一种基于动态区间减少移动检测延时的方法*

赵庆林+, 李忠诚, 张玉军, 李 军, 王 恺

(中国科学院 计算技术研究所 信息网络室,北京 100080)

A Method for Reducing Movement Detection Delay Based on Dynamic Region

ZHAO Qing-Lin+, LI Zhong-Cheng, ZHANG Yu-Jun, LI Jun, WANG Kai

(Laboratory of Information Network, Institute of Computing Technology, The Chinese Academy of Sciences, Beijing 100080, China)

+ Corresponding author: Phn: +86-10-62565533, Fax: +86-10-62567724, E-mail: zql@ict.ac.cn

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Abstract: In Mobile IP, MN detects its movement according to subnet prefix and router advertisement interval which forms a uniform distribution in the region [min,max]. Therefore, the size of this region has a direct impact on movement detection delay. However, this region is configured statically in Mobile IP, which is inconvenient and inflexible. In this paper, this region is adjusted by using the link bandwidth, and a movement detection delay formula is given. In addition, the proposed method is modeled and analyzed. All the results show that the dynamic region, compared with the fixed region, could reduce the unnecessary movement detection delay drastically.

Key words: handoff process; movement detection; eager cell switching; dynamic region; advertisement interval; renewal process; compound Poisson process

摘 要: 在移动IP中,根据子网前缀以及均匀分布于区间[min,max]上的广告间隙,移动节点检测它自身是否移动.因此,区间的长度对于移动检测延时有直接的影响.然而,在移动 IP 中,区间的静态配置既不方便也不灵活.根据链路带宽的利用率,提出了一种动态调整区间的新方法,并且进行了理论分析.结果显示,与静态区间相比,动态区间的方法显著地减少了不必要的移动检测延时.

关键词: 切换过程;移动检测;热心蜂窝切换;动态区间;广告间隙;更新过程;复合泊松过程

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ZHAO Qing-Lin was born in 1974. He is a Ph.D. candidate at the Institute of Computing Technology, the Chinese Academy of Sciences. His current research areas are wireless communication and mobile networks etc. **LI Zhong-Cheng** was born in 1962. He is a professor and doctoral supervisor at the Institute of Computing Technology, the Chinese Academy of Sciences. His researches areas are computer networks etc. **ZHANG Yu-Jun** was born in 1976. He received the B.S. degree from Nankai University in 1999 and the Ph.D. degree from the Institute of Computing Technology, the Chinese Academy of Sciences in 2004 respectively. His research areas are the next generation Internet protocol, protocol testing and mobile computing etc. **LI Jun** was born in 1974. He is a Ph.D. candidate at the Institute of Computing Technology, the Chinese Academy of Sciences. His current research interests include wireless communication and mobile networks etc. **WANG Kai** was born in 1975. He is a Ph.D. candidate at the Institute of Computing Technology, the Chinese Academy of Sciences. His research areas are network measurement etc.

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1 Introduction

Mobile IP[1,2] is a solution for mobility on the global Internet by IETF. When MN moves from an old Access Router (oAR) to a new Access Router (nAR), it will carry out a handoff which contains three stages: (1) link layer handoff; (2) movement detection; (3) binding update and media redirection, etc. However, the handoff process will cause extraordinary latency, some methods are proposed to reduce the latency, e.g. In Ref.[3], the author proposes a seamless handoff architecture which builds on the top of the hierarchical approach[4], the fast handoff mechanism[5] etc. In this paper, we aims at reducing the movement detection delay.

Movement detection is an important stage during the handoff process. MN detects its movement according to subnet prefix and router advertisement interval. Movement detection delay has a close relationship with router advertisement interval. In Ref.[6], the movement detection delay in the case of period advertisement interval has been analyzed; in Ref.[7], some people analyze it in the case of uniform distribution advertisement interval. However, in Ref.[7], the whole analysis is not strict, which is built on the following “intuition”: (See the explanation in Fig.1.)

