UDC 004.7

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COSTS EVALUATION METHODIC OF ENERGY EFFICIENT COMPUTER NETWORK REENGINEERING

С.А. Нестеренко, *Ю.С. Нестеренко*. **Методика вартісної оцінки енергоефективного реінжинірингу комп'ютерної мережі.** Одним з основних напрямів реінжинірингу сучасних комп'ютерних мереж є їх переведення на нову енергозберігаючу технологію IEEE 802.3az. Для прийняття аргументованого рішення щодо переведення на нову технологію необхідна методика, яка дозволяє мережним інженерам відповісти на питання відносно економічної доцільності проведення модернізації мережі. ***Мета***: Метою роботи є розробка методики розрахунку економічної ефективності проведення енергоефективного реінжинірингу комп'ютерної мережі. ***Матеріали і методи:*** Методика використовує аналітичні моделі розрахунку споживчої потужності портом комп'ютерної мережі, яка працює за стандартом IEEE 802.3 та в енергоефектиному режимі стандарту IEEE 802.3az. Для розрахунку часу передачі кадру в каналі зв'язку використовуються моделі масового обслуговування. Для визначення значень параметрів функціонування мережі запропоновано використовувати мультиагентний метод мережного моніторингу. ***Результати***: Запропоновано методику, яка дозволяє розраховувати економічний ефект від переведення комп'ютерної мережі на енергозберігаючу технологію IEEE 802.3az. Для визначення параметрів функціонування мережі запропоновано використовувати SNMP-системи мережного моніторингу на базі агентів RMON MIB.

Ключові слова: стандарт IEEE 802.3az, аналітичні моделі, споживча потужність мережного порту, SNMP-менеджер, агент RMON MIB.

S.A. Nesterenko, *J.S. Nesterenko*. **Costs evaluation methodic of energy efficient computer network reengineering.** A key direction of modern computer networks reengineering is their transfer to a new energy-saving technology IEEE 802.3az. To make a reasoned decision about the transition to the new technology is needed a technique that allows network engineers to answer the question about the economic feasibility of a network upgrade. ***Aim:*** The aim of this research is development of methodic for calculating the cost-effectiveness of energy-efficient computer network reengineering. ***Materials and Methods***: The methodic uses analytical models for calculating power consumption of a computer network port operating in IEEE 802.3 standard and energy-efficient mode of IEEE 802.3az standard. For frame transmission time calculation in the communication channel used the queuing model. To determine the values of the network operation parameters proposed to use multiagent network monitoring method. ***Results***: The methodic allows calculating the economic impact of a computer network transfer to energy-saving technology IEEE 802.3az. To determine the network performance parameters proposed to use network SNMP monitoring systems based on RMON MIB agents.

Keywords: IEEE 802.3az standard, analytical models, network port power consumption, SNMP-manager, RMON MIB agent.

Introduction. The incoming of the IEEE 802.3az energy efficiency standards — Energy Efficient Ethernet (EEE) [1], which has a low power mode and the appearance of a large number of communication devices and network interface cards that support this standard, formed one of the main trends of reengineering of modern computer networks (CN) associated with the transition to new energy-saving IEEE 802.3az technology. In order to make a reasoned decision about the transition to the new technology requires a methodic that enables network engineers to answer the question about the economic feasibility of CN modernization.

Analysis of known publications on the field of EEE shows that most of them are devoted to study of the effectiveness of different switching modes from the active channel state (Active) to a state with low power consumption (Low Power Idle — LPI) [2…5] These works are used complex simulation or analytical models that required for calculating special modeling systems, and have rather theoretical than practical nature. There are a number of works devoted to the practical study of communication devices (CD) and network interface cards (NIC) of certain manufacturers [6…8]. However, in these studies there are no models and calculation methodic and the results are meaningful only for certain CD or NIC types.

The aim of this research is development of methodic for calculating the cost-effectiveness of energy-efficient computer network reengineering. The methodic and instrumental tools, allowing obtaining traffic parameters for real networks, which are used in the calculation models, was proposed.

