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移动 IP 的切换特征分析*

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Characterization of Handoff in Mobile IP

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Abstract: Mobile IP is a simple and scalable global mobility solution. This paper numerically analyzes the characterization of handoff for Mobile IP: the probability distribution about packet loss and packet disorder. By using the result, the radius of overlap region is optimized. The illustrations show that the model precisely reflects the handoff behavior. The probability is very helpful to evaluate the handoff performance.

Key words: mobile IP; cell overlap; packet loss; packet disorder

摘 要: 移动 IP 是一种简单的、可扩展的全球移动管理方案.从理论上分析了移动 IP 的切换特征——分组丢失和分组乱序的概率分布.应用这个结果,优化了重叠区域半径.实例表明,模型准确地刻画了移动 IP 的切换行为.结果对于评价移动 IP 的切换性能非常有用.

关键词: 移动 IP;蜂窝重叠;分组丢失;分组乱序

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1 Introduction

Mobile IP[1,2] is a solution for mobility on the global Internet by IETF. It allows a Mobile Node (MN) to change its point of attachment from an old Access Router (oAR) to a new Access Router (nAR), across media of similar or dissimilar type; and allows Correspondent Node (CN) to send IP packets to the MN transparently. With the help of Mobile IP, people can freely access many different kinds of services in Internet. Although there are many advantages using Mobile IP, its limitations are also very obvious. For example, when MN moves from one place to another, the whole handoff procedure might go with these phenomena, e.g., packet loss, packet disorder, and etc. These phenomena badly affect handoff performance, and they perhaps have some relationships with the following factors: (1) the cell layout, e.g., cell overlap vs. no overlap; (2) the handoff type, e.g., soft handoff vs. hard handoff; (3) the handoff initiation strategies[3], e.g., Eager Cell Switching (ECS) strategy vs. Lazy Cell Switching (LCS) strategy; (4) movement velocity etc.

In the case of no overlap, MN doesn't receive out-of-sequence packets, however, it will suffer packet loss, which can be analyzed according to the handoff delay. In the case of cell overlap, if adopting hard handoff---i.e. , an MN firstly disconnects with oAR before it makes a handoff, this case is similar to no overlap. However, if adopting soft handoff---i.e., MN keeps connections with oAR and nAR simultaneously when it carries out a handoff, this case is especially complicated.

The packet loss also deeply depends on the handoff initiation strategies, e.g., the packet loss might be much less adopting ECS strategy than LCS 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.[3]. Note that for LCS strategy, it is easy to know that the handoff performance in the case of cell overlap is the same to the case of no overlap.

Some research results on performance analysis of Mobile IP can be found in Refs.[4−6] . However, as said in Ref.[7], these results are carried out mostly by simulations. In addition, they pay more attention to the handoff delay than packet loss and packet disorder; moreover, the handoff performance in the case of cell overlap is rarely analyzed.

In this paper, considering that MN carries out soft handoff which adopts ECS strategy, we will model and analyze packet loss and packet disorder. As said in Ref.[8], in the case of Internet access, the average number of these metrics is not very important, and their distributions are much more interesting. Therefore, we try to get the distributions of number of the lost packets and out-of-sequence packets.

This paper is organized as follows: In Section 2, we outline handoff procedure for Mobile IP. Then, in Section 3, we model and analyze packet loss, packet disorder, and get a general expression about their probabilities. In Section 4, by using the results of Section 3, we optimize the radius of overlap region. In Section 5, some illustrations show that our model conforms to our observation perfectly. Finally, Section 6 concludes the paper with some further research directions.

In this paper, we assume that a Cell is equivalent to an AR domain, and use the concepts in Mobile IPv6, but the analysis method and the results are suitable for Mobile IPv4.

2 Handoff Process for Mobile IP

2.1 Basic definitions

Now let us firstly give the basic definitions in order to make the further analysis.

Because there is no buffer and forwarding strategy in basic Mobile IP[1,2], some packets will be lost during the handoff procedure. Therefore, we define:

Number of lost packets: the number of packets resided in oAR, which won't be forwarded to MN due to handoff. It is denoted by **N**.

When MN carries out soft handoff, it will keep connections with oAR and nAR simultaneously. Therefore, there are maybe some intervals in which the packets from nAR arrive at MN more early than the packets from oAR. We call the interval as the interval of packet disorder.

