Vertical Handoff Decision Algorithms in Integrated Heterogeneous Networks

S. Reddy Vamshidhar Reddy[1] and Sanjay Dhar Roy[2]

Dept. of Electronics & Communication Engineering National Institute of Technology, Durgapur, India
sreddyvamshidharreddy@gmail.com[1], s_dharroy@yahoo.com[2]

Abstract

The desired characteristic of next generation wireless communication is convergence of various heterogeneous technologies. By integrating heterogeneous technologies user will be provided high data rates, good service and connectivity. In this paper we consider the integration of wireless local area network (WLAN) in 3G network. We evaluate performance of two vertical handoff (VHO) algorithms for an integrated 3G and WLAN network. The number of handoffs and decision delay are estimated as the mobile terminal (MT) moves from the centre of 3G network base station (BS) towards the AP(access point) of WLAN with hysteresis and dwell timer approaches. We consider the log normal distribution which describes the shadow fading effect and Mapping of resources between heterogeneous networks also explained in this.

Keywords: *VHO-algorithm, WLAN, 3G network, decision delay, seamless handover, bandwidth conversion*

1. Introduction

Handoff refers to change in radio channel as user moves in or out of the cells. Efficient handoff algorithm is essential for better resource utilization as well as improvement in quality of service (QoS). If mobile moves to WLAN coverage from GSM network, intersystem or vertical handover will be necessary. Vertical Handoffs refer to handoff between two network access points, which are usually using different network connection technology. In next-generation heterogeneous wireless systems, one of the major challenges is seamless vertical handoff. Seamless handover is challenge due to following heterogeneities: 1) Next Generation Wireless Systems integrate Bluetooth, GPRS, and IEEE 802.11 based WLANs, WiMAX, UMTS. All these systems have different cell sizes of radii ranging from few meters to few kilometers and may have overlapping or partially overlapping coverage areas [1]. 2) Different network architectures have different transport, routing and mobility management protocols. 3) They are optimized for specific service demands like Bluetooth provides very small coverage area for personal use, IEEE 802.11based WLANs for local area internet connectivity, limited ability, VoIP calls, UMTS provides full mobility, Teleservices, SMS, MMS, Packet data, E-mail, VoIP, Internet WiMAX provides very limited mobility, P2P, Point-to-Multipoint, Internet connection, VoIP, *etc.* [1],

Received signal strength is the measurement of power present in a received radio signal. Signal must be strong enough between base station (BS) and mobile station (MS) to maintain signal quality at receiver. The signal gets weaker as mobile moves far away from BS/AP and gets stronger as it gets closer to BS/AP. Handoff decision is based on received signal strength from current BS to neighbor BS of 3G cellular network or AP of WLAN. When a mobile device has access to both WLAN and 3G cellular network, the mobile directly switches to WLAN because it provides higher data rate(1 to 11 Mbps) in a local area (<100m) . As the mobile moves away from the access point of WLAN, its data rate decreases and 3G networks, which provides global coverage at limited data rate becomes dominant and thus network access can be transferred from WLAN to 3G cellular network. Vertical handoff includes three sequential steps namely handoff initiation, handoff decision and handoff execution. Handoff initiation is concerned with measurement of received signal strength. The vertical handoffs from WLAN to 3G cellular network are different from those from 3G cellular network to WLAN. Similar to horizontal handoff, vertical handoff from WLAN to 3G cellular network are mainly initiated when the user is not in coverage area. As WLAN user is moving away from AP, RSS decreases. When user detects that RSS from WLAN is below threshold, mobile will initiate a handoff request. If 3G cellular network has sufficient resources to accommodate, it will accept the request, otherwise it will drop the request. In this case, user is totally disconnected from interworking system. The handoffs from 3G cellular network to WLAN are triggered to seek low-cost or high-speed services or to reduce 3G cellular network congestion. Since WLAN has rather small coverage and usually locates within a single 3G cell, the user requesting a vertical handoff from 3G to WLAN is always within the coverage area of 3G cellular network. If WLAN accepts the handoff request, the user will break the connection with 3G network and start to communicate with WLAN. Even if WLAN denies the handoff request, the user can still remain in the original connection with 3G as it is still within the coverage of 3G cell. That is, user is always connected to the interworking system. There is no real blocking for the vertical handoff from 3G cellular network to WLAN. RSS from WLAN and 3G network cannot be directly compared with each other due to their heterogeneity. So another QOS parameter is consider as in [10]. As network bandwidth is most preferable QOS parameter to the user so we take this QOS parameter for mapping purpose.