DOI 10.15276/opu.2.49.2016.10.A

Materials and Methods. *The ownership cost of IEEE 802.3 standard communication networks.* Calculation of communication network power consumption is carried at the level of each its port. In this article a network communication ports defined as switch and router ports or network interface cards through which the subscribers are connected to the network. Obviously, any wired link contains two ports and power consumption in a channel is defined as the sum of consumption in each of its ports. Power consumed by the communication network is

$$P_C = \sum_{i=1}^{N} P_{CD_i} + \sum_{j=1}^{M} P_{NIC_j},$$

where P_C — power consumed by the communication network,

P_{CD_i} — power consumed by the *i*-th port of communication device,

P_{NIC_j} — power consumed by the *j*-th network interface card (subscriber port of CN),

N — number of ports in the communication network,

M — number of network interface cards in a communication network.

We will call wired channel IEEE 802.3 mode — as the standard operation mode. Then the power consumed by the port in the standard operation mode will be equal to [3]

$$P_i^S = [P_A U_i + P_P(1-U_i)], \tag{1}$$

where P_A — power consumed by the port in the active state,

P_P — power consumed in pause state,

U_i — *i*-th port loading.

Expression (1) is a power consumption model of the port working at IEEE 802.3 standard operation mode.

The *i*-th port loading is defined as

$$U_i = \lambda_i T_{Ti},$$

where λ_i — the average intensity of incoming frames per port,

T_{Ti} — average frame transmission time via *i*-th port.

Given the assumption of simplest frames flow in a channel and exponential distribution of their service time the average frame transmission time via *i*-th port T_{T_i} may be expressed as

$$T_{T_i} = \frac{\lambda_i T_{TR_i}}{\lambda_i(1-\lambda_i T_{TR_i})}, \quad T_{TP_i} = \frac{L_{S_i} + L_P}{V_{C_i}},$$

where T_{TR_i} — frame transaction time over physical channel of *i*-th port,

L_{S_i} — average size of the transmitted frames through the *i*-th port,

L_P — minimum pause size between frames equal to 96 bytes [1],

V_{C_i} — transmission rate over physical channel of *i*-th port.

The amount of energy Q_i^S consumed by *i*-th port in standard mode during time *T* is expressed as

$$Q_i^S = P_i^S T.$$

The amount of energy Q^S consumed by *M*-input CD operating in the standard mode during time *T*, can be written as

$$Q^S = T\sum_{i=1}^{M} P_i^S.$$

Maintenance cost of CD working in IEEE 802.3 standard mode during time *T* is equal to

$$C^S = Q^S C_{kW},$$

where C_{kW}— cost of 1 kW / hour of electricity.

If the communication network includes L CD, to which are connected N subscribers, the amount of energy consumed during time T working in standard mode Q_{CN}^S, expressed in the following form

$$Q_{CN}^S = \sum_{i=1}^{L} Q_{CD_i}^S + \sum_{j=1}^{N} Q_{NIC_j}^S,$$

where $Q_{CD_i}^S$ — amount of energy consumed by i-th CD operating in standard mode during time T,

$Q_{NIC_j}^S$ — amount of energy consumed by the j-th NIC operating in standard mode during time T.

Cost of maintenance of the communication network operating in IEEE 802.3 standard mode C_{CN}^S during time T will be equal to

$$C_{CN}^S = Q_{CN}^S C_{kW}.$$

The ownership cost of IEEE 802.3az standard communications network. In IEEE 802.3az standard frame transmission time depends on in which channel state frame arrives [1]. Let us consider the situation of IEEE 802.3az standard implementations for 100 and 1000 Mbps/s. If the frame comes into an active state or when the channel is in transition to a low power state, the frame transmission time is minimum and equal to

$$T_T^{\min} = \frac{\lambda T_T}{\lambda(1-\lambda T_T)}.$$

If the frame comes in a low power state, the initially is a transition duration T_W to active state, and then performed the frame transmission. Obviously, in this case will be the maximum transmission time

$$T_T^{\max} = T_T^{\min} + T_W.$$

Then the average frame transmission time can be represented as

$$T_T^{avr} = T_T^{\min} P_1 + T_T^{\max} P_2,$$

where P_1 — probability of the next frame arrival at the time of previous frame transmission when the channel is active or in the time before the completion phase T_S, when the channel has not had time to switch to a low power state,

P_2 — probability of the opposite event.