Number of out-of-sequence packets: the number of packets received from oAR during the interval of packet disorder. It is denoted by **W**.

Packet disorder will bring unwanted effects[9]. For example, for TCP congestion control, it creates duplicate ACKs, and invoke unnecessary packets retransmission. Some papers[10,11] have paid attention to it and tried to prevent it.

2.2 Handoff process for mobile IP

Handoff in mobile IP is Layer 3 handoff. When MN moves from one oAR domain(also called one subnet) into one nAR domain, it will carry out a handoff which contains three stages (see Fig.1): (1) link layer handoff; (2) handoff initiation (also called movement detection); (3) binding update and media redirection, etc.

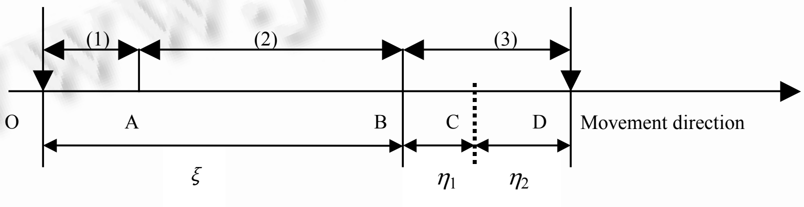

Fig.1 Handoff process for mobile IP

Figure 1 plots the handoff process for Mobile IP. At time O, MN begins to carry out Layer 2 handoff. At time A, MN finishes Layer 2 handoff. After this, MN begins to carry out handoff initiation. At time B, MN sends a binding update message, and begins to carry out location registration. At time C, the binding update message arrives at CN, and after this, packets are redirected to nAR. At time D, MN receives binding update acknowledge message, and finishes the whole handoff process. After this, it may receive packets from nAR. By the definition of A, B, C, D, we can define ξ, η_1 and η_2, where ξ denotes the interval from the time when MN begins to carry out Layer 2 handoff to the time when MN tries to send a binding update message; η_1 denotes the one-way delay from MN to CN; η_2 denotes the one-way delay from CN to MN. Let $f_\xi(x)$, $f_{\eta 1}(y)$, $f_{\eta 2}(z)$ and $f_{\xi,\eta 1,\eta 2}(x,y,z)$ denote the probability density function of ξ, η_1, η_2 and their joint probability density function, respectively, it is obvious that ξ is independent of η_1, η_2.

3 Model and Analysis of Packet Loss in the Case of Cell Overlap

Assume that MN moves from oAR to nAR along fairly straight lines, and it always can receive the advertisements and packets from oAR and nAR when it resides in the overlap region, see Fig.2.

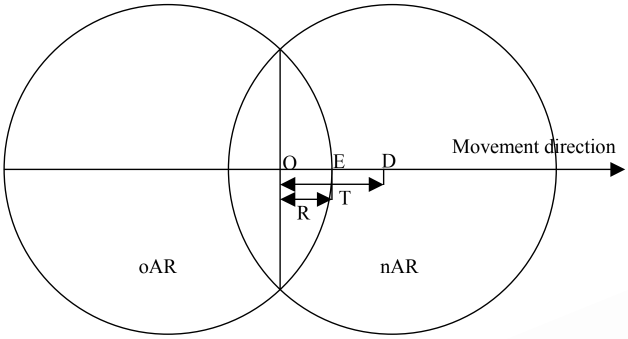

Fig.2 The case of cell overlap

Figure 2 plots the case of cell overlap. At time *O*, *MN* begins to carry out Layer 2 handoff. At time *E*, *MN* moves out of the overlap region. At time *D*, *MN* receives the first packet from nAR. By Section 2.2, we have $T=\xi+\eta_1+\eta_2$. Let *R* denote the distance between *O* and *E*, which is called the radius of overlap region, *V* denote the movement velocity of *MN*, and set $M1=R/V$, then, it denotes the interval from the time when *MN* begins to carry out Layer 2 handoff to the time when *MN* moves out of the overlap region; let V_{CN} denote the packets sending velocity for *CN*, V_{MN} denote the packets receiving velocity for MN, and set $M2=\gamma S$, $\gamma=V_{CN}/V_{MN}$, $S=\xi+\eta$ (In this paper, we only analyze the case of $\gamma \geq 1$), then, it denotes the interval from the time when *MN* begins to carry out Layer 2 handoff to the time when *MN* receives all packets resided in oAR if possible. Let time *O* be the origin point, by the definitions of *T*, *M*1, *M*2, we have the following six cases.

