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An Efficient Energy Saving Strategy Combined with Network Calculus Theory and Markov Model

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Abstract: With the expanding size of the networks and the updating of the devices, there has been a sharp increase and low efficiency in the energy consumption. So how to save energy consumption and build the green networks has not only become an urgent issue that need to be solved but also a significant factor on national development strategies. Effective energy management should meet the requirements of "green" and QoS simultaneously. In this study, by combining the network calculus theory and Markov stale model, we propose a strategy for optimizing the trade-off between QoS and energy consumption. In the strategy, we utilize network calculus to calculate the maximum value of buffer capacity which is required by system for preventing the packets loss, then let system run different modes and service rates, so power consumption can be reduced by operating at sleep mode and lower data rate under the condition of guaranteed delay and packet loss.

Key words: Energy efficiency, network calculus, Markov stale model, QoS

INTRODUCTION

There are more and more multimedia information, such as voice, graphics, video, animation was transferred for the rapid development of network technology. Those applications asked for higher limits in performance of the network. Therefore, for a long time, a large number of network researches pay close attention on how to improve the network throughput, reduce the data delay and ensure the transmission accuracy. But with the recent development of cloud computing and data center, these researches treat energy as an important factor affecting the improvement of the performance for the energy cost. So saving network energy become a research topic as important as the QoS.

Network calculus is a new theory for network performance analysis that has drawn great attention when it was purposed by authors in some studys. Cruz (1991, 1991) developed a mode of the flow characteristics (s, r) and a calculation method about delay. (Parekh and Gallager, 1993; 1994) analyzed a service mode for GPS scheduler. According to the service mode, Cruz (1995) give a general definition about service curve. In this situation, (Chang and Lin, 2001; 1998) and Le Boudec (1998) in their studys formally propose the mathematical explanation of network calculus theory on the basis of mi-plus algebra. This theory is widely used to analyze the scheduler, traffic shaping and resource optimization. Arrival curve and service curve is the core of the network calculus theory. Arrival curve limits the traffic arrival pattern and service curve describes the feature of the server's service capability. The node's backlog upper bound is decided by the maximum vertical distance between arrival curve and service curve. The node's delay upper bound is described by the maximum horizontal distance between arrival curve and service curve. But without considering energy consumption when using the network calculus theory to analyze performance parameters, so there is a tremendous opportunity for introducing energy awareness. In this study, with a given arrival curve and buffer capacity, in order to introduce energy, the study firstly presents a new Markov model of the Dual-Threshold Policy. The new features of the mode concern its ability to take into account the buffer size which is computed by the network calculus. The Markov mode has been applied in the green network for a long time, several Control Polices have been already proposed. Gross and Harris (1998) presented a Markov mode of the single-Threshold Policy, which is based on output buffer occupancy, or queue length. This is a simplest mode where a service rate transition can occur during a service period. In this police, if the output buffer queue length exceeds the threshold, then the service rate must be transitioned to high. If the output queue decreases below the threshold, then the rate can be reduced to low. To make this mode suitable for Ethernet, rate change can only

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occur at a service completion (Gunaratne *et al*., 2008). The authors also presented a Markov model of the Dual-Threshold Policy (Gunaratne *et al*., 2006). This policy has two different threshold, if the output buffer queue length exceeds the higher threshold, the service rate must be transitioned to high. If the output queue decreases below the lower threshold, then the rate can be reduced to low. The main limitation of their model is that it does not take into account the rate switching times. Another limitation is given by the fact that they consider an infinite queue. So as to address these two issues. The authors in their studys proposed a model of the Dual-Threshold Policy which takes into the rate switching times and the buffer size (Callegari *et al*., 2009). In all studys, the system has been active during its history, they have not considered that the service will become idle once the output buffer becomes empty. And the author did not calculate the maximum of the buffer size.

In this study, we propose a new Markov model of the single-Threshold Policy, so as to address these two shortcoming. Our Markov model takes into account the sleep mode when the service becomes idle and the buffer size which is calculated by network calculus for preventing the packets loss.

NETWORK CALCULUS BASIC

In order to achieve the guaranteed QoS, the system usually constrains the arriving flow's peak rate by the leaky bucket. But recently many researches show that many kinds of network traffics are self-similar, which can't be described by traditional leaky bucket algorithm. So Jian *et al*. (2004) use the fractal leaky bucket to limit the flow. After shaping, the arrival curve about the system can be described:

$$\alpha(t) = \min \begin{cases} r^*t + b^*, t \ge T \\ Ct + M, t > T \end{cases}$$

$$r^* = r + \sigma(1-H)(2\gamma)^{1/2}\left(\frac{H}{1-H}\right)^{1/2H-2}$$

$$b^* = \sigma(1-H)(2\gamma)^{1/2}\left(\frac{H}{1-H}\right)^{1/2H}$$

In the expression, r, σ and H represent long-term average rate, standard deviation and self-parameter, respectively. γ represents positive constant number. C and M are called the speed of the link and the biggest packet length, respectively.

