International Journal of Multimedia and Ubiquitous Engineering
Vol. 2, No. 3, July, 2007

Priority Dropping for Scalable Video

[1]Yang Xiaogang, [2]Liu Jiqiang, [3]Li Ning, and [4]Tai-hoon Kim

[1,3]State Key Lab. of Software Development Env., Beihang University, Beijing, China
[2]Dep. of Computer and Inf. Technology, Beijing jiaotong University, Beijing, China
[4]Dept. of Multimedia Engineering, Hannam University, Daejeon, Korea
[1]yangxg@nlsde.buaa.edu.cn, [2]jqliu@bjtu.edu.cn, [3]lining@nlsde.buaa.edu.cn,
[4]taihoonn@hannam.ac.kr

Abstract

For H.264/SVC, different layers or frames have different order of precedence according to their importance on video quality and the decoding process. Network should provide more protection for high priority layers or frames when SVC stream is transmitted over IP network. This paper proposes an active queue management algorithm based on priority dropping and PID algorithm, called PID_PD, which first drops the least important packets when network congestion arises. PID_PD implements differentiated service in IP layer to provide high quality video for end user. In addition, PID_PD does not create a side effect for the performance of control system. In this paper, we use BCC (Binomial Congestion Control) as source rate control protocol. BCC and PID_PD form a close-loop control system. By using a classic control theoretic approach to analyze the stability of the close-loop system, we present a method to decide the PID_PD parameters. Simulation shows PID_PD can protect important video data well, lower the disturbance of background flow, and decrease the packet loss rate of SVC flow.

1. Introduction

Scalable H.264 Coding (SVC) [8] [9] is a new ongoing video coding standard, which is proposed by the Joint Video Team (JVT) of the International Telecommunication Union -- Telecommunication Standardization Sector (ITU-T) and the Moving Picture Experts Group (MPEG). SVC is an extension and amendment of the latest advanced video coding (H.264/AVC) [10]. It uses layered coding schema to generate multi-layer bitstream for heterogeneous networks and terminal devices. A SVC bitstream is composed of one base layer (BL) and several enhancement layers (EL). Base layer provides a minimum level of quality while the enhancement layers are mainly used to refine the video quality. SVC offers three most important scalabilities: spatial scalability, temporal scalability and SNR scalability.

SVC is very appropriate for real-time transmission of video data in heterogeneous network environments. The different layers of one SVC bitstream can be transmitted via different channels, e.g., wireless channel may only transmit base layer data while wire channel can transmit all layers data. Different terminal devices can choose to receive partial bitstream, e.g., mobile devices can only receive base layer data, and HDTV can receive all bitstream.

For network applications based on SVC, congestion control is a crucial issue. Congestion control includes the rate control algorithm in the end hosts and the queue management in the router nodes.

The basic idea behind an AQM (active queue management) algorithm is to sense the congestion level within the network and inform the packet source about this so that they reduce their sending rate. As an effective supplement to end-to-end congestion control mechanism, active queue management aims to keep high link utilization while maintaining low queue delay, eliminating the prejudice against the burst traffic, avoiding the unnecessary packet dropping. So far, many AQM algorithms have been proposed, such as RED [4], PI [2], PID [6], etc.

In scalable bit stream, different layers have different order of precedence, which depend on their importance on video quality and the decoding process. Basic layer is the most important because it contains the most basic video information. The information of the layer l is a supplement for the information of its adjacent lower $l-1$ layers. The decoding of layer l depends on the information of the previous $l-1$ layers. The importance of every layer can be ordered descendent by basic layer, enhancement layer one, enhancement layer two,$\cdots$ and the last enhancement layer. We suppose I is the importance index, l_i $(i=0,1,\cdots)$ is the layer number, and then the importance is expressed as follows.

$$I(l_0) > I(l_1) > I(l_2) > \cdots$$

Furthermore, different frames have different importance, which determined by their contribution to the quality of the reconstructed video. I (Intra) frames and P (Predictive) are more important than B (Bi-directional predictive) frames and FGS frames, because I frames and P frames maybe are used as the reference frames of other frames. If I frames and P frames are loss, some frames which depend on them as reference cannot be decoded truly. Other frames such as B frames and FGS frames usually are not used as the reference frames, they do not affect on the other frames even if they are loss, and the errors introduced by their loss do not propagate furthermore.

