Delaying Inter-tier Handover in Hierarchical Networks

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Abstract

In hierarchical network where a macro cell includes multiple small scale cells such as micro, femto cells and Wi-Fi hot-spots, preventing unnecessary handover is one of the most important matters due to so many inter-tier handovers. From the observation that there are many temporary visitors who stay in a small scale cell with short residence time, some recent handover schemes propose to delay the handover from macro to small scale cell to prevent unnecessary handovers made by those temporary visitors. Using such a conservative admission policy, we can prevent temporary visitor being handed over to small cell so that the number of inter-tier handovers can be significantly decreased. As a new concern of performance, we analyze the negative side effect of delayed handover scheme by using the theory of probability. Based on the analysis, we present some insights to determine the proper delay parameter to minimize the negative side effect probability.

Keywords: *reducing unnecessary handovers, hierarchical network, temporary visitor, short residence time, delaying handover*

1. Introduction

Currently, many ISPs (Internet Service Providers) are rushing to deploy hierarchical network where a macro cell includes multiple small scale cells such as micro, femto cells and Wi-Fi hotspot [11-13]. In the hierarchical network, macro-embedded small scale cells provide spatially separated concurrent channel access so that the overall communication capacity can be significantly enhanced compared to traditional macro cell only system [1]. However the signaling overhead also increases with respect to the number of macro-embedded small scale cells. Especially, frequent macro ↔ small scale cell handovers may cause a large burden to the macro cell base station. Therefore, it is more important to reduce unnecessary handovers in hierarchical cellular system than in conventional macro cell only system [14].

Traditionally, the unnecessary handover is referred as *ping-pong effect* where mobile device is handed back and forth several times from one base station to the other base station during few hundred milliseconds [2]. However, for small scale cellular systems, it is required to use the term "*unnecessary handover*" in the broader definition than

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before. According to the measurement results in [3], more than 50% and 70% of small scale cellular system user reside in a cell for less than 3 and 10 seconds respectively. In short, there are many *temporary visitors* who are connected to small scale cell with short residence time. Based on this observation, we recognize macro→small scale cell handovers made by such *temporary visitors* also as *unnecessary handover* [14].

To handle *unnecessary handover* problem caused by *temporary visitors* of small scale cell, recent handover decision schemes propose to delay macro → small scale cell handover until pre-determined delay parameter d [4-7]. In the delayed handover, when the user comes into the small scale cell, the system does not start macro → small cell handover immediately. Rather, it makes a reservation for the handover process at after d seconds later. If the user comes back out of the small scale cell, the reservation is automatically canceled. By this intended hesitation, we can effectively prevent *unnecessary handover* made by temporary visitors [14].

In the delayed handover policy, one of the most important thing is to set delay parameter d properly. If delay parameter is too short, *unnecessary handovers* are not avoided well. Conversely, if delay parameter is too long, the system prevents not only unnecessary handover, but also necessary handovers made by long residence time users. Hence, we define a new performance concern referred as the *negative side effect* of delayed handover which is useful to balance the above trade-offs. Using the theory of probability, we analyze the relationship between the *negative side effect* and residence time distributions of small cell visitors. Based on the analysis, we present a method to determine the proper delay parameter to minimize the *negative side effect* probability. Our numerical results show that the number of macro → small scale cell handover can be significantly reduced by delaying handover process just a few seconds while the *negative side effect* probability is still small.

The remaining part of this paper is as followings: In Section 2, we explain delayed handover protocol and present the method to determine the proper delay parameter. Then, in Section 3, numerical results are discussed. Finally, we conclude in Section 4.

2. Delaying Macro → Small Scale Cell Handover

2.1. Problem Definition [14]

As we discussed in section 1, we refer temporary visitor as the mobile user who stays in a small scale cell with short residence time. The exact criterion of temporary visitor may be different for administration policy and visiting pattern of system. Here, we use a threshold time t_{Th} as a discriminant of temporary visitor. In our definition, the small scale cell user is temporary visitor if the connection holding time t_C is shorter than t_{Th}.

$$0 < t_C < t_{Th} \tag{1}$$

Our goal is to design a handover decision algorithm to prevent unnecessary handovers meeting the above condition as many as possible.