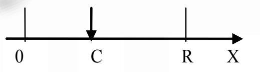

Fig.1 The movement detection model in Ref.[7]

Figure 1 plots the movement detection model in Ref.[7], where C denotes the time at which an MN enters a new link; R denotes the time at which the MN receives the first router advertisement after C; 0 denotes the time at which router sends an advertisement prior to R. The author assumes that the probability that C occurs in an interval is proportional to the length of the interval, which maybe conforms to our intuition, but it is not strict to analyze the movement detection delay based on the intuition. However, this paper will analyze the movement detection delay using the renewal theory. In Ref.[8], the author passively reduces the movement detection delay by making a fast response to router solicitations. However, this paper proposes an active method to reduce it by the current link information.

This paper is organized as follows: In Section 2, we give the basic definitions; in Section 3, we model and analyze movement detection delay based on fixed region; and then, in Section 4, we model and analyze movement detection delay based on dynamic region; in Section 5, the numerical results are illustrated; finally, in Section 6, we give the further research directions and conclude the whole paper.

In this paper, we use concepts in Mobile IPv6, but the result is true for Mobile IPv4.

2 Basic Definitions

Before analyzing the movement detection delay, we firstly give the following definitions.

Movement Detection Delay: the interval from when an MN finishes Layer 2 handoff to when it begins to Layer 3 handoff. It is a random variable. The flag of Layer 3 handoff is that MN sends a binding update message.

In this paper, we only analyze the movement detection delay based on the Eager Cell Switching (ECS) strategy. The basic idea of ECS strategy is that MN should carry out Layer 3 handoff upon receiving a new router advertisement. The detailed description can be found in Ref.[9].

Advertisement Interval: the interval from when an AR sends an advertisement to when it sends the next advertisement. It is a random variable.

Region R: Denoted by $R=[a,b]$.

We call R as a region in order to distinguish with advertisement interval. R is uniquely decided by a and b. In this paper, it is often said that the advertisement interval forms a uniform distribution in region R. In addition, in order to avoid trivial analysis, we assume that the time when an MN enters a new subnet is the time when it has finished Layer 2 handoff. However, it doesn't mean that we neglect the Layer 2 handoff delay.

3 Model and Analysis of Movement Detection Delay Based on Fixed Region

It is suggested in Ref.[10] that the advertisement interval should be a stochastic time in order to prevent long-range periodic transmissions from synchronizing with each other. Furthermore, it is recommended to let the advertisement interval be independent of each other, and form a uniform distribution in the region [min,max]. Unlike the analysis in Ref.[7], in this section, we analyze the ECS strategy in the case of a general stochastic advertisement interval using the renewal theory[11]. If we model each advertisement interval as a random variable, then, we get a stochastic sequence (ξ_n), which should be independent of each other, and identically distributed with the same random variable ξ. In addition, let θ denote the movement detection delay for ECS strategy, then, (ξ_n) is called a renewal process, and θ is called a residual life (See Fig.2.).

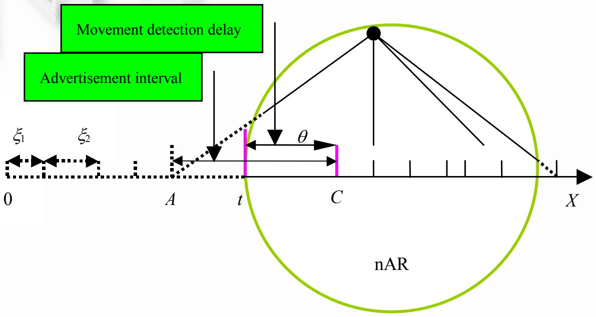

Fig.2 ECS scheme

Figure 1 shows the ECS strategy. At a random time t, an MN enters the nAR; at time C, MN receives the first advertisement from the nFA. The advertisement prior to time C is sent at time A, which is not received by MN because MN does not enter the nFA at time A.

Let $F_\xi(t)$, $E(\xi)$, $D(\xi)$ be the distribution function, mean and variance of ξ, respectively; let $f_\theta(x)$, $E(\theta)$ be the density function and mean of θ, respectively. By Ref.[11], we have

$$f_\theta(x)=\frac{1-F_\xi(x)}{E(\xi)},\ E(\theta)=\frac{E(\xi^2)}{2E(\xi)}=\frac{D(\xi)+E(\xi)^2}{2E(\xi)} \quad (1)$$

Proposition 1. If the advertisement is sent periodically, ξ could be looked as a degenerated distribution with constant a (a>0). By (1), we have:

$$E(\xi)=a,\ D(\xi)=0,\ f_\theta(x)=\begin{cases}1/a, & 0\le x\le a\\ 0, & \text{otherwise}\end{cases},\ E(\theta)=\frac{a}{2} \quad (2)$$

Therefore, θ is a uniform distribution. This conforms to the result in Ref.[6].