For ensuring the quality of decoding video, the high important layers or frames should be provided more protection in IP network. That is, they should be given a special precedence.

This paper presents a new AQM algorithm PID_PD based on priority dropping and PID algorithm. It drops the lower priority packets once network congestion arises. Experiment shows that PID_PD can protect high priority data, lower the disturbance of background flows while it does not affect the performance of the control system. In addition, PID_PD implements the differentiated service, and guarantees the video quality. We use BCC as the source control algorithm. BCC and PID_PD forms a close-loop control system. We tune PID parameters by analyzing the stability of the close-loop system of BCC/PID.

The reminder of this paper is organized as follows. In section 2, we review related research on active queue management. We then introduce PID control algorithm in section 3. In section 4, we propose priority dropping PID mechanism, called PID_PD. In section 5, we present a differential equation model for Binomial Congestion Control protocol for tuning the PID parameters. In section 6, we discuss the method to decide PID control parameters by analyzing the stability of close-loop system of BCC/PID. We then use NS2 to simulation network topology and verify the PID_PD algorithm in section 7. Finally, we draw a conclusion.

2. Related work

In this section, we will review some AQM algorithms.

S.Floyd et al. proposed the first AQM algorithm, RED (random early detect). It adopts the preemptive dropping or marking to prevent congestion by using probability judgment mechanism. The main fault of RED is that the response time is too long because it smoothes the queue length by using a low pass filter, which increases the delay time of control system, and bring in instability and the low frequent oscillation of congestion window.

Network congestion control system including AQM is considered as a close loop feedback control system from the control-theoretic point of view. The control target is queue length, and the control quantity is dropping probability of router. So many congestion controllers are built by using the method of control theory.

Hollot et al. [2] used a control theoretic approach to analyze the RED algorithm, and proposed PI (proportional integral) algorithm. PI controller eliminates the steady-state error, and has smaller queue length oscillation than RED. But the transient performance of the PI controller is not perfect.

Fan YF et al. presented a PID algorithm [6], which makes the instantaneous performance of system obviously superior to that of PI algorithm. In addition, compared to RED and DropTail, PID can keep faster response speed, smaller queue length oscillation and higher link utilization.

3. PID control

PID is a type of traditional powerful controller, which is composed of proportion, integral and derivative controller. It computes a control action based on the input state and feedback gain multipliers that control stability, error and response. The Proportional-Integral design avoids the steady-state error, but slows down the responsiveness by almost one degree of magnitude. A derivative part helps to reduce the overshoot and the settling time. The network feedback control based on PID is as Figure 1.

Where q_0 is expected queue length, q is instantaneous queue length. $e = q - q_0$ is error signal, which is the input of PID controller. p is packet loss rate at some time, which is the output of the PID controller. Router queue is the plant of PID, and the rate control algorithm of source is the executer of system.

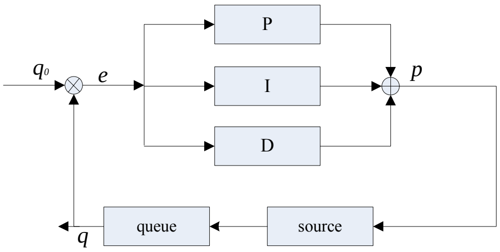


Figure 1. PID feedback control system

In the system, PID computes the dropping rate p of every arriving packet according to the variance of router queue length. The dropping rate will be detected by the source after a link delay time. The source judges the congestion state according to p and adjusts its sending rate, so the length of the router is controlled.

The input $e(t)$ and the output $p(t)$ satisfy the following relation.

$$p(t) = K_p[e(t) + \frac{1}{T_i}\int e(t)dt + T_d \frac{de(t)}{dt}]$$

Where T_i is integral-time constant, T_d is derivative-time constant. K_p is proportion coefficient, $K_i = K_p / T_i$ is called as integral coefficient, $K_d = K_p T_d$ is called as derivative coefficient.