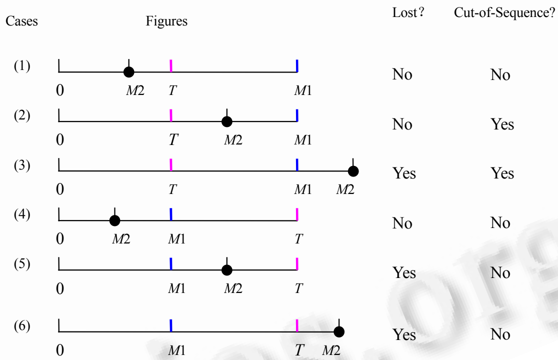

Fig.3 The six cases in cell overlap

Figure 3 reflects that packet loss and packet disorder change as *T*, *M*1, *M*2 change. For example, in the 6th case of *M*2>*T*>M1, *T*>*M*1 means that, in the overlap region, MN couldn't receive any packet from nAR; *M*2>*M*1 means that, when *MN* moves out of the overlap region, some packets resided in oAR still aren't forward to *MN*. They must be lost because there is no buffer and forwarding strategy in the basic Mobile IP[1,2]; *M*2>*T* means that, when *MN* receives the first packet from nAR, packet forwarding from oAR to MN still doesn't end if *MN* could receive all packets resided in oAR. Therefore, *MN* will not receive any out-of-sequence packets, but the handoff causes packet loss. When the overlap region is small and $E(\xi)$ is large, the 6th case will happen. From Fig.3, we have:

$$N=\begin{cases}0, & T<M1,M2<T\\ 0, & T<M1,M2>T,M2<M1\\ SV_{CN}-M1V_{MN}, & T<M1,M2>T,M2>M1\\ 0, & T>M1,M2<M1\\ SV_{CN}-M1V_{MN}, & T>M1,M2>M1,T>M2\\ SV_{CN}-M1V_{MN}, & T>M1,M2>M1,M2>T\end{cases},\quad W=\begin{cases}0, & T<M1,M2<T\\ (M2-T)V_{MN}, & T<M1,M2>T,M2<M1\\ (M1-T)V_{MN}, & T<M1,M2>T,M2>M1\\ 0, & T>M1,M2<M1\\ 0, & T>M1,M2>M1,T>M2\\ 0, & T>M1,M2>M1,M2>T\end{cases}$$

3.1 Packet loss

By the expression of N, the distribution of N is

$$P(N<t)=P(SV_{CN}-M1V_{MN}<t,M2>M1>T)+P(SV_{CN}-M1V_{MN}<t,T>M2>M1)$$

$$+P(SV_{CN}-M1V_{MN}<t,M2>T>M1)=P(SV_{CN}-M1V_{MN}<t,M2>M1>T)$$

$$+P(SV_{CN}-M1V_{MN}<t,T>M1,M2>M1)=A+B$$

$$A=\iiint\limits_{\substack{SV_{CN}-M1V_{MN}<t\\ x+y+z<M1\\ \gamma(x+y)>M1}} f_{\xi,\eta_1,\eta_2}(x,y,z)\mathrm{d}x\mathrm{d}y\mathrm{d}z\quad B=\iiint\limits_{\substack{SV_{CN}-M1V_{MN}<t\\ x+y+z>M1\\ \gamma(x+y)>M1}} f_{\xi,\eta_1,\eta_2}(x,y,z)\mathrm{d}x\mathrm{d}y\mathrm{d}z$$

$$A=\begin{cases}\iint\limits_{S_{12}}[\int_0^{M1-(x+y)} f_{\xi,\eta_1,\eta_2}(x,y,z)\mathrm{d}z]\mathrm{d}x\mathrm{d}y, & \dfrac{M1}{\gamma}+\dfrac{t}{V_{CN}}\le M1\\ \iint\limits_{S_{22}}[\int_0^{M1-(x+y)} f_{\xi,\eta_1,\eta_2}(x,y,z)\mathrm{d}z]\mathrm{d}x\mathrm{d}y, & \dfrac{M1}{\gamma}+\dfrac{t}{V_{CN}}>M1\end{cases}$$