Proposition 2. If ξ is a uniform distribution in the region $[a,b]$, by (1), we have

$$E(\xi)=\frac{a+b}{2},\ D(\xi)=\frac{(b-a)^2}{12},\ f_\theta(x)=\begin{cases}u, & 0\le x<a\\ \frac{u(b-x)}{b-a}, & a\le x<b\\ 0, & \text{otherwise}\end{cases},\ E(\theta)=\frac{a^2+b^2+ab}{3(a+b)} \tag{3}$$

By (1), (3), if $E(\xi)$ is fixed, $E(\theta)$ decreases as $D(\xi)$ decreases, which indicates that a lower value of $E(\theta)$ is achieved by letting a and b have values close to each other (See Fig.4). The phenomenon is also observed in Ref.[7]. Specially, if $b=a$, the advertisement is sent periodically, $E(\theta)=a/2$. This also conforms to (2).

Proposition 3. Let ξ_1 denote a degenerated distribution, ξ_2 denote a uniform distribution, ξ_3 denote an exponential distribution, and $E(\xi_1)=E(\xi_2)=E(\xi_3)$, then, by (1), we have $E(\theta_1)<E(\theta_2)<E(\theta_3)$, which indicates the movement detection delay is minimal if adopting a period advertisement interval.

4 Model and Analysis for Movement Detection Based on Dynamic Region

In Mobile IP, MN detects its movement depending on subnet prefix and router advertisement interval which forms a uniform distribution in the region [min,max]. Therefore, the size of this region has a direct impact on movement detection delay. However, this region needs to be configured statically; moreover, it is very difficult to configure a right value for different links (e.g. the advertisement being sent fast will waste limited wireless bandwidth and cause congestion; otherwise, it will add movement detection delay). Therefore, this is inconvenient and inflexible. Contrary to this, in this section, we adapt to the use of link bandwidth to make this region be adjusted dynamically.

Based on the above analysis, we define three regions: region $R_1=[\alpha_1,\beta_1]$: the minimum allowed region; region $R_2=[\alpha_2,\beta_2]$: the middle region; region $R_3=[\alpha_3,\beta_3]$: the maximum allowed region, where $\beta_1-\alpha_1\le\beta_2-\alpha_2\le\beta_3-\alpha_3$. Next, we analyze the following case: the advertisement interval forms a uniform distribution ξ_i in region R_i ($1\le i\le 3$).

Table 1 The notation for movement detection based on dynamic region

C	The original bandwidth for the given link
C_0	The size of router advertisement packet, we regard it as a constant
γ	The adjustment factor.
B_i	The available bandwidth except which consumed by advertisement in region R_i
Y_n	The bandwidth required by an incoming call (new or handoff call)
Y_g	The bandwidth released by a leaving call
N_t	The number of arrival calls at region $[0,t]$
Y_i	The bandwidth consumed by the ith on-going call, Y_i ($1\le i\le N_t$) is IID with Y
X_t	The current total bandwidth consumed by all on-going calls at interval $[0,t]$
$\varphi(s)$	The characteristic function of Y
$\varphi_t(s)$	The characteristic function of X_t
$P_t(k)$	The discrete density function of X_t
ξ_i	The uniform distribution in the region R_i

where IID denote Independent and Identically Distributed. By the definitions of B_i, $\underset{i=1,2}{B_i}=C-\frac{\gamma C_0}{E(\xi_i)}$, $E(\xi_i)=\frac{\alpha_i+\beta_i}{2}$, and set $B_0=0$, $B_3=\infty$ to avoid trivial specification, we have $B_1\le B_2\le B_3$.