2.2. Delayed Handover: From the Protocol Perspective

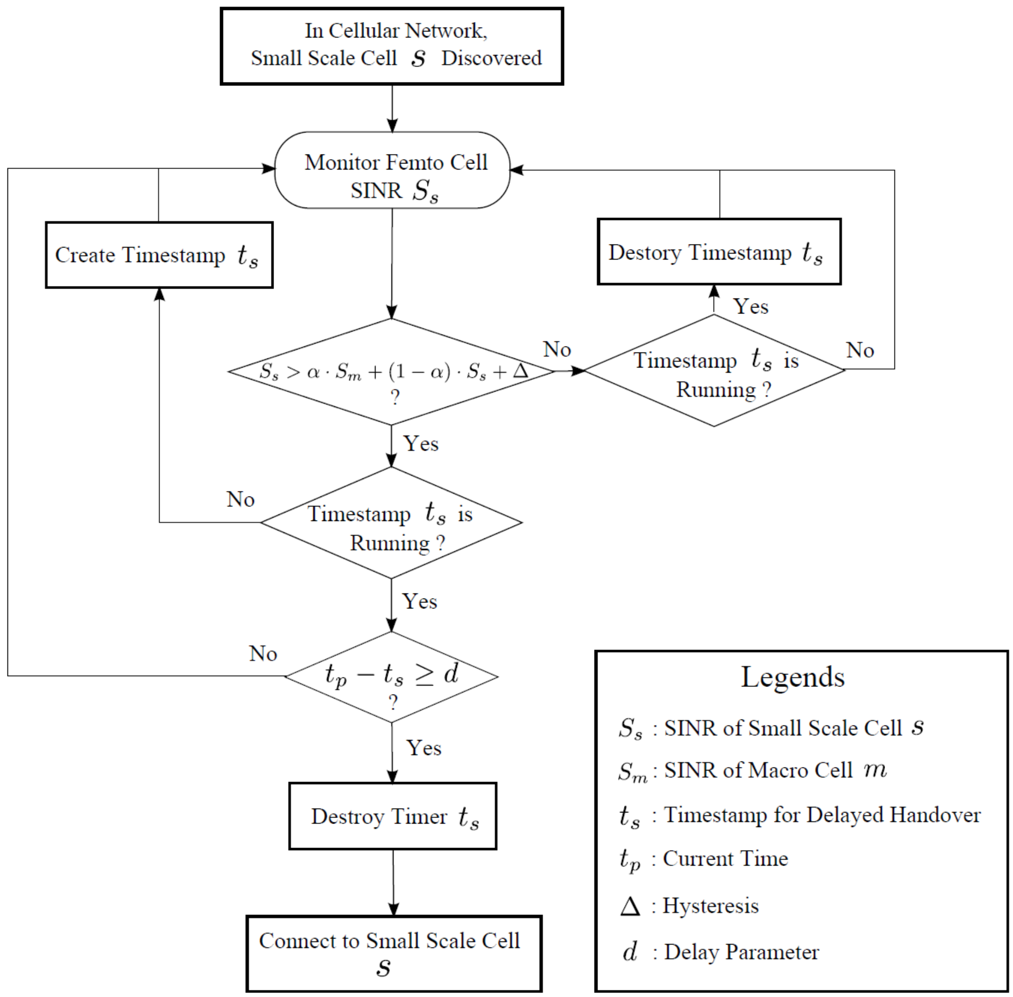


Figure 1. Flow Chart of Delayed Handover Scheme

From the protocol perspective, delayed handover scheme is a slightly augmented version of conventional handover decision scheme. The conventional scheme decides to conduct handover or not by checking the handover criterion about SINR (Signal-to-Interference-Noise-Ratio) and hysteresis to avoid ping-pong effects [2]. For example, *Moon et al* uses the following criterion for macro → small scale cell handover [8]:

$$S_S > \alpha \cdot S_m + (1-\alpha) \cdot S_S + \Delta, (0 \leq \alpha \leq 1) \quad (2)$$

where S_m and S_S are the SINR of the macro and small scale cell respectively, α is a combination factor, and Δ is the hysteresis.[2] Traditional handover decision scheme may start the macro → small scale cell handover immediately when the criterion is satisfied.