$$B=\begin{cases}\iint\limits_{S_{12}}\left[\int_{M1-(x+y)}^{\infty} f_{\xi,\eta_1,\eta_2}(x,y,z)\mathrm{d}z\right]\mathrm{d}x\mathrm{d}y, & \dfrac{M1}{\gamma}+\dfrac{t}{V_{CN}}\le M1\\ \iint\limits_{S_{22}}\left[\int_{M1-(x+y)}^{\infty} f_{\xi,\eta_1,\eta_2}(x,y,z)\mathrm{d}z\right]\mathrm{d}x\mathrm{d}y+\iint\limits_{S_{23}}\left[\int_0^{\infty} f_{\xi,\eta_1,\eta_2}(x,y,z)\mathrm{d}z\right]\mathrm{d}x\mathrm{d}y, & \dfrac{M1}{\gamma}+\dfrac{t}{V_{CN}}>M1\end{cases}$$

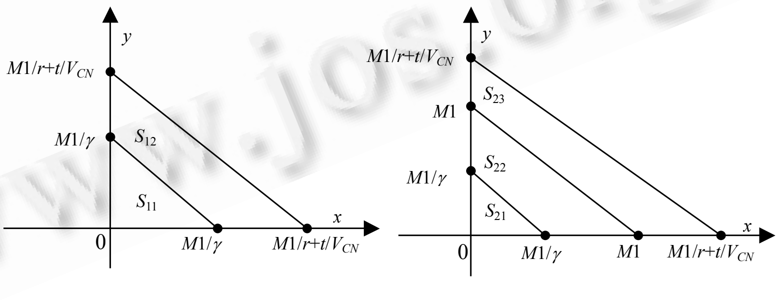

Fig.4

In the case of no overlap, we have $N=(\xi+\eta_1)V_{CN}$, then $P(N<t)=P((\xi+\eta_1)V_{CN}<t)=\dfrac{1}{V_{CN}}\int_0^t f_{\xi+\eta_1}(\dfrac{\tau}{V_{CN}})\mathrm{d}\tau$, where $f_{\xi+\eta_1}(t)$ is the probability density function of $\xi+\eta_1$.

3.2 Out-of-Sequence packets

Similarly, the distribution of W is $P(W<t)=P((M2-T)V_{MN}<t,T<M2<M1)+P((M1-T)V_{MN}<t,T<M1<M2)$.

Obviously, we may analyze the probability about the number of out-of-sequence packets similarly, here we omit it.

Because ξ is independent of η_1, η_2, if we further assume that η_1 is independent of η_2, then ξ, η_1, η_2 are independent. Therefore, $f_{\xi,\eta_1,\eta_2}(x,y,z)=f_\xi(x)f_{\eta_1}(y)f_{\eta_2}(z)$, $f_{\xi+\eta_1}(t)=f_\xi(x)*f_{\eta_1}(y)$ (i.e. $f_{\xi+\eta_1}(t)$ is the integral convolution of $f_\xi(x)$, $f_{\eta_1}(y)$), then it is easy to get $P(N<t)$, $P(W<t)$.

One general distribution, which is often used in many applications[7,12], is the Gamma distribution $\Gamma(\alpha,\beta)$, whose density function is given as follows: $f(t)=\dfrac{\beta^\alpha t^{\alpha-1}}{\Gamma(\alpha)}e^{-\beta t}$, $\alpha>0, \beta>0$, where α is the shape parameter, and $\Gamma(\alpha)$ is the Gamma function. In Ref.[13], the one-way delay distribution shows Gamma-like shape.

In Sections 4, 5, we will give some illustrations based on the following assumptions:

η_1,η_2 are independent for each other.

$\Gamma(\alpha_1,\beta 1)$, $\Gamma(\alpha_2,\beta_2)$, $\Gamma(\alpha_3,\beta_3)$ are the distribution functions of ξ, η_1, η_2, respectively.

4 Optimal Radius of Overlap Region

In this section, we give an example of optimizing the radius of overlap region.