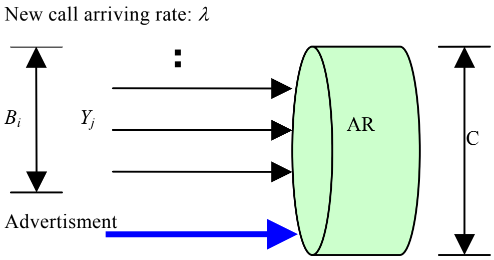

Fig.2 The region adjusted dynamically

By the use of link bandwidth, we propose Region Adjustment Algorithm (RAA):

Let R denote the current region ($1\le i\le 3$, see Table 1 and Fig.3).

When a new or handoff call arrives in the given RA domain, if $B_{i-1}\le X_t+Y_n<B_i$, then $R=R_i$.

When a call leaves from the given RA domain, if $B_{i-1}\le X_t-Y_g<B_i$, then $R=R_i$.

Similar to Section 3, let θ be the movement detection delay based on the dynamic region, by the RAA and the complete mathematical expectation formula, we have

$$E(\theta)=\sum_{i=1}^{3}E(\theta|\xi_i)P(\xi_i)=\sum_{i=1}^{3}\frac{\alpha_i^2+\beta_i^2+\alpha_i\beta_i}{3(\alpha_i+\beta_i)}\left[\sum_{B_{i-1}\le k<B_i}P_t(k)\right] \tag{4}$$

where, by (3), $E(\theta|\xi_i)=\dfrac{\alpha_i^2+\beta_i^2+\alpha_i\beta_i}{3(\alpha_i+\beta_i)}$; by RAA, $P(\xi_i)=P(R=R_i)=P(B_{i-1}<N_t<B_i)=\sum_{B_{i-1}\le k<B_i}P_t(k)$.

Now, we will compute the expression of $P_t(k)$. Similar to Ref.[12], we assume that Y_i ($1\le i\le N_t$) is independent and identically distributed with Y, and let N_t be a Poisson process with parameter λ. It is obvious that: $X_t=\sum_{n=1}^{N_t}Y_n$.

By Ref.[11], X_t is called compound Poisson process, $\varphi_t(s)=e^{\lambda t(\varphi(s)-1)}$. Therefore, by the inversion formula, $P_t(k)=\dfrac{1}{2\pi}\int_{-\pi}^{\pi}e^{-isk}\varphi_t(s)\mathrm{d}s$.

In specialty, we have:

If Y is a degenerated distribution with parameter a, i.e., $P(Y=a)=1$ $(a\in N)$, then $\varphi(s)=e^{isa}$, $\phi_t(s)=e^{\lambda t(e^{isa}-1)}$, we have (Let $N^+=\{0,1,2,...\}$, $j_0\in N^+$):

If $k=aj_0$, then,

$$P_t(k)=P(N_t=k)=\frac{1}{2\pi}\int_{-\pi}^{\pi}e^{-isk}e^{\lambda t(e^{isa}-1)}\mathrm{d}s=e^{-\lambda t}\frac{1}{2\pi}\int_{-\pi}^{\pi}e^{-isk}e^{\lambda te^{isa}}\mathrm{d}s$$

$$=e^{-\lambda t}\frac{1}{2\pi}\int_{-\pi}^{\pi}e^{-isk}\sum_{j=0}^{\infty}\frac{(\lambda te^{isa})^j}{j!}\mathrm{d}s=e^{-\lambda t}\frac{1}{2\pi}\int_{-\pi}^{\pi}\sum_{j=0}^{\infty}\frac{(\lambda t)^j e^{is(aj-k)}}{j!}\mathrm{d}s=e^{-\lambda t}\frac{1}{2\pi}\sum_{j=0}^{\infty}\frac{(\lambda t)^j}{j!}\int_{-\pi}^{\pi}e^{is(aj-k)}\mathrm{d}s$$

$$=e^{-\lambda t}\frac{1}{2\pi}\left[\frac{(\lambda t)^{j_0}}{j_0!}2\pi+\sum_{j\neq j_0}\frac{(\lambda t)^j}{j!}\int_{-\pi}^{\pi}e^{is(aj-k)}\mathrm{d}s\right]=e^{-\lambda t}\frac{(\lambda t)^{j_0}}{j_0!}$$

If $k\neq aj_0$, then $P_t(k)=0$.

