if $r > 0$. If $r = 0$, the system is empty after the first request left the system. Then the time interval t_2-t_1 equals the sum of two time intervals, namely the time interval starting in t_1 until another request arrives and the time interval equal to service time of the second request. Other requests may enter the system only during service time of the second request due to the fact that the system remained empty between t_1 and the arrival of another request.

Let the service time of a request be t. If we consider Poisson flow of request occurrence in the system, the probability of the occurrence of j requests in the system during the service time t of the particular request:

$$v_j(t) = \frac{(\lambda t)^j}{j!}e^{-\lambda t} \text{ for } j = 1, 2, 3, ... \qquad (7)$$

Then we assume that service time distribution is determined by its probability density $g(t)$. The probability that j requests will enter the system during the service time of a particular request will be:

$$\beta_j = \int_0^\infty v_j(t)g(t)dt. \qquad (8)$$

Equation (8) quantifies the probability of j requests entering the system while an other request is being processed/serviced but does not reflect the change of the probability if the number of requests is finite where requests number limits outside the system are $j \in \langle 1; n-1 \rangle$.

We will now analyze processes that may occur in the system during the interval t_2-t_1. Let p_k be the probability of the transition of the system from condition k to condition $k+1$. The probability also holds true in the reversed order.

This assumption results from the fact that the number of transitions from condition k to $k+1$ must equal the number of transitions from condition $k+1$ to k. In order to determine the probability, we must define the probability $\beta_{k,j}$ which represents the number of requests j occurring in the system during the service time when it contained k requests.

Following equations will provide the desired data:

$$p_0(t_2) = p_0(t_1)\beta_{1,0} + p_1(t_1)\beta_{1,0}$$

$$p_1(t_2) = p_0(t_1)\beta_{1,1} + p_1(t_1)\beta_{1,1} + p_2(t_1)\beta_{2,0} \qquad (9),(10),(11)$$

$$p_2(t_2) = p_0(t_1)\beta_{1,2} + p_1(t_1)\beta_{1,2} + p_2(t_1)\beta_{2,1} + p_3(t_1)\beta_{3,0}$$

Analogically, equation for k requests remaining in the system after time interval t_2 can be constructed. Then

$$p_k(t_2) = p_0(t_1)\beta_{1,k} + p_1(t_1)\beta_{1,k} + p_2(t_1)\beta_{2,(k-1)} + ,.... + p_k(t_1)\beta_{k,1} + p_{(k+1)}\beta_{(k+1),0} \quad (12)$$

for $k = 1, 2, 3, ..., n-2$.

In compliance with the above stated equations we will suggest normalizing condition for the sum of probability

$$\sum_{k=0}^{k=n-1} p_k = 1. \quad (13)$$

For permanent regime for time-dependent probabilities the following limit can be accepted according to [2,3]:

$$p_k = \lim_{t\to\infty} p_k(t). \quad (14)$$

The equations (9) to (13) will then be arranged as follows

$$p_0 = (p_0 + p_1)\beta_{1,0}. \quad (15)$$

For $k=1, 2, ..., n-2$ we will determine the probability p_k that the system contains k requests in the relation

$$p_k = (p_0 + p_1)\beta_{1,k} + p_2\beta_{2,k-1} + ... + p_k\beta_{k,1} + p_{k+1}\beta_{k+1,0}, \quad (16)$$

where $k=1, 2, ..., n-2$.

If the service time is t and at the beginning of the service the system contains k requests, the probability that out of total number of requests $(n-k)$ out of system j requests will be returned into the system and $(n-k-j)$ will not be returned is

$$\binom{n-k}{j}\left(1-e^{-\lambda t}\right)^j\left(e^{-\lambda t}\right)^{n-k-j}. \quad (17)$$

As density of service time probability is $g(t)$, for $\beta_{k,j}$ we will obtain

$$\beta_{k,j} = \binom{n-k}{j}\int_0^\infty \left(1-e^{-\lambda t}\right)^j\left(e^{-\lambda t}\right)^{n-k-j} g(t)dt. \quad (18)$$

Relation (18) is applicable for the situation when service time is a random variable but continuous and has density $g(t)$. This enables us to count the probability $\beta_{k,j}$. Applying the equation (16) and standardizing condition (13) we will obtain an equation system which will enable us to determine p_0, i.e. when the system is empty. Employing relation (6) and the probability p_0 help us determine average waiting time of a request in a queue W. Average cycle C_y of each peripheral given by mean values consists of the following time intervals

$$C_y = 1/\lambda + W + \tau. \quad (19)$$

Average number of returns of the peripheral into the system can be calculated by

$$N = 1/C_y. \quad (20)$$

3. Conclusion

Modelling of a home access network by means of bulk service in a closed circuit which circulates constant number of requests constitutes a framework enabling us to determine performance and time characteristics of peripherals communicating with residential gateway regardless of technical and program equipment.