In this paper, we consider Received signal strength (RSS) based vertical handoff taking two wireless systems in concern: 3G cellular network and WLAN. We present analytical frame work to evaluate VHO-algorithms. We propose two VHO-algorithms, hysteresis and dwell timer based handoff decision algorithms with hysteresis margin (H) =4 dB, dwell timer = 5sec. in order to reduce the number of handoffs and to avoid the ping pong effect. We consider two main performance evaluation metrics number of handoffs and handoff delay. Effect of standard deviation of shadow fading (σ_{dB}) and velocity of MT on the performance is also explicated.

2. Related work

A lot of researches have been dedicated to enhance the performance of handover in Next Generation heterogeneous Wireless Networks. Recently a number of cross layer protocols and algorithms have been proposed to support seamless handoff in NGWS. In [1] a cross layer handoff management protocol scheme has been proposed. They tried to enhance the handoff performance by analyzing the speed of the mobile node, handoff signaling delay, relative signal strength of old and new base station and their relation with handoff failure probability. A novel mobility management system is proposed in [2] for vertical handoff between WWAN and WLAN. The system integrates a connection manager (CM) that intelligently detects the changes in wireless network and a virtual connectivity manager (VCM) maintains connectivity using end-to-end principle. Authors of [3] propose solutions towards enabling and supporting all types of mobility in heterogeneous networks. The proposed approach does not support real time applications by the network mobility functionality. This keeps the application unaware of network mobility and works as a backup for real time applications.

Handoff using received signal strength (RSS) of BS has been proposed also to reduce handoff latency in NGWS. In [4], the authors proposed a handoff algorithm in which the received pilot signal strength is typically averaged to diminish the undesirable effect of the fast fading component. Unfortunately, the averaging process can substantially alter the characteristics of path loss and shadowing components, causing increased handoff delay. In [5], a handoff algorithm using multi-level thresholds is proposed. The performance results obtained, shows that an 8-level threshold algorithm operates better than a single threshold algorithm in terms of forced termination and call blocking probabilities. In [6] signal to interference ratio between old base station and neighboring base-stations are calculated to make the handoff initiation decision for next generation wireless system or 4G networks. It was shown in [7] that the optimal value for the dwelling timer varies along with the user data rate or, to be more precise, with the effective throughput ratio. In [8], it is devised to evaluate the performance of vertical handover in terms of received signal strength measurement with suitable propagation model in heterogeneous network for hotspot communication. In [9], the authors proposed a received signal strength measurement based handoff technique to improve handoff probability, by calculating the speed of MT (Mobile Terminal) and signaling delay information they try to take the right decision of handoff initiation time.

3. System Model

In our network model, we consider the mobile station (MT) is moving from center of 3G network base station to AP of WLAN.

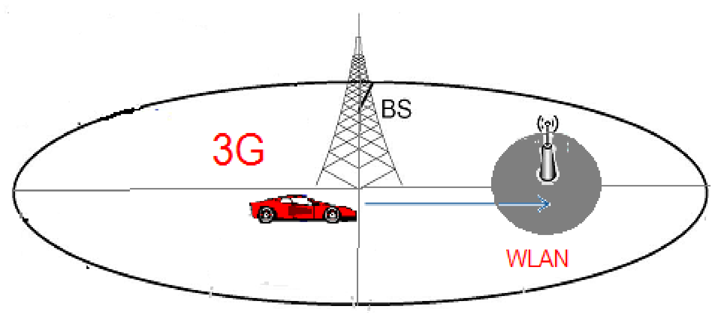

Figure 1. System model

For our proposed model, while moving from 3G to WLAN, only one vertical handoff will occur in the absence of shadowing term. But practically in the presence of shadowing term, signal fluctuates at MT. Due to this we will get two different types of vertical hand offs i.e 3G network to WLAN and WLAN to 3G network. So we have measured the number of handoff and decision delay as a performance measure for moving MT from 3G to WLAN. The figure represents the overall scenario. WLAN is surrounded by 3G network. In our system model initially MT is connected to 3G.As it moves towards the AP of WLAN, received signal strength increases gradually. After some time the signal strength increases even above 3G. At that point it seamlessly detaches from 3G and start accessing WLAN making handoff. If WLAN signal strength is much enough it accesses the WLAN even though 3G is present. Thus continuous connectivity to internet is maintained. Similarly, when MT starts receiving higher signal strength from 3G than RSS from WLAN it switches to former making handoff again.

In 3G networks, channel and time slots are allocated to a MT beforehand by its BS, so it can be assumed that the bandwidth is constant when the MT moves within hundreds of meters. In 802.11 WLAN systems, the data rate is chosen based on achievable RSS to meet a certain link quality, so the bandwidth is dynamic. Measured signal strength has three components

- Path loss
- Large-scale fluctuations (shadow fading)
- Small-scale fluctuations (multipath fading)

Multipath fading is not considered (average, low-pass filter) to avoid unnecessary handovers and no termination (hang-up) probability is considered.