In order to guarantee the service for each node, the service curve can be described:

$$\beta(t) = \begin{cases} B(t-D), t > D \\ 0, t \le D \end{cases}$$

Parameters B and D are called service rate which is provided by system and waiting time, respectively.

The backlog upper bound can be calculated by the network calculus theory, its expression is:

$$B_{max} = \begin{cases} b^* + \dfrac{(r^*-B)(b^*-C)}{(M-r^*)} + BD, M \ge B \ge r^*, D \le T \\ C + MD, B \ge M \ge r^*, D \le T \\ b^* + r^*D, D > T \end{cases}$$

ENERGY SAVING SCHEMES

We can get the performance parameters by the network calculus theory but the theory will make the system consume a non-trivial amount of energy. So there is a strong motivation to reduce energy consumption on the basis of guaranteed performance parameters.

In order to reduce energy consumption, we assume that the system can run two different modes: sleep mode and active mode. The system will enter the sleep mode when the buffer is empty, if no packets arrive at this time, the system will keep the mode until new packets enter. Otherwise, the system will transfer to the active mode at the end of this sleep period. In the active mode, the system has two different service rates. The system can reduce energy consumption by running in the sleep mode and the lower rate and achieve required QoS by transferring between different states and rates.

The arrival rate can be expressed γ and the lower service rate is u_1, while the higher service rate is u_2. During the service period, if the queue length of the output buffer becomes equal to or greater than the threshold and no more than B_{max} which is called backlog upper bound, the system will transfer to the higher rate. However, if the queue length of the output buffer becomes less than the threshold, the system will transfer to the lower rate. This policy can be expressed:

$$u(t) = \begin{cases} u_2\left(Q \ge k \cap u(t^-) = u_1\right) \\ u_1\left(Q \le k \cap u(t^-) = u_2\right) \end{cases}$$

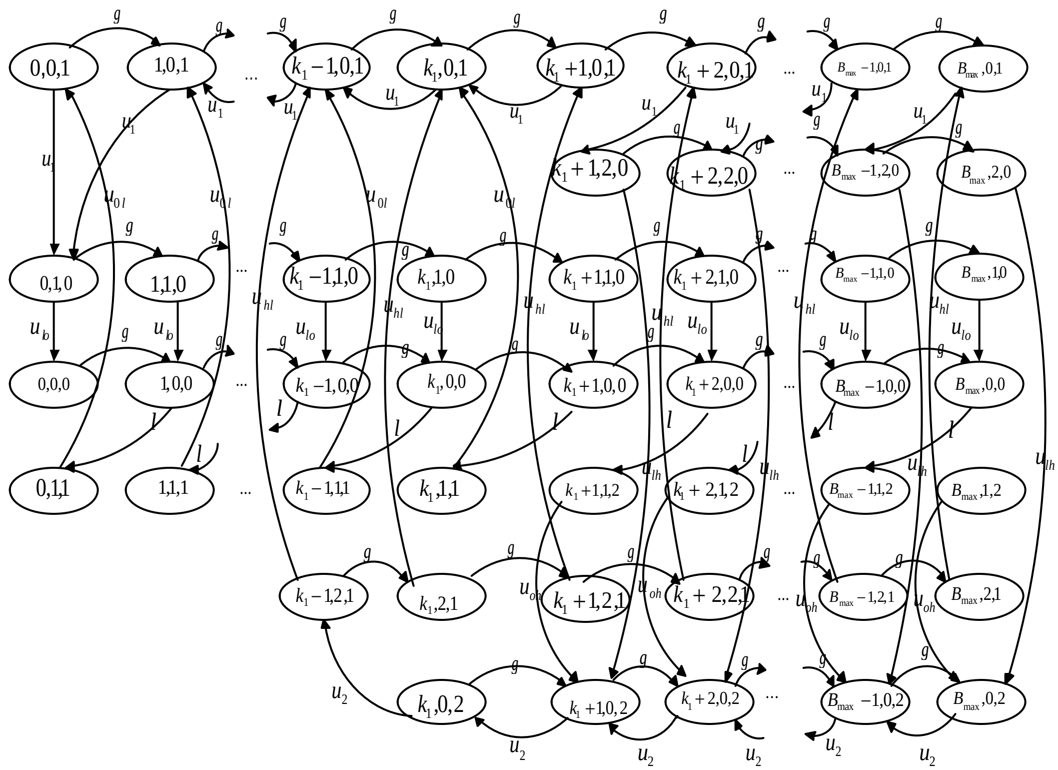

Fig. 1: State-transition diagram of the Markov model

In this study, our Markov model takes into account the buffer size because of the constrained buffer capacity. In addition, the switching time between different states can influence the energy consumption, so to consider the switching time in the Markov model is necessary. The parameters u_{LH} and u_{HL} are the transition rates which are changing from low to high and reverse direction , u_{OL} and u_{LO} are the transition rates which are changing from sleep to low and reverse direction. u_{OH} is the transition rate which is changing from sleep to high. During the transition period, the system is inactive and no packets can be transmitted on it, in this period, the packets will wait in the buffer for the next service period.