Under the assumption that time intervals between the arrival of frames distributed over Poisson law probabilities P_1 and P_2 will be equal to

$$P_1 = T_T^{\min}(1-e^{-\lambda T}),\ P_2 = T_T^{\min} e^{-\lambda T}.$$

Loading the i-th switch port U_i operating in EEE mode can be written as

$$U_i = \lambda_i T_{T_i}^{avr}.$$

The power consumed by the i-th port in EEE mode will be equal

$$P_i^{EEE} = [P_A U_i + P_{LPI}(1-U_i)], \quad (2)$$

where P_{LPI} — power consumption in a low power state LPI [1].

Expression (2) is the power consumption model of a network port working on standard IEEE 802.3az in EEE mode.

To verify the adequacy of the model were compared the data of port power consumption obtained using the model and experimental data given in [7]. Analysis shows that the error of calculation using the proposed model is not more than 8 % over the whole range of port loadings.

The amount of energy Q_i^{EEE} consumed by i-th port in EEE mode, during time T is expressed as

$$Q_i^{EEE} = P_i^{EEE} T .$$

The amount of energy Q_{CD}^{EEE} consumed by the N-input CD operating in EEE mode during time T, can be written as

$$Q_{CD}^{EEE} = \sum_{i=1}^{N} Q_i^{EEE} .$$

If the communication network includes L CD, to which is connected N subscribers, the amount of consumed energy during the time T working in EEE mode expressed in the form

$$Q_C^{EEE} = \sum_{i=1}^{L} Q_{CD_i}^{EEE} + \sum_{j=1}^{N} Q_{NIC_j}^{EEE} ,$$

where $Q_{CD_i}^{EEE}$ — amount of consumed energy by the i-th CD operating in the EEE mode during time T,

$Q_{NIC_j}^{EEE}$ — amount of consumed energy by j-th NIC operating in EEE mode during time T.

Cost of maintenance of the communication network working in the IEEE 802.3az standard in EEE mode C_C^{EEE} during time T is equal to

$$C_C^{EEE} = Q_C^{EEE} C_{kW} .$$

Economic efficiency calculation of computer network EEE reengineering. The total cost savings C_T^{EEE} associated with the operation of upgraded network in EEE mode during period of time T is equal to

$$C_T^{EEE} = C_{kW} (Q_C^S - Q_C^{EEE}). \qquad (3)$$

Payback term T_P of energy-efficient CN modernization, associated with buying L CD and N NIC operating in EEE standard, can be expressed as

$$T_P = \frac{\sum_{i=1}^{L} C_{CD_i}^{EEE} + \sum_{j=1}^{N} C_{NIC_j}^{EEE}}{[C_{kW} (Q_C^S - Q_C^{EEE})]} , \qquad (4)$$

where $C_{CD_i}^{EEE}$ — cost of i-th CD operating in the EEE standard,

$C_{NIC_j}^{EEE}$ — cost of j-th NIC operating in EEE standard.

Obviously, the expression (3) and (4) can be used to calculate the cost-effectiveness and costs payback period of EEE modernization as a whole CN and any of it fragments.

Results. For the calculations of energy efficiency modernization in a real network it is necessary to determine the values of four parameters that are present in the models (1) and (2). These are the power consumed by the port in the active state P_A, the power consumed in the pause state P_P, the average intensity of transmission frames λ and the average frames size L_S. These parameters must be defined for each port of CN.

The values of power P_A and P_P are determined based on the passport data of the maximum $P_{\max}$ and minimum $P_{\min}$ power of CD or NIC consumption. Maximum power consumption corresponds to the situation when all CD ports loaded by 100% and the minimum – when ports loading is equal to 0%. Consequently, for the CD containing N ports P_A and P_P values are calculated for the port as a