By considering path loss and shadow fading, the received power at a distance d from WLAN is:

$$P_w(d) = \mu_{RSS}(d) + S(\sigma, d) \tag{1}$$

The average signal strength $\mu_{rss}(d)$ can be expressed as

$$\mu_{RSS}(d) = K - P_L(d) \tag{2}$$

where K is the parameter, that include transmitted power and transmitting/receiving antenna gain and $P_L(d)$ is the path loss. Which is represented as [10].

$$PL(d) = 32.5 + 20\log F + 10 n_I \log(d) \tag{3}$$

where F is the carrier frequency, n_I is path loss exponent for indoor environment, S(σ,d) represents shadowing effect, denotes Gaussian random variable with standard deviation σ.

Now the probability that MT receiver can translate the data correctly can be represented as [11]

$$\Pr[\mathrm{P_w}(d) > S_R] = 1 - Q\left(\frac{S_R - \mu_{RSS}(d)}{\sigma}\right) \tag{4}$$

where Q(•) is Q-function.

The data rates in the WLAN are as below.

$$DR_W[\mu_{RSS}(d)] = \begin{cases} r_1, \mu_{RSS}(d) \in (-\infty, S_1) \\ r_2, \mu_{RSS}(d) \in (S_1, S_2) \\ \vdots \\ r_m, \mu_{RSS}(d) \in (S_{m-1}, \infty) \end{cases}, r_1 < r_2 < \cdots < r_m \tag{5}$$

where $S_1, S_2, \cdots, S_{m-1}$ are receiver sensitivity values required for different level of data rate from r_2 *to* r_m.

The bandwidths in WLAN can be represented as [10]

$$B_W(d) = \Pr[\mathrm{P_w}(d) > S_R] * DR_W[\mu_{RSS}(d)] \tag{6}$$

The band width of 3G network can be converted to the equivalent RSS of WLAN network.

4. Simulation Model

In this section, we evaluate the performance of our proposed model by using hysteresis and dwell timer based algorithms. We consider that a mobile terminal moves from 3G cellular network to indoor environment of WLAN. The indoor propagation channel differs considerably from the outdoor one [12]. Indoor channels may be classified as line-of-sight (LOS) or obstructed (OBS). We assume 3G will provide global coverage with constant RSS denoted by P_{3G} whereas RSS from WLAN has two parts. Firstly the average signal strength $\mu_{rss}(d)$ which depends on whether MT is inside or outside the building [10]. When the MT is inside the building, the indoor average signal strength can be expressed as:

$$\mu_{RSS}(d) = C - 10 n_I \log_{10} d, d \in (0, d_d) \tag{7}$$

where d_d is the distance between the door and the AP, and n_I is the path loss exponent for indoor environment and

$$C = K - 32.5 - \log_{10} f \tag{8}$$

where f is the operating frequency (in GHz) of WLAN system.

Now when the MT is outside the building, a portion of the signal is coming by penetrating through the walls and another portion is coming after diffraction. The strength of penetrating and diffracted signal strength [10] are as below

$$P_{Pe}(d) = C - 10 * n_I \log_{10} d_d - O_L - 10 * n_0 \log_{\cdot 10}(d / d_d) \tag{9}$$

$$P_{Di}(d) = C - 10 * n_I \log_{10} d_d - 10 * n_0 \log_{10}(d - d_d + 1) \tag{10}$$

where O_L is the obstacle loss and n_O is path loss exponent for outdoor environment . Thus the outdoor average signal strength of the WLAN is [12]:

$$\mu_{RSS}(d) = 10 \log_{10}(10^{PPe(d)} + 10^{PDi(d)}), d \in (d_d, \infty) \tag{11}$$

The shadowing effect S(σ,d) is caused by obstacle. The autocorrelation coefficient between $S(\sigma,d_1)$ and $S(\sigma,d_2)$ is assumed to be

$$\rho_{S(\sigma,d_1),S(\sigma,d_2)} = \rho^{|d_1 - d_2|}, \rho \in (0,1) \tag{12}$$

where d_1 and d_2 are two different distances from an AP. The MT is moving from 3G towards WLAN at constant speed (v m/s). Received signal strength from an AP are sampled at the MT of interest at a distance $k.d_s$ from the AP, where k is an integer (0,1,2….) indicating sampling instant and d_s is the sampling distance (= $v.T_s$,where the T_s is the sampling interval in sec).