We define eight states of the Markov model. The state (0, 0) expresses that we are in the sleep mode. While (0, 1) expresses that users are serviced at the low service rate and (0, 2) expresses that users are serviced at the high service rate. In addition, the rest of the states are used to determine the kind of switching, i,e if the state is (1, 0), we are in the low-to-sleep rate switching time period and (1, 1) decides the transition in opposite direction, the state (1, 2) determines the kind of switching is from sleep-to-high, only when all the packets in the buffer are transmitted, will the system enter the sleep mode, so the kind of high-to-sleep switching is non-existent. The state (2, 0) expresses that we are in the low-to-high switching time period and (2, 1) expresses that we are in the diverse direction switching time period. In order to consider the number of the packets waiting in the buffer, the other variable is necessary. The Markov model of this policy can be showed in Fig. 1.

We can get the steady-state probability by the Markov process and the power consumptions, P_1, can be calculated as follows:

$$P_{cons} = P_o\sum_{n=0}^{B_{max}} Pr(n,0,0) + P_l\sum_{n=0}^{B_{max}} Pr(n,0,1) + P_h\sum_{n=k_1}^{B_{max}} Pr(n,0,2) + P_s\left[\sum_{n=k_1+1}^{B_{max}} Pr(n,2,0) + \sum_{n=0}^{B_{max}} Pr(n,1,0) + \sum_{n=0}^{k_1} Pr(n,1,1) + \sum_{n=k_1+1}^{B_{max}} Pr(n,1,2) + \sum_{n=k_1-1}^{B_{max}} Pr(n,2,1)\right]$$

The simulation results have showed in Fig. 2 and 3, The Fig. 2 shows that how the energy saving changes with the Threshold and R which is equal to u_1/u_2. From this figure, it can be observed that the energy saving

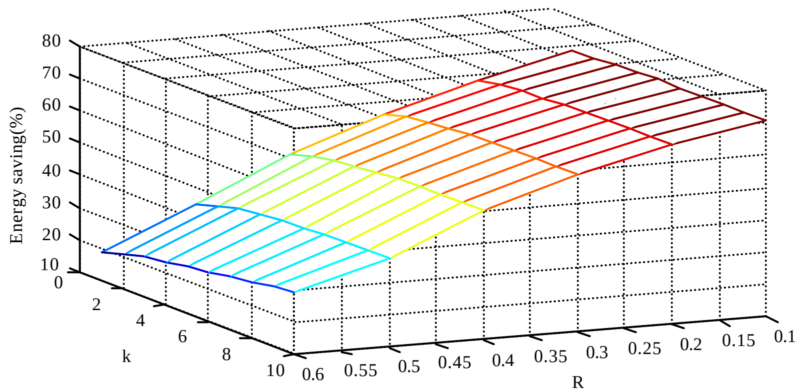

Fig. 2: Energy saving vs. k and the ratio between two rates

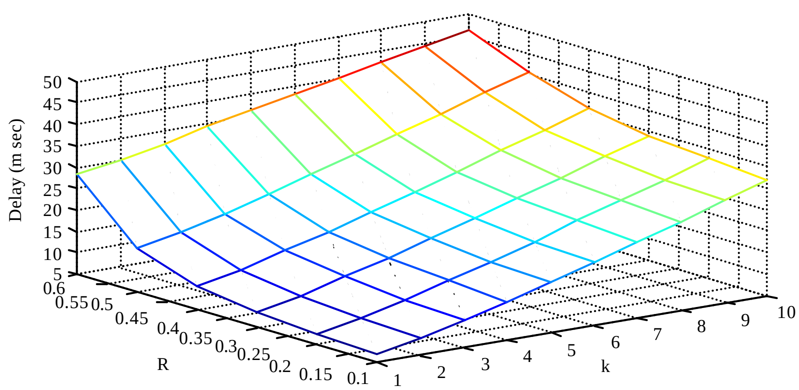

Fig. 3: Mean delay vs, Threshold k and the ratio between two rates

greatly dependents on the two variables. Because the service rate is one of the main factors affecting energy consumption, the lower service rate decides how much the energy can reduce and the higher service rate prevents the packet loss, in addition to this, the service curve has a greatly relationship with the service rate in the network calculus theory, in order to make the buffer size which is calculated by the network calculus theory apply to the variable speed rate of energy saving strategy, the reasonable ratio R was set up depending on the needs.

Figure 3 shows that how the mean delay changes with the Threshold and R which is equal to u_1/u_2,we can see the mean delay can be accepted in this energy saving policy, the mean delay increase gradually with the increase of R, this is because that the service rate decides the system processing rate.

CONCLUSION

How to save network energy and build green network under the condition of certain QoS is a hot topic in the field of communication. In this study, we use the network calculus to compute the maximum buffer size which is needed for the system, so we can prevent the packets loss. In this situation, we propose a new Markov model with adaptive modes and variable service rates to reduce the energy consumption, so we finally implements the trade-off between energy consumption and quality of service.

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