$$P_A = \frac{P_{\max}}{N} , \quad P_P = \frac{P_{\min}}{N} .$$

It is obvious that the NIC value of P_A and P_P are defined as

$$P_A = P_{\max} , \quad P_P = P_{\min} .$$

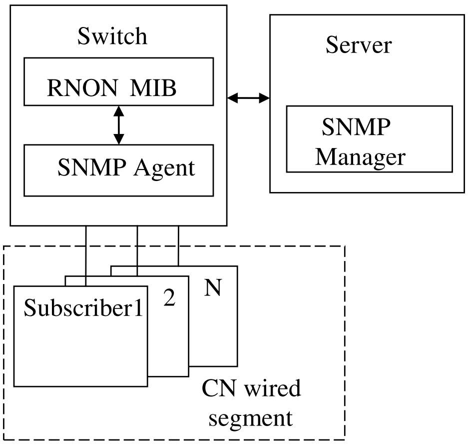

Fig. 1. The structure of a network monitoring SNMP-system

To carry out the measurement of values λ and L_S it suggested to use one of the standard network monitoring SNMP-systems [9]. Examples of such systems are AggreGate Network Manager, Zabbix, Nagios, etc. These systems operate under the agent-manager scheme [10]. Manager located on one of the network servers. As an SNMP-agents used RMON MIB agents, which are located at communication equipment (Fig. 1).

To calculate the average values of λ and L_S manager via SNMP protocol periodically polls the values of the corresponding table of the RMON MIB database for each CD port. To calculate the average frame rate is read out values of *Statistics* group, namely value of the parameter *etherStatsPkts*, which characterizes the total number of packets received at this port. Then the average frame rate value for the port is equal to

$$\lambda = \frac{K_{i+1} - K_i}{\Delta T},$$

where K_i, K_{i+1} — number of frames received by the port, respectively, at the beginning and end of the measurement period ΔT.

To calculate the average size of transmitted frames is read out values of *Statistics* group, namely value of the parameter *etherStatsOctet*, which characterizes the total number of bytes received at this port. Then, the average value of the transmitted frames size in the investigated port is equal to

$$L_S = \frac{B_{i+1} - B_i}{K_{i+1} - K_i},$$

where B_i, B_{i+1} — number of bytes received by port, respectively, at the beginning and the end of the measurement period ΔT.

Thus reading the values of only two parameters from the RMON MIB base for each port allows calculating the average values of the intensity and frame sizes for all CN ports. Using the built-in capabilities of network SNMP-monitors for data processing we can regulate the frequency of RMON MIB parameters poll and calculate the average values of λ and L_S for any work interval of CN.

Conclusion. In the paper presents simple analytical models for calculation the power port consumption operating in IEEE 802.3 standard mode and low-power mode EEE. Verification of obtained models shows that they have sufficient accuracy for engineering calculations of power consumption for the CN communication systems. The paper presents the analytical dependences allow to calculate the economic effect from the communications network transfer to the EEE technology. The methodic allows calculating the parameters of the real network which are used in the models of power consumption calculation. As an instrumental tool for collection of CN traffic parameters standard SNMP-system of network monitoring was suggested. The analytical dependences allowing on the basis of variables from the RMON MIB database calculate parameters for the models of port power consumption calculation was proposed. The developed methodic is an effective tool for network engineers in decision-making tasks of energy-efficient CN reengineering.

Література

1. IEEE Standard 802.3az-2010. Part 3: CSMA/CD Access Method and Physical Layer Specifications Amendment 5: Media Access Control Parameters, Physical Layers, and Management Parameters for Energy-Efficient Ethernet / Institute of Electrical and Electronics Engineers. — IEEE, 2010. — 272 P.