Now we analyze two metrics – the decision delay and the number of handoff as performance evaluation function.

4.1. Decision delay

In ideal case only one VHO should occur at the position where $\mu_{RSS}(d)$ of WLAN equal to P_{3G} of 3G network. Let us refer the sampling instance corresponding to such position as optimum handoff instant, k_O. Due to the presence of shadowing part S(σ,d) in the RSS, MT will face more than one VHO (back-and-forth) during the movement. Let us consider that the first and last handoffs occur at k_F and k_L Sampling instant respectively. The decision delay is defined as mean of first and last handoff decision delay as follows [10]

$$D = T*(\frac{E(k_L) + E(k_F)}{2} - k_O) \tag{13}$$

In our proposed model we analyze and evaluate the decision delay for dwell-timer and hysteresis based handoff algorithm subsequently**.**

4.2. Hysteresis based VHO-algorithm:

Handoff is made if the RSS of AP (BS) exceeds that of the current network BS (AP) by hysteresis margin (H). i.e. condition for vertical handoff from X-th network to Y-th network at k-th instant as considered in [17] is

$$RSS_Y(k) > RSS_X(k) + H$$

4.3. Dwell timer based VHO-algorithm:

A In this algorithm [17] a counter of predefined threshold is started when the RSS from a BS (AP) of another network exceeds the RSS from the current AP (BS). Here RSS means the equivalent RSS converted from the bandwidth of the corresponding network. If this condition continues till the counter is expired, a vertical handoff is initiated. i.e. the condition for vertical handoff from X-th network to Y-th network at k-th instant is,

for *l=k-N+1: k*

$$RSS_X(l) < RSS_Y(l)$$

end;

Here we assume that the MT is connected to X-th network at (k-N)-th instant. And N is the equivalent sampling instant corresponding to dwell timer value in seconds. RSS_X, RSS_Y Are decision parameters from X, Y networks respectively.

A handover to the network with appropriate service is performed according to the algorithms as shown in flow chart (Figure 2).

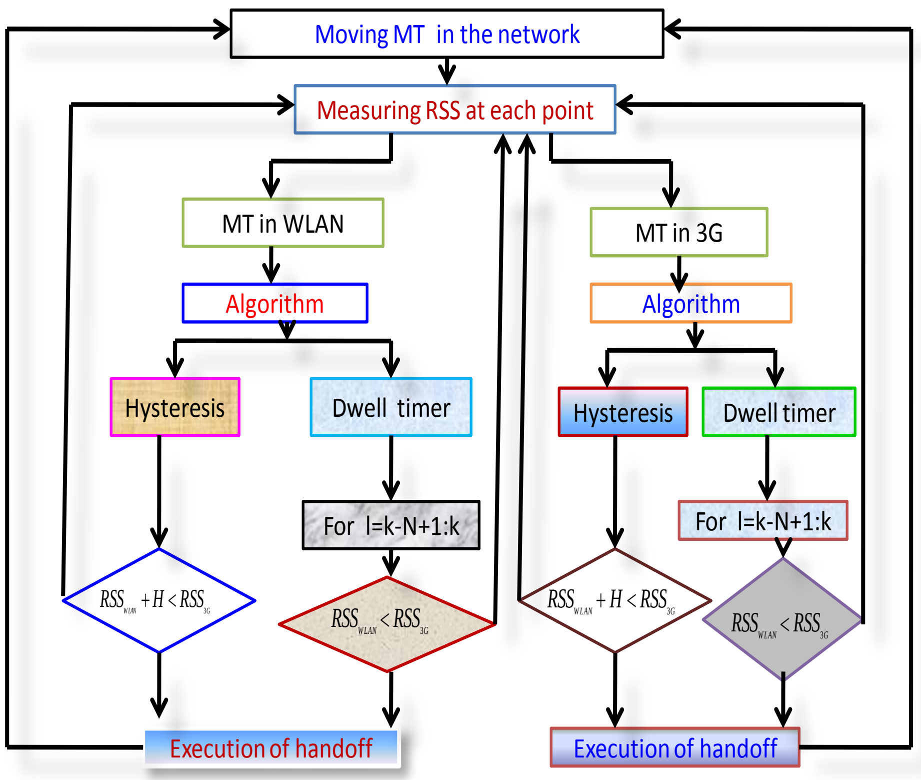

Figure 2. Flow chart for VHO-algorithms

5. Results and discussions

The main parameters of the analytical framework are set as follows [10]:

Table 1. Parameters

Parameter	Description	Value
K	Transmitted power and transmitting/ receiving antenna gain in dB	20.1 dBm
F	Carrier frequency	2.4 Ghz
P	Correlation Coefficient	0.8
n_I	Path loss exponent for indoor environment	3.2
n_O	Path loss exponent for outdoor environment	3.5
T	Sampling interval	0.1s
B_{3G}	Bandwidth of 3G network	2.4 Mbps
S_R	Receiver Sensitivity	-94 dBm

A MT is moving from 3G network through the AP of WLAN with constant velocity, v =2m/s. Received Signal Strength are sampled with sampling duration of 0.1s. The transmission data rate for WLAN is a function of received signal strength. A details regarding data rate in WLAN as a function of receiver sensitivity is discussed in [13].

$$DR_w(\mu_{RSS}(d)) = \begin{cases} 1Mbps, \mu_{RSS}(d) \in (-\infty, -91dBm) \\ 2Mbps, \mu_{RSS}(d) \in [-91dBm, -87dBm) \\ 5.5Mbps, \mu_{RSS}(d) \in [-87dBm, -82dBm) \\ 11Mbps, \mu_{RSS}(d) \in [-82dBm, \infty) \end{cases} \quad (13)$$

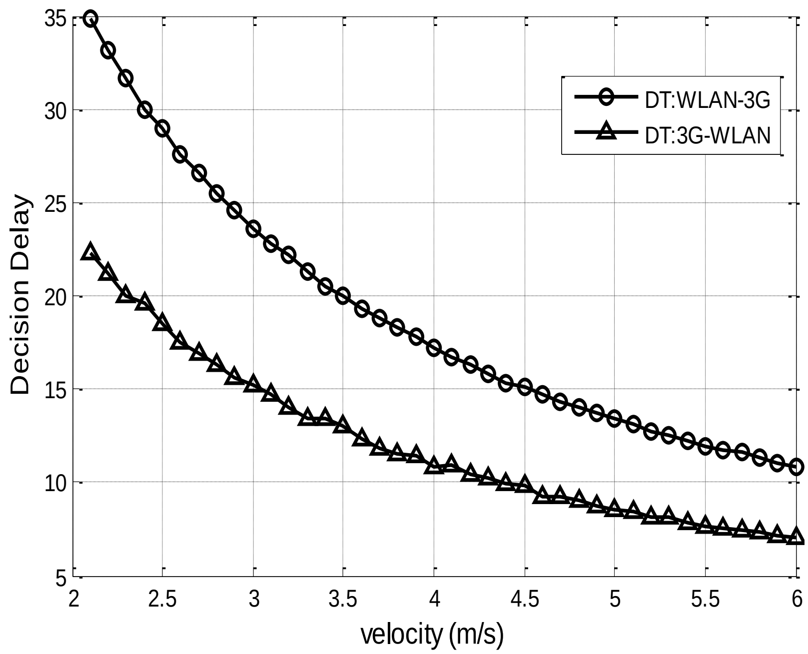

Figure 3. The decision delay vs velocity (m/s) for σ = 8dB, d_d = 20m, and O_L = 7dB for dwell timer based VHO algorithm

In Figure 3, the decision delay is shown as a function of velocity for dwell timer based VHO algorithm when the MT moved from 3G network to the centre of WLAN. . Here DT:3G-WLAN indicates time taken by MT to access WLAN connectivity and DT:WLAN-3G indicates delay between first and last handoff from WLAN to 3G. Figure 4 shows that the decision delay decreases with velocity of MT of interest for hysteresis based handoff algorithm for our network model. HYS:3G-WLAN, HYS:WLAN-3G are similar to DT:3G-WLAN, DT:WLAN-3G except algorithm used is hysteresis based algorithm. With increasing velocity, sampling distance increases and hence RSS increases rapidly with respect to time which makes lesser sampling points between k_F and k_L , so it takes less decision delay. In dwell-timer based algorithm we get less decision delay. Because in dwell-timer based algorithm handoff may occur only once in the entire timer period which reduces the frequency of handoffs for 3G to WLAN movement.