[2] We do not have to use eq. (2) for every case. Other types of criterion can be used according to the network characteristics and administration policy. For instance, we can use the criterion especially designed to enhance the utilization rate of hierarchical cellular systems by *Lee et al* [9].

Unlike them, delayed handover scheme suspends the handover process for until delay time d is elapsed. This approach is widely adopted by various macro → small scale cell handover decision algorithms for hierarchical macro-femto cell networks [4-7]. Figure 1 depicts the delayed handover scheme using a flow chart.

2.3. Determining Proper Delay Parameter

Delayed handover can cause the negative side effect depending on the cell residence time of user. Let us assume that both of t_{Th} and d are 5 seconds. If the user's cell residence time t_R is 7 seconds, the actual connection time of the user is just 2 seconds under the delayed handover ($t_C = t_R - d = 2 \leq t_{Th}$). In this example, the user is handed over to the small cell since t_R is longer than d. However his/her actual connection time becomes shorter than the threshold t_{Th} due to the delayed association. In short, it is better not to use delayed handover. We referred this situation as the *negative side effect* of delayed handover.

From the above explanation, we can see that delay parameter d must be decided to minimize the occurrences of the negative side effect. Based on our observation, the size relationship among t_R, t_C, d and t_{Th} determines whether the negative side effect occurs or not. We analyze when the negative side effect occurs according to the relationships as followings:

Case 1 (when $t_R < d \leq t_{Th} < d + t_{Th}$): Handover is not performed due to $d > t_R$. Since t_R is less than t_{Th}, the user is a temporary visitor. In this case, the delayed handover results in a proper prevention of unnecessary handover.

Case 2 (when $d < t_R < t_{Th} < d + t_{Th}$): Handover is performed due to $d < t_R$. However, the user becomes temporary visitor because $t_R < d + t_{Th}$ which is equivalent to $t_C = t_R - d < t_{Th}$. Although, handover is done, the user becomes a temporary visitor. This is an obviously negative side effect of the delayed handover.

Case 3 (when $d \leq t_{Th} \leq t_R < d + t_{Th}$): Handover is performed due to $d \leq t_R$. However, the user becomes temporary visitor because $t_R < d + t_{Th}$. This is the same situation as in the case 2. Hence, negative side effect occurs.

Case 4 (when $d \leq t_{Th} < d + t_{Th} < t_R$): Handover is occurred due to $d < t_R$. The user does not become temporary visitor because $t_R > d + t_{Th}$ which is equivalent to $t_C = t_R - d \geq t_{Th}$. This is a proper handover.

Case 5 (when $t_R < t_{Th} < d < d + t_{Th}$): Handover is not performed due to $d > t_R$. And, t_R is less than t_{Th}. This case is the same situation as in the case 1, a proper prevention of unnecessary handover.

Case 6 (when $t_{Th} \leq t_R < d < d + t_{Th}$): Handover is not performed due to $d > t_R$. However, if the handover starts as soon as the user comes into the femto cell, t_C will be greater than t_{Th}. Hence, the delayed handover results in an improper prevention of necessary handover.

Case 7 (when $t_{Th} < d \leq t_R < d + t_{Th}$): Handover is performed due to $d \leq t_R$. However the user becomes temporary visitor because $t_R < d + t_{Th}$. This is the same situation as in the case 2. Negative side effect occurs.

Case 8 (when $t_{Th} < d < d + t_{Th} \le t_R$): Handover is performed due to $d < t_R$. The user does not become temporary visitor because $t_R \ge d + t_{Th}$. This is a proper handover as in the case 4.

Among above 8 cases, negative side effect is occurred when the case 2, 3, 6, and 7. The next thing we have to do is to calculate the probability with those cases. We exploit the cell residence time distribution function which is one of the most representative mathematical tools of mobility analysis for network systems. Let us denote the probability of negative side effect occurrence as $Pr_{t_{Th},d}[Negative\ Side\ Effect]$. It is the sum of the probability of the case 2, 3, 6, and 7.

$$Pr_{t_{Th},d}[Negative\ Side\ Effect] =$$

$$\begin{cases} Pr[d \le t_R < t_{Th} < d + t_{Th}] + Pr[d \le t_{Th} < t_R < d + t_{Th}], d \le t_{Th} \\ Pr[t_{Th} \le t_R < d < d + t_{Th}] + Pr[t_{Th} < d \le t_R < d + t_{Th}], d > t_{Th} \end{cases} =$$

$$\begin{cases} Pr[d \le t_R < d + t_{Th}], d \le t_{Th} \\ Pr[t_{Th} \le t_R < d + t_{Th}], d > t_{Th} \end{cases} \quad (3)$$