Let $t = kT$, replace integral by sum, replace derivative by increment, we get discrete PID expression.

$$p(kT) = k_p e(kT) + K_i \sum_{j=0}^{k} e(jT) + k_d(e(kT) - e(kT - T))$$

We have the probability dropping formula by getting increment both sides from above expression.

$$p(kT) = k_p(q(kT) - q(kT - T)) + k_i(q_0 - q(kT)) + k_d(q(kT) + q(kT - 2T) - 2q(kT - T)) + p(kT - T)$$

Furthermore, we can write the pseudo code as follows.

$$p = a*(q - q\_obj) + b*(q\_obj - q\_pre) + c*(q - q\_pre\_pre) + p\_pre$$

Where q_obj is the expected queue length, q is current queue length, q_pre is the previous queue length, q_pre_pre is previous two queue length, p_pre is previous dropping rate. a, b and c are constants.

Because the probability p always is between 0 and 1, we define p as follows.

$$p = \begin{cases} 0 & p < 0 \\ p & 0 \le p \le 1 \\ 1 & p > 1 \end{cases} \tag{1}$$

4. Priority dropping

We will present a new active queue management schema PID_PD based on priority dropping PID in this section.

Suppose SVC has m layers, every layer has n priority ranks, and then we can define the following priority matrix to express the SVC priority.

$$P = \begin{bmatrix} p_{11} & p_{12} & \cdots & p_{1n} \\ \vdots & \vdots & & \vdots \\ p_{m1} & p_{m2} & \cdots & p_{mn} \end{bmatrix}$$

The matrix satisfies the following relation.

$$p_{ij} \ge p_{i,j-1}$$

$$p_{ij} \ge p_{i-1,j}$$

The minimal priority of l layer is:

$$p_{\min}(l) = p_{l,1}$$

The maximal priority of l layer is:

$$p_{\max}(l) = p_{l,n}$$

If the priority number increments by step h in intra-layer, and by step w in inter-layer, then,

$$p_{i,j} = f(p_{11}, i, j, h, w) = p_{11} + h*(j-1) + w*(i-1) \tag{2}$$

The implementation procedure of priority dropping is as follows. We firstly define packet priority number according to (2) when video data is packetized in application layer, writing the priority number to the priority filed of the packet. For other background flows, we set their priority number to be zero. The router maintenances a packet queue. We then update the queue when packets enter queue or depart queue. For a new arriving packet, firstly we calculate its dropping probability according to (1). When the current packet is determined to drop, then we look for the packet whose priority number is less than the current packet in the queue, if finding the lower priority packet, we drop the low priority packet, and the current packet enters the queue. Otherwise, the current packet is dropped. The process is expressed as follows by using pseudo code.

5. Source rate control

In this section, we will discuss the source control algorithm and its dynamics model.

BCC [13] is the rate control protocol suitable for streaming video application. The sender increases congestion window when it receives a normal feedback, and decreases window when it detect the packet loss. BCC uses four parameters k , l , α , β to describe the algorithm as follows.

$$I \quad W_{t+R} = W_t + \alpha / W_t^k$$

$$D \quad W_{t+\delta} = W_t - \beta W_t^l$$

```
$receive(pkt)$
  $p = calculaus\_p(pkt)$
$if(drop)$
  $if(pkt.prio = 0)$
    $drop(pkt);$
  $else$
    $l\_pkt = lookfor\_lowpriority(queues)$
    $if(l\_pkt)$
      $drop(l\_pkt);$
      $enque(pkt)$
    $else$
      $drop(pkt)$
```

where I refers to the increase in window, D refers to the decrease in window, R is the round-trip time (RTT), W_t is the window size.

Misra et al. [14] proposed a fluid-flow model to describe the dynamic behavior of TCP protocol by using stochastic differential equation analysis. We use the similar way to give a dynamic model of BCC.