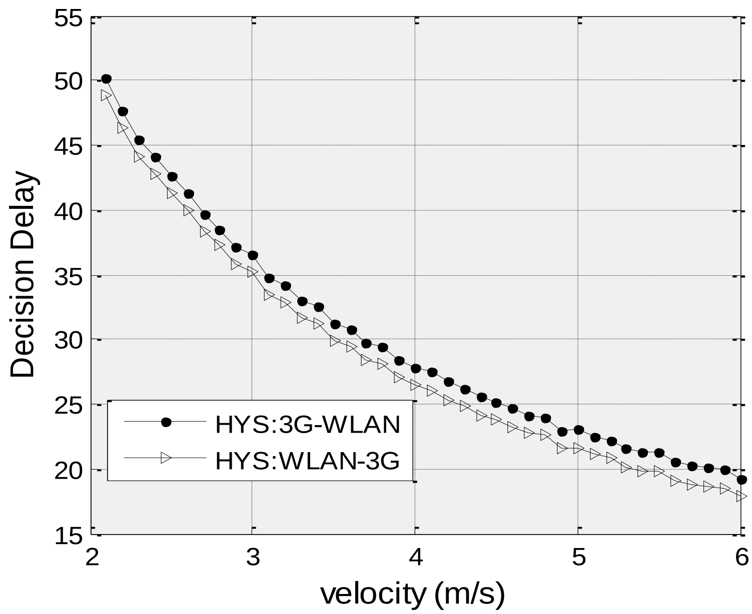

Figure 4. The decision delay vs velocity for σ = 8 dB, d_d = 20 m, and O_L = 7 Db for hysteresis based VHO-algorithm

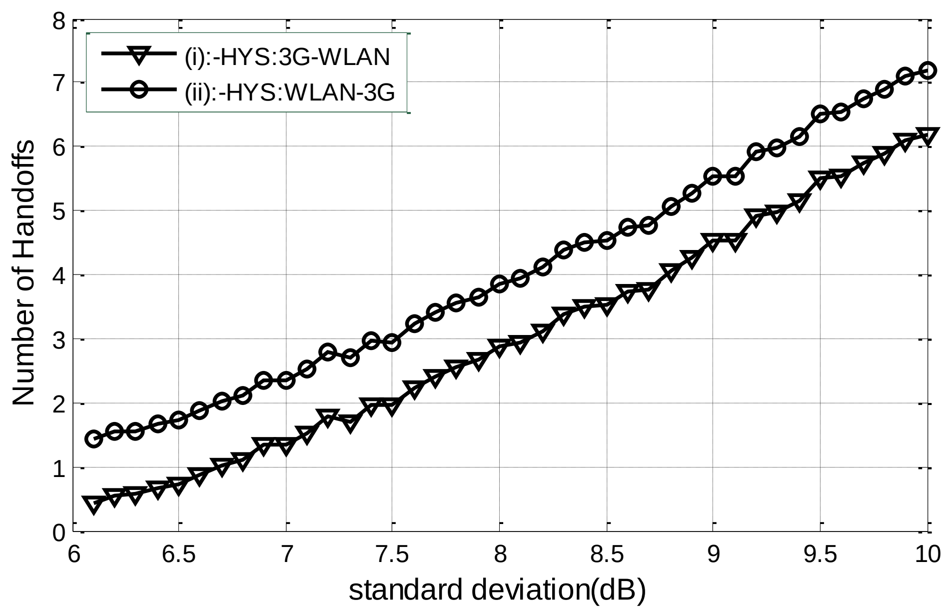

Figure 5. The number of handoffs vs standard deviation of shadowing for v=2m/s, d_d = 20m and O_L = 7 dB for hysteresis based VHO-algorithm

Figure 5 shows the number of handoffs vs the standard deviation of shadowing for hysteresis based algorithm for our proposed network model. In the plot HYS:3G-WLAN, HYS: WLAN-3G indicates number of handoffs from 3G to WLAN, WLAN to 3G. And the Figure 6 shows that how the standard deviation of shadowing is effecting on number of handoffs. Here DT;3G-WLAN, DT:WLAN-3G are also similar except algorithm. Here the number of handoff increases with sigma (σ). Because with increasing sigma (σ), signal vacillated more and more at the MT of interest and the number of handoff increases. Hysteresis margin plays vital role in the VHO-algorithms. Hysteresis margin value of more than 1 dB will be necessary to reduce unnecessary handoffs and it should not so high such that user call will not drop due to hysteresis value. From figure, we see that dwell-timer based handoff algorithm have less number of handoff than hysteresis based handoff algorithm. Because in dwell-timer based algorithm handoff may occur only once in the entire timer period which reduces unnecessary handoff.