As seen in the above equations, the probability of the negative side effect can be directly calculated using the pdf (probability density function) of t_R. When t_{Th} is given as a constant, proper delay parameter must be determined as following minimization problem:

$$\arg\min_d Pr_{t_{Th},d}[Negative\ Side\ Effect] \quad (4)$$

Here, observing eq. (3) and (4), we find the proper delay parameter must be equal to or smaller than t_{Th}. We describe such a property as following theorem.

Theorem 1. *For an arbitrary probability density function of t_R, the proper delay parameter for eq. (4) cannot be higher than t_{Th}.*

Proof. we make the proof by showing eq. (3) is always smaller when $d = t_{Th}$ than when $d > t_{Th}$. Firstly, when $d = t_{Th}$, eq. (3) is expressed as

$$Pr_{t_{Th},t_{Th}}[Negative\ Side\ Effect] = \int_{t_{Th}}^{2t_{Th}} f_{t_R}(t)dt. \quad (5)$$

On the other hands, if $d > t_{Th}$, then $d = t_{Th} + \delta$ ($0 < \delta < \infty$). We have

$$Pr_{t_{Th},t_{Th}+\delta}[Negative\ Side\ Effect] = \int_{t_{Th}}^{2t_{Th}+\delta} f_{t_R}(t)dt. \quad (6)$$

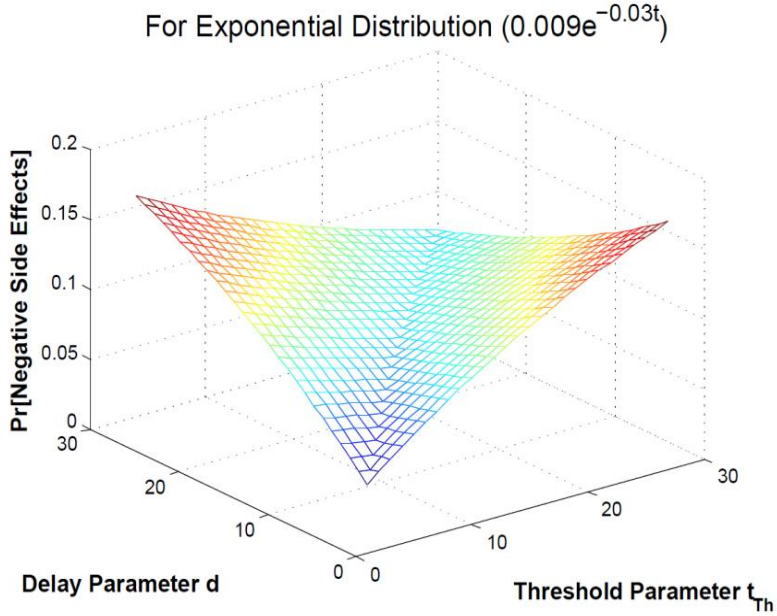
Since eq. (5) is always smaller than (6), the solution of eq. (4) should not be higher than t_{Th}. □

Theorem 1 means that we do not have to consider the case of $d > t_{Th}$ for solving eq. (4). Thereby, we can rewrite eq. (4) as