Let $X(t)$ is a random variable, which indicates the number of the acknowledgements of packets loss in time interval $(t, t+RTT)$. Suppose $X(t) \le 1$, the dynamic behavior of BCC protocol can be described as follows.

$$W(t+R) = (W(t) + \frac{\alpha}{W^k})(1 - X(t)) + (W(t) - \beta W^l)X(t)$$

Rearranging, we have,

$$W(t+R) - W(t) = \frac{\alpha}{W^k} - (\frac{\alpha}{W^k} + \beta W^l)X(t)$$

Let $N(t)$ is a Poisson Process whose average rate is $\lambda(t)$, then $dN(t) = \lambda(t)dt$. We approximate $X(t)$ by that of $N(t+R) - N(t)$, then

$$W(t+R) - W(t) = \frac{\alpha}{R \cdot W^k} R - (\beta W^l + \frac{\alpha}{W^k})(N(t+R) - N(t))$$

From the above expression, we have the following differential equation,

$$\frac{dW}{dt} = \frac{\alpha}{R \cdot W^k} - (\beta W^l + \frac{\alpha}{W^k})\lambda(t)$$

$\lambda(t)$ can be approximated by the product of the probability of packet drop/mark and the sending rate, that is, $\lambda(t) = p(t-R) \times W(t-R) / R(t-R)$. So we get

$$\frac{dW}{dt} = \frac{\alpha}{R(t) \cdot W^k} - \frac{1}{R(t-R(t))}(\beta W^l + \frac{\alpha}{W^k})W(t-R(t))p(t-R(t)) \tag{3}$$

Where p is the probability of packet drop/mark.

The active queue management in the router is modeled as follows [15].

$$\frac{dq}{dt} = \frac{W(t)}{R(t)}N(t) - C \tag{4}$$

Where q is the queue length, $N(t)$ is the load factor (number of TCP sessions), C is the link capacity.

6. Tuning PID parameters

There are three control parameters in PID control to decide. We will present a method to tune them by classic control theoretic approach.

Linearizing (3) and (4) in stable point (W_0, q_0, p_0) by the same method as that in [14], we obtain,

$$\delta\dot{W} \doteq -g_1\delta W - g_2\delta p(t-R) \tag{5}$$

$$\delta\dot{q} = \frac{N}{R_0}\delta W - \frac{1}{R_0}\delta q$$

(6)

where $\delta W = W - W_0$, $\delta p = p - p_0$, $\delta q = q - q_0$ and

$$g_1 = (\frac{\alpha\beta}{R_0}\frac{(k+l)(\frac{R_0C}{N})^{l-1}}{(\alpha+\beta(\frac{R_0C}{N})^{l+k})} + \frac{\alpha N^{k+1}}{R_0^{\,k+2}C^{k+1}})$$

$$g_2 = \frac{C}{N}(\frac{\alpha N^k}{(R_0C)^k} + \beta(\frac{R_0C}{N})^l$$

Performing a Laplace transform for (5) and (6), we can obtain $P_{BCC}(s)$, the transfer function form δp to δW, and $P_{queue}(s)$, the transfer function form δW to δq as follows.

$$P_{BCC}(s) = \frac{g_2}{s+g_1}$$

$$P_{queue}(s) = \frac{N/R_0}{s+1/R_0}$$

Suppose the AQM is PID, the feedback close-loop system block diagram is shown in Fig. 2.

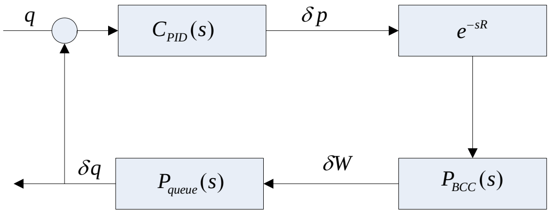


Figure 2. PID feedback system block diagram

Where C_{PID} is the transfer function of PID,

$$C_{PID}(s) = k_p + \frac{k_I}{s} + k_D s$$

k_p, k_I, k_D are the control parameters.