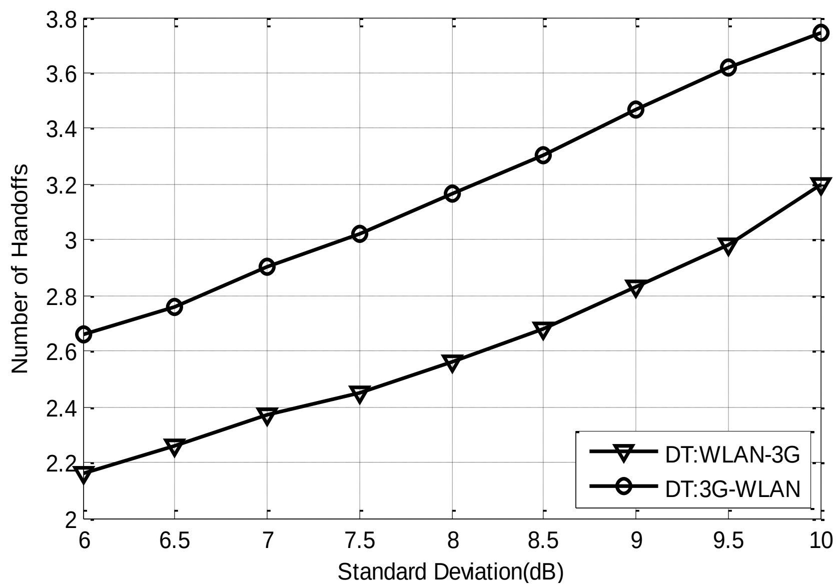

Figure 6. The number of handoffs vs sigma (dB) for v=2 m/s, d_d = 20 m & O_L=7 dB for dwell timer based VHO-algorithm

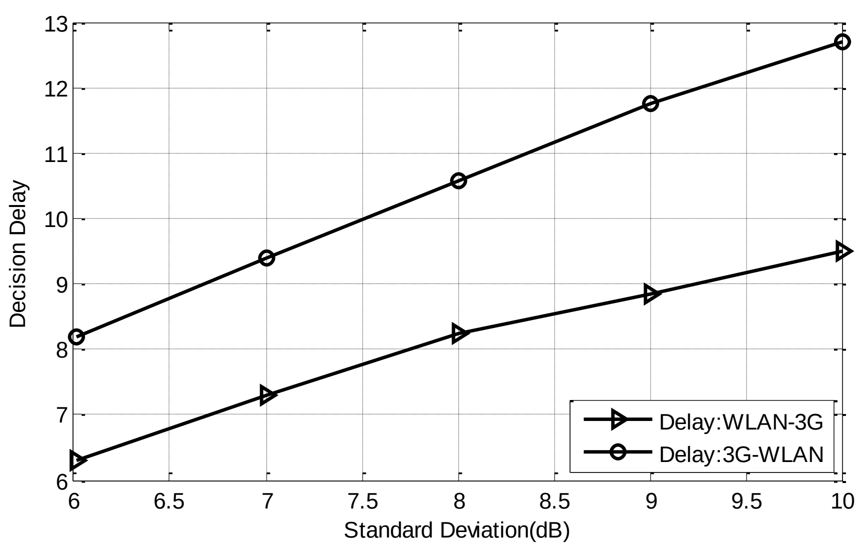

Figure 7. The decision delay vs standard deviation of shadow fading for v=2m/s, d_d = 20m and O_L = 7dB

In Figure 7, the decision delay is shown as a function of standard deviation of shadowing (σ_{dB}). The decision delay increases with increase in standard deviation of shadowing (σ_{dB}). With the increased standard deviation of shadow fading term, uncertainty of signal increases. As the standard deviation (σ_{dB}) increasing from 6 dB to 10 dB, signal vacillated at the receiver. So received signal fluctuates more at MT. Due to this user's connection oscillates between these networks and increases number of handoffs. Which makes more handoff sampling points between k_F and k_L. The distance between first handoff and last handoff also increases as standard deviation increases. As the distance increases the decision delay is also increases. So the decision delay increases with standard deviation of shadow fading.

We observe less number of handoffs and handoff decision delay in case of dwell timer based VHO-algorithms than hysteresis based VHO-algorithms. In dwell timer algorithm, the handoff condition is checked for the entire timer duration, which tries to minimize the effect of shadow fading. So in dwell-timer based algorithm, handoff may or may not occur only once in the entire timer period which reduces unnecessary handoff. But in case of hysteresis based algorithm, handoff condition is checked for each and every iteration of 0.1 sec and if the handoff condition satisfies during at any iteration, handoff will occur. Hence we get more number of handoffs and delay with hysteresis based VHO-algorithm comparing to dwell timer based VHO-algorithm.

6. Conclusion

In this paper, we consider a simulation framework to evaluate the performance of two VHO algorithms in a new network model. We evaluate vertical handoffs and decision delay for 3G and WLAN integrated network model. From the simulation results it is clear that dwell timer will eliminate ping pong effect by reducing the effect of shadow fading, so dwell timer algorithm produced less number of handoffs and less decision delay comparing to hysteresis based algorithm. Hysteresis VHO-algorithm is suitable for abrupt decay environment.

This integration process may deployable for various heterogeneous networks for example 4G networks. Reducing the decision delay in this kind of network will be a major focus in our future work.