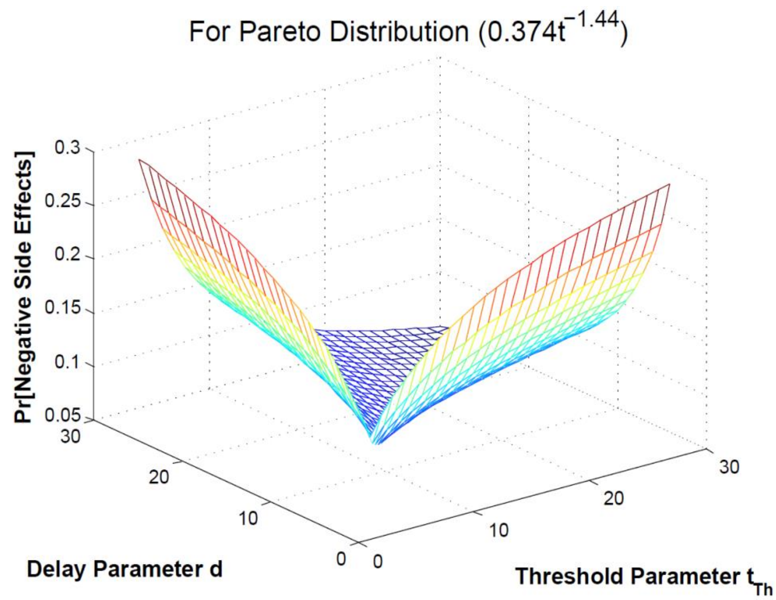
$$\arg\min_d Pr_{t_{Th},d}[Negative\ Side\ Effect] = \int_d^{t_{Th}+d} f_{t_R}(t)dt, (d \le t_{Th}). \quad (7)$$

When t_{Th} is given, eq. (7) can be easily solved by well-known numerical minimization methods so that the proper delay parameter is obtained [10].

3. Numerical Evaluations



(a)



(b)

Figure 2. Negative Side Effect Probability to respect with t_{Th} and d

We conduct numerical experiments using cell residence time distribution functions introduced by *Thajchayapong* et al [3]. They derive two distribution functions from the measurement data in the microcellular network at *Carnegie Mellon University*. The functions are expressed as followings:

$$\textbf{Exponential Distribution: } 0.009e^{-0.03t}, (t > 4) \quad (8)$$

$$\textbf{Pareto Distribution: } 0.374t^{-1.44}, (t > 4) \quad (9)$$

Figure 2 (a) and (b) show the negative side effect probabilities according to t_{Th} and d for eq. (8) and (9). Here, the most notable things is that when $d = t_{Th}$, the negative side effect probability is minimized for both of eq. (8) and (9). This is because both of them are the monotonic decreasing function. We explain such a property as following theorem:

Theorem 2. *When the pdf of t_R ($f_{t_R}(t)$) is monotonic decreasing function, the proper parameter to minimize eq. (7) is t_{Th}.*

Proof. For an arbitrary monotonic decreasing pdf, when $d = t_{Th}$, the negative side effect probability is expressed as

$$Pr_{t_{Th},t_{Th}}[Negative\ Side\ Effect] = \int_{t_{Th}}^{2t_{Th}} f_{t_R}(t)dt. \quad (10)$$

If $d < t_{Th}$, then $d = t_{Th} - \delta$ ($0 < \delta < t_{Th}$), we have

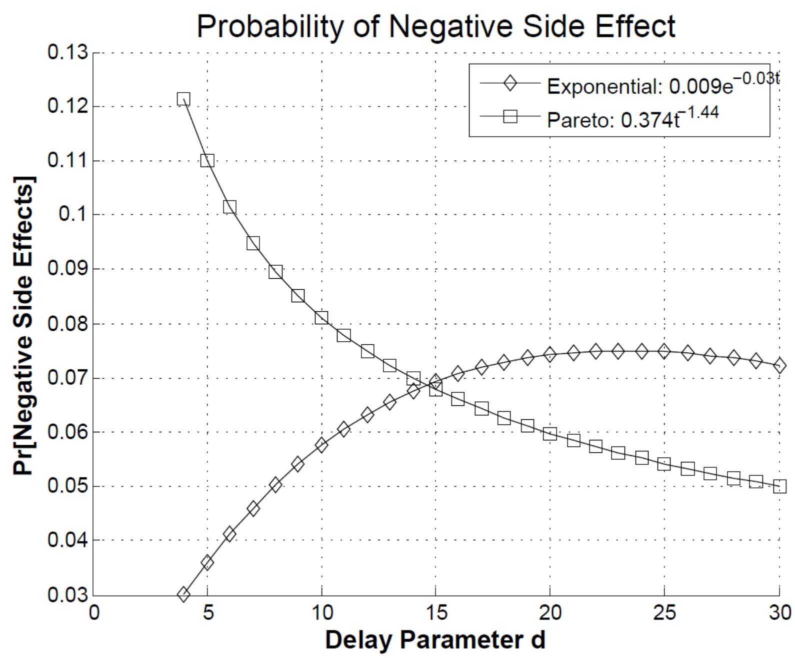
$$Pr_{t_{Th},t_{Th}-\delta}[Negative\ Side\ Effect] = \int_{t_{Th}-\delta}^{2t_{Th}-\delta} f_{t_R}(t)dt. \quad (11)$$