The system open-loop transfer function is as follows.

$$G(s) = C_{PID}(s)P_{BCC}(s)P_{queue}(s)e^{-sR_0} = (k_p + \frac{k_I}{s} + k_D s)\frac{g_2/g_1Ne^{-sR_0}}{(R_0s+1)(1/g_1s+1)}$$

We can get the control parameters by using classis control theory to analysis the stability of the system. The procedure is quite complex, and we will discuss the question in another paper.

7. Experiment

We will use JSVM4-11 [11] and NS2 [12] to build the experiment in this section. JSVM is H.264/SVC reference software, which is used to create SVC bitstream. NS2 is used to build the network simulation environment. BCC algorithm is used as end rate control algorithm. The router queue management algorithm is PID_PD.

7.1. Simulation model

The simulation model is shown in Figure 3. s1 is SVC source. s2,…,sn (n=120) are ftp background flows, d1 receives s1 flow, d2,…,dn are the corresponding ftp flows sinks. The link between router R1 and R2 is bottleneck link. The bandwidth of bottleneck link is 5M, the other link bandwidth is 10M. The delay of all links is a random number between 5ms and 10ms. The length of the max queue is 200 packets, and the expected queue length is 100 packets. The parameters of PID controller are set by using the similar method as [2]. The sampled frequency is 160HZ, a=0.000014, b=-0.00002228, and c=0.000008729.

The H.264/SVC bitstream in the experiment includes two spatial layers, 4800 frames. The first layer (80x44) and the second layer (176x144) have the same frame rate, 30fps. Gop size of the bitstream is 16.

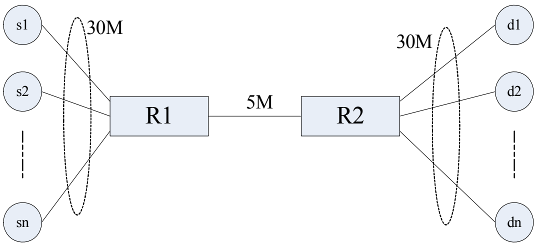
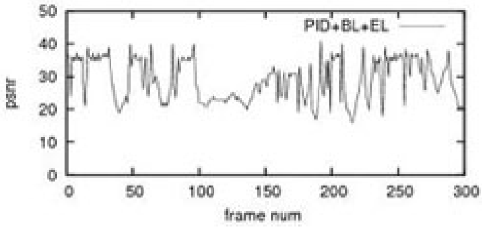


Figure 3. Simulation Mode

7.2. Simulation results



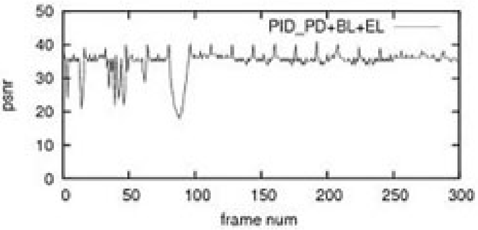
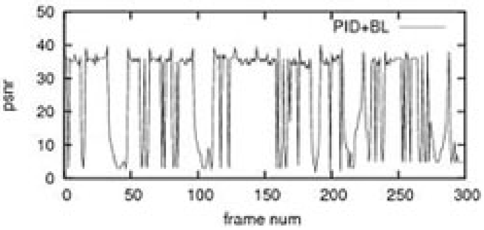


Figure 4. BL+EL PSNR using PID

Figure 5. BL+EL PSNR using PID_PD



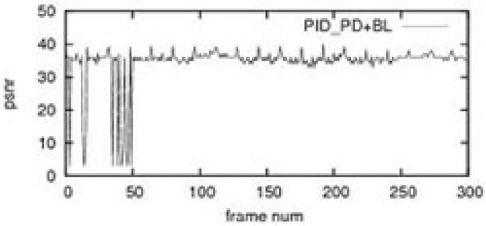


Figure 6. BL bitstream PSNR using PID

Figure 7. BL PSNR using PID_PD

The simulation results are shown in this part. We only draw the first 300 frames in Figure 4, Figure 5, Figure 6 and Figure7.