Therefore, we have

$$P_t(k)=\begin{cases}e^{-\lambda t}\dfrac{(\lambda t)^{j_0}}{j_0!} & k=aj_0,\ j_0\in N^+\\ 0 & k\neq aj_0, j_0\in N^+\end{cases} \tag{5}$$

If Y is a logarithm distribution, i.e., $P(Y=k)=\dfrac{-q^k}{(k\log p)}, k=1,2,..., p\in(0,1), q=1-p$, then

$$\varphi(s)=\frac{\log(1-qe^{it})}{\log p},\ \phi_\tau(s)=e^{\lambda t(\frac{\log(1-qe^{is})}{\log p}-1)}=e^{\lambda\tau(\frac{\log\frac{(1-qe^{is})}{p}}{\log p})}\overset{\lambda=-r\log p}{=}e^{-r\log pt(\frac{\log\frac{(1-qe^{is})}{p}}{\log p})}=e^{\log(\frac{p}{1-qe^{is}})^{rt}}=\left(\frac{p}{1-qe^{is}}\right)^{rt}$$

It is easy to know: $\phi_\tau(s)$ is the characteristic function of negative binomial distribution. Therefore, X_t is a negative binomial distribution.

$$P_t(k)=\binom{rt+k-1}{k}p^{rt}q^k, k=1,2,...,r=\frac{-\lambda}{\log p}>0, p\in(0,1), q=1-p \tag{6}$$

Because $\underset{i=1,2}{B_i}=C-\dfrac{\gamma C_0}{E(\xi_i)}$, if $C>>\dfrac{\gamma C_0}{E(\xi_i)}$, then $B_1\approx B_2$. By (4), RA can always send fast the router advertisement, which indicates the proposed method have no effect on the link which has plentiful wireless bandwidth.

5 Numerical Results

In Fig.4, $E(\theta)$ is plotted by (3), which is a function of $b-a$ when $b+a$ is fixed. It indicates that we may decrease $E(\theta)$ by letting a and b have values close to each other. In Fig.5, It is plotted by (6); In Fig.6, the curve Fixed Region is plotted by (3), where $a=\alpha_1$, $b=\beta_1$; the curve Dynamic Region is plotted by (4) and (6). It shows that: as λ increases, $E(\theta)$ based on the Dynamic Region increases, while $E(\theta)$ based on the Fixed Region keeps horizontal. This indicates that the proposed method can dynamically adjust the region by using the link bandwidth. When the link is idle, RA sends fast the advertisement, so that MN can early receive the router advertisement; when the link is congested, RA sends slowly the advertisement to avoid further congestion. Therefore, the proposed method can reduce unnecessary movement detection delay.

Table 2 The parameters in Figs.4,5,6

$\alpha1$	$\beta1$	$\alpha2$	$\beta2$	$\alpha3$	$\beta3$
0.04	0.06	0.4	0.6	0.9	1.1
C	$C0$	γ	a	p	C
300	5	1	10	0.03	300

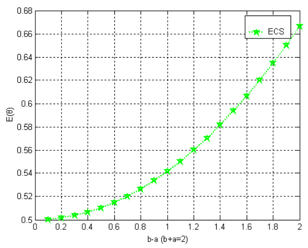

Fig.4 $E(\theta)$ vs. $b-a$

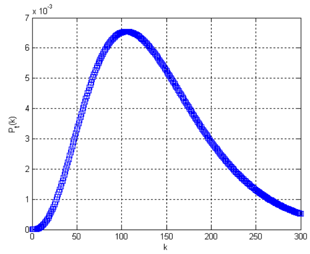

Fig.5 $P_t(k)$ vs. k

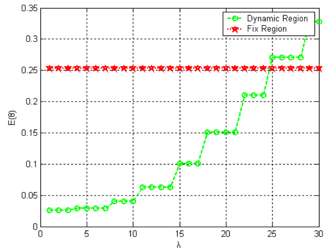

Fig.6 $E(\theta)$ vs. λ

6 Conclusions

In this paper, we model and analyze the movement detection delay in Mobile IP using the renewal theory. Then, aiming at the defection of movement detection algorithm based on the fixed region in Mobile IP, we propose the movement detection algorithm based on the dynamic regions, which could be adjusted automatically by the current link information. The illustration shows the proposed method is better than the one in Mobile IP.

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