From the property of integral, we obtain

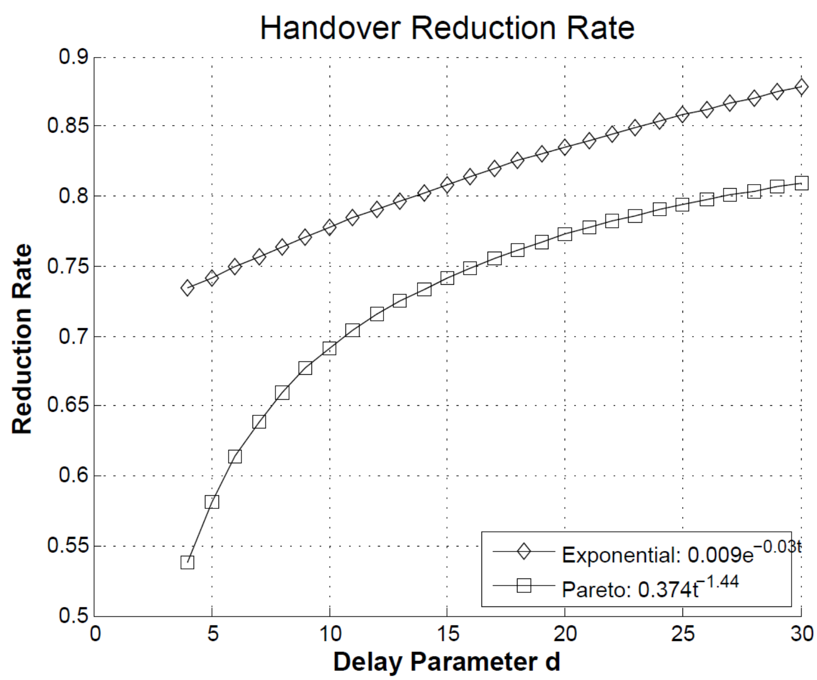
$$\begin{aligned} &Pr_{t_{Th},t_{Th}-\delta}[Negative\ Side\ Effect] \\ &= \int_{t_{Th}-\delta}^{t_{Th}} f_{t_R}(t)dt + \int_{t_{Th}}^{2t_{Th}} f_{t_R}(t)dt - \int_{2t_{Th}-\delta}^{2t_{Th}} f_{t_R}(t)dt \\ &= \int_{t_{Th}}^{2t_{Th}} f_{t_R}(t)dt + \int_{t_{Th}-\delta}^{t_{Th}} f_{t_R}(t)dt - \int_{2t_{Th}-\delta}^{2t_{Th}} f_{t_R}(t)dt \\ &= Pr_{t_{Th},t_{Th}}[Negative\ Side\ Effect] + \int_{t_{Th}}^{2t_{Th}} f_{t_R}(t)dt - \int_{2t_{Th}-\delta}^{2t_{Th}} f_{t_R}(t)dt. \end{aligned} \quad (12)$$

If $f_{t_R}(t)$ is a monotonic decreasing function, it is obvious that $\int_{t_{Th}-\delta}^{t_{Th}} f_{t_R}(t)dt - \int_{2t_{Th}-\delta}^{2t_{Th}} f_{t_R}(t)dt > 0$ due to $t_{Th} - \delta < t_{Th} < 2t_{Th} - \delta < 2t_{Th}$. Thus, eq. (10) is always larger than eq. (11) when $f_{t_R}(t)$ is a monotonic decreasing function. □

Theorem 2 shows that we may not have to solve eq. (10) any more when the probability distribution of the user residence time monotonically decreases. Generally, many types of probability distribution functions monotonically decrease respect with its total or partial domain. Considering that, Theorem 2 shows an useful property in determining the proper delay parameter d.