Figure 4 shows the PSNR of the whole bitstream (BL+EL) by using PID, and Figure 5 shows the PSNR of the whole bitstream by using PID_PD. Figure 6 and Figure 7 show the PSNR of the base layer (BL) by using PID and PID_PD respectively.

It can be seen from the experiment results, the packet loss rate of base layer (BL) and the whole bitstream (BL+EL) are obviously cut down by using PID_PD schema. The reason is that packet loss is moved to higher layer or background flows. The video quality of decoding sequence is improved obviously.

Figure 8 and Figure 9 show the queue length of bottleneck link by using PID and PID_PD respectively.

The results indicate PID_PD has the almost same control result for queue length as PID.

In addition, our experiments also indicate that PID_PD does not introduce a side effect. BCC performance has not degradation, which is TCP friendly. The link utilization rate, total packet loss rate and queue length of the bottleneck link keep the almost same results as PID.

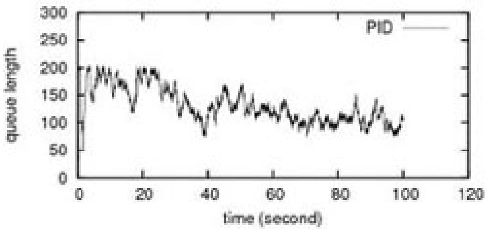


Figure 8. Queue length using PID

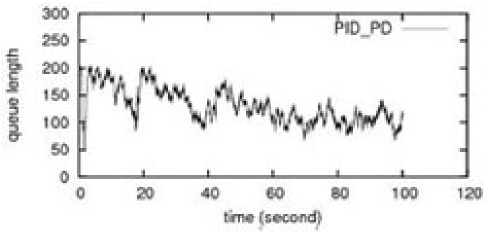


Figure 9. Queue length using PID_PD

8. Conclusion

H.264/SVC is new video standard that extends H.264/AVC. It supports video layered coding and transmission. For the application based on H.264/SVC, congestion control takes a critical role.

This paper proposes a new priority dropping active queue management algorithm PID_PD, which is designed based on PID mechanism, provides differentiated service for the different layers or frames according to their weightiness. The binomial congestion control algorithm is used in end hosts. We tune the PID parameters by using a classic control theoretic approach to analyzing the stability of the close-loop system of BCC/PID. Result shows the schema can prevent the high priority layer or frame from dropping, and provides high video quality to the end users.

Acknowledgment

The paper is an extension of MUE'07 paper. We thank Dr. Tai-hoon Kim very much for providing the fund support for the paper publication.

References

[1] C.V Hollot, Vishal Misra, Don Towsley, Wei-Bo Gong., “A Control Theoretic Analysis of RED”, In: Proceedings of IEEE/INFOCOM, April 2001

[2] C.V. Hollot, Vishal Misra., Don Towsley, Wei-Bo Gong., “On Designing Improved Controllers for AQM Routers Supporting TCP Flows”, In: Proceedings of IEEE/INFOCOM,2001.

[3] Lee C H., “A Survey of PID Controller Design Based on Gain and Phase Margins”, International Journal of Computational Cognitioy 2004,2(3): 63- 100

[4] S. Floyd and V. Jacobson, “Random early detection gateways for congestion avoidance”, IEEE/ACM Trans. on Networking, Aug. 1993.

[5] S. Bajaj, L. Breslau and S. Shenker, “Uniform versus Priority Dropping for Layered Video”, in Proc. of SIGCOM’97.

[6] Fan YF, Ren FY, Lin C., “Design a PID controller for active queue management”, In: Proc. of the 8th IEEE Int’l Symp. (ISCC 2003). 2003. 985−990.

[7] Jinsheng Sun, Guanrong Chen, King-Tim, “PD-Controller: A New Active Queue Management Scheme”, Proc IEEE INFOCOM, Mar, 2003.

[8] H. Schwarz, T. Hinz, H. Kirchhoffer, D. Marpe, and T. Wiegand, "Technical Description of the HHI proposal for SVC CE1," ISO/IEC JTC1/SC29/WG11, Document M11244, Palma de Mallorca, Spain, Oct. 2004.