The presented results illustrate mutual dependence of the number of network peripherals and time characteristics determining operation of the network. Any changes in hardware or software structure of peripherals or residential gateway will result in changes of response time characteristics of the model.

Acknowledgment

This project was supported by the VEGA grant No. 1/0375/08 of Ministry of Education of the Slovak Republic.

Authors

IZABELA KRBILOVÁ graduated in 1967 with the Master's degree in Safety and Communication Engineering at the University of Transport and Communications in Žilina. Since 1969 she was employed at the Department of Information and Safety Systems. In 1979 she accomplished her dissertation thesis in the field of "Line Wire Communications Engineering". Since 1984 she is working as an associate professor at the Department of Control and Information Systems at the Faculty of Electrical Engineering, University of Žilina. Specialisation: application of queuing theory in communication systems. Reliability and diagnostics of complex systems.

VLADIMIR HOTTMAR graduated from the University of Žilina in 1975 with the Master's degree in Transport and Communications. At the beginning of his career he was employed at the Research Institute of Computers Techniques in Žilina, where he worked as a researcher in the Department of Microcomputers and Development Systems for 22 years, later being responsible for running the Research Department. Currently he is employed at the University of Žilina in the Department of Telecommunications in the position of an associate professor and is also involved in some research work. He is a project leader of the project VEGA. In 1999 he accomplished his PhD studies at the University of Žilina. Since May 2006 he has worked on the post of an associate professor at the University of Žilina.

BOHUMIL ADAMEC graduated from the University of Žilina in 2007 with the Master's degree in Telecommunications. Currently he is a PhD student at the University of Žilina in the Department of Telecommunications and Multimedia. His range of interest is home networking especially simulation and mathematical modeling of modern multimedia home networks.

References

[1] Mitrani, I.,
Modelling of computer and communication systems.
Cambridge University Press, 1987,
pp.73–74.

[2] Neuschl, Š. et al.,
Modelling and simulation.
SNTL, Praha, 1989, pp.304–354.

[3] Robertazzi, T. G.,
Computer Networks and Systems:
Queuening Theory and Performance Evalution.
Springer-Verlag Inc., New York, USA, 1990.

[4] Hottmar, V.,
Network model of the processor system,
Híradástechnika (Infocommunications Journal),
Selected Papers, Vol. LX, No. 12, 2005, Hungary.

[5] Peško, Š, Smieško, J.,
Stochastic models of operational analysis,
Published by the University of Žilina, 1999,
ISBN 80-7100-570-3.

[6] Hottmar, V.,
Model of a computational system.
Scientific studies of the ŽU, Electrotechn. Series 25,
1999, pp.11–21.,
ISBN 80-7100-716-1, ISBN 80-7100-913-X.

[7] Kalas, J.,
Markov's chains, published by
the Comenius University in Bratislava, 1993.
ISBN 80-223-0560-X.

[8] Zahariadis, T.,
Home Networking Technologies and Standards.
Artech House, London, 2003.

[9] Ungar, S.,
System and Architectural Requirements for
a Broadband Residential Gateway.
Request for Information, Bell Comm. Research,
July 24, 1997, pp.33–37.

[10] Lawrence, V.,
Digital Gateways for Multimedia Home Networks.
Telecommunication Systems Journal, August 2003.

[11] Zahariadis, T., Pramataris, K., Zervos, N.,
A Comparison of Competing Broadband
In Home Technologies.
IEE Electronics and Comm. Engineering J. (ECEJ),
August 2002, pp.133–142.

[12] Galko, M., Krbilová, I., Vestenický, P.,
Blocking Probability Influence on the Single-Channel
Service System Operation with Various Input Flows.
In TRANSCOM'97, Vol. 2, Žilina, 1997, pp.37–40.,
ISBN 80-7100-416-2.