Let E_N, E_W denote the mean number of lost packets and out-of-sequence packets respectively, then $E_N=\int_{-\infty}^{-\infty} tdP(N<t)$, $E_W=\int_{-\infty}^{-\infty} tdP(W<t)$. We want to find an optimal R such that E_N and E_W are as small as possible. For example, by the parameters in Table 1.

Table 1 The parameters to optimize the radius of overlap region

1. α_1	1. β_1	1. α_2	1. β_2	1. α_3	1. β_3	1. V_{CN}	1. V_{MN}	1. V
2. 1	2. 1/20	2. 1	2. 1.2	2. 1	2. 1	2. 1.2	2. 1	2. 1

$$E_N(R)=\frac{1}{23}exp(-R)\left(-1+576exp\left(\frac{23}{24}R\right)\right), \frac{dE_N(R)}{dR}<0$$

$$E_W(R)=\frac{25}{138}exp\left(-\frac{6}{5}R\right)-\frac{36}{161}exp\left(-\frac{7}{6}R\right)+\frac{1}{23}exp(-R)+\frac{9600}{437}exp\left(-\frac{1}{20}R\right)$$
$$-\frac{576}{2185}exp\left(-\frac{5}{24}R\right)-\frac{576}{23}exp\left(-\frac{1}{24}R\right)+\frac{237}{70}, \frac{dE_W(R)}{dR}>0$$

It means that $E_N(R)$ decreases and $E_W(R)$ increases when R increases. Therefore, there exists an optimal R, such that $E_N(R)$ and $E_W(R)$are as small as possible (See Fig.11).

5 Numerical Results

In the following figures, we mark packet loss, packet disorder in the case of cell overlap as loss, disorder, respectively, mark packet loss in the case of no overlap as loss1, and mark the corresponding probability in Fig.3 as $p1$, $p2$, $p3$, $p4$, $p5$, $p6$, respectively, where $p1=P(M1>T>M2)$, $p2=P(M1>M2>T)$, $p3=P(M2>M1>T)$, $p4=P(T>M1>M2)$, $p5=P(T>M2>M1)$, $p6=P(M2>T>M1)$. Similar to Section 3, it is easy to compute them (here we omit it). In the following figures, Figs.5, 6, 8, and 9 are plotted by the expressions of $P(N<t)$, $P(W<t)$ in Section 3 and the parameters in Table 2; Figs.7 and 10 are plotted by $pi(1\le i\le 6)$ and the parameters in Table 2.

Table 2 The parameters in Figs.5,6,7,8,9,10

1. β_1	1. α_2	1. β_2	1. α_3	1. β_3	1.V_{CN}	1.V_{MN}	1.V
2. 2	2. 1	2. 2	2. 1	2. 2	2. 1.2	2. 1	2. 1