[9] H. Schwarz, D. Marpe, and T. Wiegand, “Scalable Extension of H.264/AVC,” ISO/IEC JTC1/SC29/WG11, Doc. M10569/S03, Mar. 2004.

[10] ITU-T Recommendation H.264 & ISO/IEC 14496-10 AVC, "Advanced Video Coding for Generic Audiovisual Services", version 3: 2005.

[11] Reichel, H. Schwarz, and M. Wien, “Joint Scalable Video Model JSVM-4,” ISO/IEC JTC1/SC29/WG11, Doc. JVT-Q202, Oct. 2005.

[12] NS2 Network Simulator. http://www.isi.edu/nsnam/ns.

[13] Bansal and H. Balakrishnan, ”Binomial Congestion Control Algorithms” Proceeding of IEEE INFOCOM, April 2001.

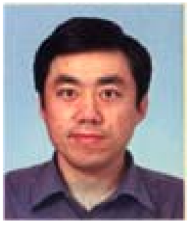
[14] Vishal Misra, Wei-Bo Gong, and Don Towsley, “Fluid-based Analysis of a Network of AQM Routers Supporting TCP Flows with an Application to RED”, in Proceedings of ACM/SIGCOMM, 2000.

[15] C.V.Hollot, Vishal Misra, Don Towsley, and Wei-Bo Gong, “On Designing Improved Controllers for AQM Routers Supporting TCP Flows”, in Proceedings of IEEE/INFOCOM, April 2001.

Authors

Yang Xiaogang

He is now a Ph.D. candidate in State Key Lab of Software Development Environment, Beihang University. His research interests include Network Management, Congestion Control, Video Coding, and Information Security.



Liu Jiqiang

Received a Ph D. degree in Mathematics Logic from Beijing Normal University, China, 1999 and joined the faculty of Beijing Jiaotong University, China, where he is currently an associate professor in Department of Computer and Information Technology. His research interests include Applied Cryptography, Security Protocol and Algorithm.

Li Ning

Received a B.S. degree in computer science and technology from Beihang University, China, 2004. He is now a Ph.D. candidate in State Key Lab of Software Development Environment, Beihang University. His research interests include Network Performance, Overlay Network, Network Coding, and Information Security.

Tai-hoon Kim

Dr. Tai Hoon Kim received his M.S. degrees and Ph.D. in Electrics, Electronics & Computer Engineering from the Sungkyunkwan University, Korea. After working with Technical Institute of Shindoricoh 2 years as a researcher and working at the Korea Information Security Agency as a senior researcher 2 years and 6 months, he worked at the DSC (Defense Security Command) about 2 years. After working with E-wha Woman University a half year as a research professor, now he is currently a professor of Hannam University.
He wrote sixteen books about the software development, OS such as Linux and Windows 2000, and computer hacking & security. And he published about 100 papers by 2006. He was a program committee of SNPD 2004, SERA 2004, SERA 2005, ISNN 2006, ICCS 2006, ICCSA 2006, ICIC 2006, RSTK 2006, SERA 2007, SmarTel 2007, SIN 2007. He was a special session and workshop chair of ICCSA 2004, PCM 2004, KES 2004, PARA 2004, ICCMSE 2004, SCI 2004, ICCSA 2005, ICIC 2005, RSFDGrC 2005, KES 2005, ICCMSE 2005, ICCSA 2006, ICIC 2006, KES 2006, ISNN 2006, ICCMSE 2006, ICCSA 2007, ICIC 2007, KES 2007, ISNN 2007, ICCMSE 2007. He was a General Chair of ICHIT 2006 and MUE 2007, Steering Committee Chair of FBIT 2007 and IPC 2007, and Publicity Chair of JRS 2007. He was a Guest Editor of AJIT and FGCS Journal, and now he is an EIC of JSE and IJSIA Journal. He researched security engineering, the evaluation of information security products or systems with Common Criteria and the process improvement for security enhancement. In these days, he researches also some approaches and methods making IT systems more secure.