(a)



(b)

Figure 3. Negative Side Effect Probability and Reduction Rate to respect d

Aside from the negative side effect, we also conduct evaluations about handover reduction rate according to delay parameter. Considering that the delayed handover scheme prevents the where $t_R < d$, the handover reduction rate is calculated by

$$\int_d^\infty f_{t_R}(t)dt = 1 - \int_0^d f_{t_R}(t)dt. \quad (13)$$

Figure 3 (a) shows side effect probabilities for eq. (8) and (9) respectively for $d = t_{Th}$. In both cases, the probability of the negative side effect is less than 10% for $t \geq 6$. This shows that delayed handover has side effects with a relatively low probability. Figure 3 (b) shows the handover reduction rate for eq. (8) and (9). When delay parameter is 10 seconds, we can reduce the number of handover by more 70% compared to immediate handover.

4. Conclusion

In this paper, we discuss to delay macro → small scale cell handovers for a few seconds to prevent unnecessary handovers made by temporary small scale cell visitors. As a new concern of performance matter, we analyze the negative side effect of delayed handover. Based on the analysis we provide some insights on how we determine the proper delay parameter to avoid the negative side effect as many as possible.

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References

[1] V. Chandrasekhar, J. Andrews and A. Gatherer, “Femtocell Networks: A Survey”, IEEE Commun. Mag. vol. 46, no. 9, **(2008)**, pp. 59-67.
[2] G. P. Pollini, “Trends in Handover Design”, IEEE Commun. Mag., vol. 34, no. 3, **(1996)**, pp. 82-90.
[3] S. Thajchayapong and J. M. Peha, “Mobility Patterns in Microcellular Wireless Networks”, IEEE Trans. Mobile Comput., vol. 5, no. 1, **(2006)**, pp. 52-63.
[4] M. Chowdhury, W. Ryu, E. Rhee and Y. M. Jang, “Handover between Macrocell and Femtocell for UMTS based Networks”, Proceedings of Int. Conf. on Advanced Communication Technology, vol. 1, **(2009)**, pp. 237-241.
[5] J. S. Kim and T. J. Lee, “Handover in UMTS Networks with Hybrid Access Femtocells”, Proceedings of Int. Conf. on Advanced Communication Technology, vol. 1, **(2010)**, pp. 904-908.
[6] A. Haider, I. Gondal and J. Kamruzzaman, “Dynamic Dwell Timer for Hybrid Vertical Handover in 4G Coupled Networks”, Proceedings of IEEE 73rd Vehicular Technology Conference, **(2011)**.
[7] R. Singoria, T. Oliveira and D. Agrawal, “Reducing Unnecessary Handovers: Call Admission Control Mechanism between WiMAX and Femtocells”, Proceedings of IEEE Global Telecommunications Conference, **(2011)**.
[8] J. M. Moon and D. H. Cho, “Efficient Handoff Algorithm for Inbound Mobility in Hierarchical Macro/Femto Cell Networks”, IEEE Commun. Lett., vol. 13, no. 10, **(2009)**, pp. 755-757.
[9] S. Lee, K. Kim, K. Hong, D. Griffith, Y. H. Kim and N. Golmie, “A Probabilistic Call Admission Control Algorithm for WLAN in Heterogeneous Wireless Environment”, IEEE Trans. Wireless Commun., vol. 8, no. 4, **(2009)**, pp. 1672-1676.
[10] S. Boyd and L. Vandenberghe, “Convex Opimization”, Cambridge Univ. Press, **(2004)**.
[11] K. Jakimoski and T. Janevski, “Vertical handover decision algorithm from WiMAX to WLAN based on the mobile node's speed and the session's priority”, International Journal of Advanced Science and Technology, vol. 49, **(2012)** December, pp. 1-14.

[12] S. Busanelli, M. Martal`o, G. Ferrari, G. Spigoni and N. Iotti, "Vertical handover between WiFi and UMTS networks: experimental performance analysis", International Journal of Energy, Information and Communications, vol. 2, no. 1, **(2011)** February, pp. 75-96.
[13] S. Nawaz, S. Cheema, S. Akram, K. Shehzad and S. M. Abbas, "Implementation of vertical handoff in heterogeneous networks", International Journal of Future Generation Communication and Networking, vol. 5, no. 3, **(2012)** September, pp. 11-20.
[14] S. Shin, M. Choi and N. Kim, "Handovers in hierarchical multi-tier systems", Proceedings of Advanced Science and Technology Letters, **(2013)** April.

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