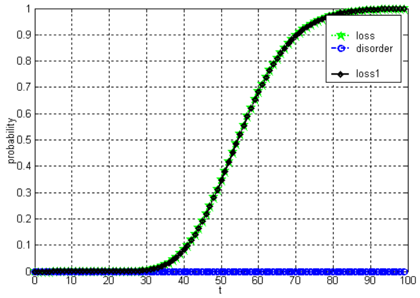

Fig.5

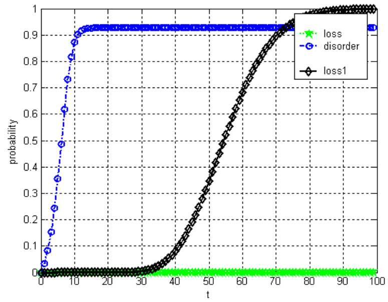

Fig.6

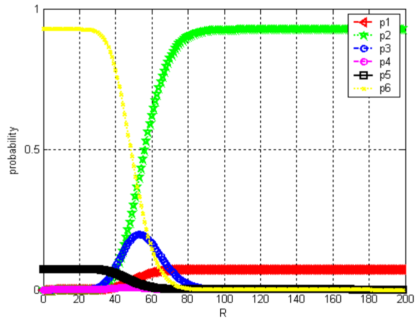

Fig.7

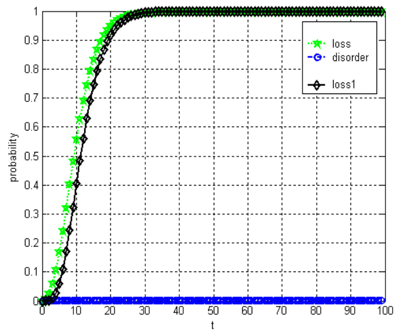

Fig.8

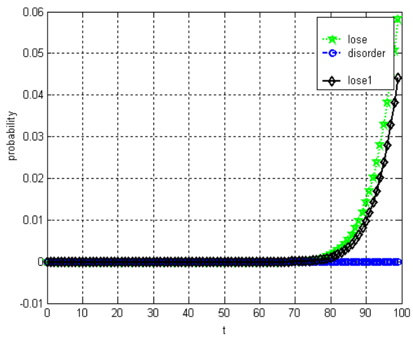

Fig.9

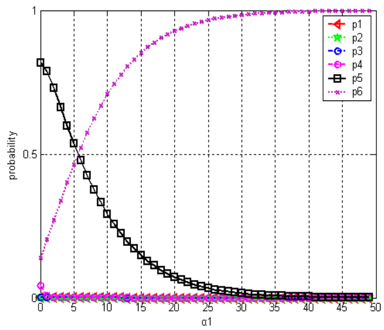

Fig.10

Figure 5 plots the case of R=0.00002, α_1=20, Figure 6 plots the case of R=200, α_1=20. Figure 7 plots when R change, how $pi(1\le i\le 6)$ Changes, where α_1=20. Figure 5 shows curve loss and loss1 almost overlap. There are almost no out-of-sequence packets. The reason is that the cells have almost no overlap, therefore, the thing in the case of cell overlap is similar to the one in the case of no overlap. It is explained in Fig.7, under this condition, the 6th case in Fig.3 happens at the biggest probability. Figure 6 shows when the radius of overlap region is large enough, the probability about number of the lost packets is almost 0; At the same time, packet disorder appears at a higher probability. It is explained in Fig.7 that under this condition, the 2nd case in Fig.3 happens at the biggest probability. Figures 5 and 6 show the two extreme cases. These illustrations show that the model has conformed to our observation perfectly.

Figure 8 plots the case of α_1=2, R=2. Figure 9 plots the case of α_1=50, R=2. Figure 10 plots when α_1 changes, how $pi(1\le i\le 6)$ changes, where R=2. Because $E(\xi)=\beta_1\alpha_1$ (where $E(\xi)$ denotes the mean value of ξ), Figures.8 and 9 show the probability change as $E(\xi)$ changes, which indicates that the number of the lost packets increases rapidly as $E(\xi)$ increases for both cell overlap and no overlap; it is explained in Fig.10 that in the case of cell overlap, when $E(\xi)$ is small, the 5th case in Fig.3 happens at the biggest probability. When $E(\xi)$ is large, the 6th case in Fig.3 happens at the biggest probability. Therefore, Fig.9 shows the number of the lost packets is bigger than the one in Fig.8. The explanations also conform to our observation perfectly. In Fig.9, it is also observed that $P(N>100)$ in the case of no overlap is higher than the one in the case of cell overlap.

In Fig.11**,** it is plotted by the expressions of $E_N(R)$, $E_W(R)$ in Section 4, It shows that $E_N(R)$ decreases and $E_W(R)$ increases as R increases, which indicates that there exists an optimal R. From Fig.11, we know that the case R=60 is more rational.

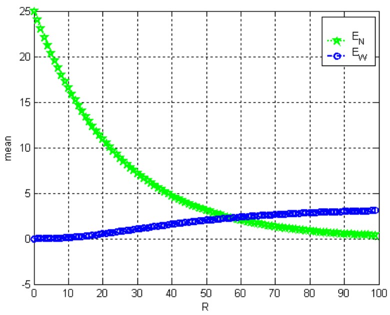

Fig.11

6 Conclusions

In this paper, we model and analyze packet loss and packet disorder in the case of cell overlap and no overlap for the first time, and get the general expressions about their probabilities, which are the most important and basic information to understand handoff performance. In addition, using these results, we can further analyze the size of buffers in AR, and optimize the radius of overlap region etc. In the future, we will further study on the performance for fast handoff[14].

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