2. IEEE 802.3az: the road to Energy Efficient Ethernet / K. Christensen, P. Reviriego, B. Nordman, *et al.* // IEEE Communications Magazine. — 2010. — Vol. 48, Issue 11. — PP. 50–56.
3. Mathematical analysis of burst transmission scheme for IEEE 802.3az energy efficient Ethernet / K.J. Kim, S. Jin, N. Tian, B.D. Choi // Performance Evaluation. — 2013. — Vol. 70, Issue 5. — PP. 350–363.
4. Modeling and understanding burst transmission algorithms for Energy Efficient Ethernet / J. Meng, F. Ren, W. Jiang, C. Lin // Proceedings of 2013 IEEE/ACM 21st International Symposium on Quality of Service (IWQoS), 3–4 June 2013, Montreal, Canada. — Piscataway, NJ: IEEE, 2013. — PP. 1–10.
5. Optimal configuration of Energy-Efficient Ethernet / S. Herrerıa-Alonso, M. Rodrıguez-Pérez, M. Fernández-Veiga, C. López-Garcıa // Computer Networks. — 2012. — Vol. 56, Issue 10. — PP. 2456–2467.
6. An Initial Evaluation of Energy Efficient Ethernet / P. Reviriego, K. Christensen, J. Rabanillo, J.A. Maestro // IEEE Communications Letters. — 2011. — Vol. 15, Issue 5. — PP. 578–580.
7. Performance evaluation of Energy Efficient Ethernet / P. Reviriego, J.A. Hernandez, D. Larrabeiti, J.A. Maestro // IEEE Communications Letters. — 2009. — Vol. 13, Issue 9. — PP. 697–699.
8. Characterizing 10 Gbps network interface energy consumption / R. Sohan, A. Rice, A.W. Moore, K. Mansley // Proceedings of 2010 IEEE 35th Conference on Local Computer Networks (LCN), 11–14 October 2010, Denver, Colorado, USA. — Piscataway, N.J.: IEEE, 2010. — PP. 268–271.
9. Stallings, W. High-speed networks and internets: Performance and quality of service / W. Stallings. — 2nd Ed. — Upper Saddle River, N.J.: Prentice Hall, 2002. — 715 p.
10. Olifer, N. Computer networks: Principles, technologies, and protocols for network design / N. Olifer, V. Olifer. — Hoboken, NJ: John Wiley & Sons, 2006. — 973 p.

References

1. Institute of Electrical and Electronics Engineers. (2010). *IEEE Standard 802.3az-2010. Part 3: CSMA/CD Access Method and Physical Layer Specifications Amendment 5: Media Access Control Parameters, Physical Layers, and Management Parameters for Energy-Efficient Ethernet*. Piscataway, N.J.: IEEE.
2. Christensen, K., Reviriego, P., Nordman, B., Bennett, M., Mostowfi, M., & Maestro, J.A. (2010). IEEE 802.3az: the road to Energy Efficient Ethernet. *IEEE Communications Magazine*, 48(11), 50–56. DOI:10.1109/MCOM.2010.5621967
3. Kim, K.J., Jin, S., Tian, N., & Choi, B.D. (2013). Mathematical analysis of burst transmission scheme for IEEE 802.3az Energy Efficient Ethernet. *Performance Evaluation*, 70(5), 350–363. DOI:10.1016/j.peva.2012.12.001
4. Meng, J., Ren, F., Jiang, W., & Lin, C. (2013). Modeling and understanding burst transmission algorithms for Energy Efficient Ethernet. In *Proceedings of 2013 IEEE/ACM 21st International Symposium on Quality of Service (IWQoS)* (pp. 1–10). Piscataway, NJ: IEEE. DOI:10.1109/IWQoS.2013.6550278
5. Herrerıa-Alonso, S., Rodrıguez-Pérez, M., Fernández-Veiga, M., & López-Garcıa, C. (2012). Optimal configuration of Energy-Efficient Ethernet. *Computer Networks*, 56(10), 2456–2467. DOI:10.1016/j.comnet.2012.03.006
6. Reviriego, P., Christensen, K., Rabanillo, J., & Maestro, J.A. (2011). An Initial Evaluation of Energy Efficient Ethernet. *IEEE Communications Letters*, 15(5), PP. 578–580. DOI:10.1109/LCOMM.2011.040111.102259
7. Reviriego, P., Hernandez, J.A., Larrabeiti, D., & Maestro, J.A. (2009). Performance evaluation of Energy Efficient Ethernet. IEEE *Communications Letters*, 13(9), 697–699. DOI:10.1109/LCOMM.2009.090880
8. Sohan, R., Rice, A., Moore, A.W., & Mansley, K. (2010). Characterizing 10 Gbps network interface energy consumption. In *Proceedings of 2010 IEEE 35th Conference on Local Computer Networks (LCN)* (pp. 268–271). Piscataway, N.J.: IEEE. DOI:10.1109/LCN.2010.5735719
9. Stallings, W. (2002). *High-Speed Networks and Internets: Performance and Quality of Service* (2nd Ed.). Upper Saddle River, N.J.: Prentice Hall.
10. Olifer, N., & Olifer, V. (2006). *Computer Networks: Principles, Technologies, and Protocols for Network Design*. Hoboken, NJ: John Wiley & Sons.

Received July 5, 2016

Accepted July 26, 2016