References

[1] K. Yang, I. Gondal and B. Qiu, "Context Aware vertical soft handoff Algorithm for heterogeneous wireless network," in Proc. Of IEEE 68th Vehicular Technology Conference, **(2008)**, (VTC 2008-Fall).

[2] Q. Zhang, C. Guo, Z. Guo and W. Zhu, Wireless and Networking Group, Microsoft Research Asia, "Efficient Mobility Management for Vertical Handoff between WWA and WLAN'' in IEEE,communicationsMagazine, **(2003)**.

[3] Brannstorm, R. Kodikara, E. R. Ahlund and C. Zaslavsky, "A Mobility Management for multiple diverse applications in heterogeneous wireless networks", Consumer Communications and Networking Conference, **(2006)**, CCNC 2006, 3rd IEEE.

[4] A. E. Leu and B. L. Mark, "Local Averaging for Fast Handoffs in Cellular Networks", in Proc. of IEEE Transactions On Wireless Communications, vol. 6, no. 3, **(2007)** March, pp. 866 - 874.

[5] Y. Kim, K. Lee and Y. Chin, "Analysis of Multi-level Threshold Handoff Algorithm", Global Telecommunications Conference (GLOBECOM'96), vol. 2, **(1996)**, pp. 1141-1145.

[6] S. B. Oubira, M. Frikha and S. Tabbane, "Handoff Management In 4G Networks", IWCMC '09, **(2009)** June 21-24, Leipzig, Germany, ACM978-1-60558-569-7/09/06.

[7] M. Ylianttila, M. Pande, J. Makela and P. Mahonen, "optimization scheme for Mobile User Performing Vertical Handoffs between IEEE 802.11 and GPRS/EDGE Networks", proc. IEEE Global Telecomm. Conf. (GLOBALCOM '01), **(2001)** November, pp. 3439-3443.

[8] K. Ayyappan and P. Dananjayan, "Rss measurement for vertical handoff in heterogeneous network", **(2005)**.

[9] D. Sarddar, J. Banerjee, S. K. Saha, M. K. Naskar, T. Jana and U. Biswas, "A Handoff Management for Next Generation Wireless Systems", **(2010)**.

[10] T. Shu, M. Liu and Z. Li, “A Performance Evaluation Model for RSS-based Vertical Handoff”, in Proc. of IEEE Conference, **(2009)** July, pp. 271-276.
[11] T. S. Rappaport, “Wireless Communications, Principles And Practice”, second edition, Prentice Hall PTR, **(2004)**.
[12] J. -P. Makela, T. Braysy and K. Pahlavan, “Analysis of the effect of handoff on the performance of tactical communication system using WLANs”, in Proc. IEEE MILCOM, **(2005)** October, Atlanta City, NJ, vol. 1, pp. 474-479.
[13] M. S. Gast, "802.11 Wireless Networks: The DefinitiveGuide", 2nd Edition, O'Reilly Media, Inc., (2005) April, pp. 235-237.
[14] A. Tibrewala, D. Pramanick, S. D. Roy and S. Kundu, “Signal strength ratio based handoff algorithm for cellular networks”, in Proc. of IEEE Indian Conference (Indicon), IIT Kanpur, India, **(2008)**.
[15] D. Ma and M. Ma, “A QoS-Based Vertical Handoff Schemes for Interworking of WLAN and Wimax,” in Proc of GLOBECOM, **(2009)** November, pp. 1 -6.
[16] S. Mohanty and I. F. **A**kyildiz, “A Cross-Layer (Layer 2+3) Handoff Management Protocol for Next-Generation Wireless Systems”, in Proc. Of IEEE Transactions On Mobile Computing, vol. 5, no. 10, (2006) October.
[17] S. Anup and S. d. Roy, “Received Signal Strength Based Vertical Handoff Algorithm in 3G Cellular Network”, in proc IEEE International Conference (ICSPCC), **(2012)**, Honk Kong Polytechnic University, pp. 326-330.

Authors

S. Reddy Vamshidhar Reddy received his B.Tech. degree in Electronics and Communication Engineering from Joginapelly Baskarrao Institute of Engineering & Technology, JNTU, Hyderabad, Andhra Pradesh, India in 2010. Currently he is pursuing his M.Tech degree in Telecommunication Engineering at NIT Durgapur, West Bengal, India and he is presently working on Vertical Handoffs in Heterogeneous Networks. He has published one article in international conference. His research areas of interests include Vertical Handoff, wireless communication networks, Cognitive Radio Networks.

Sanjay Dhar Roy received his B.E. (Hons.) degree in Electronics and Telecommunication Engineering in 1997 from Jadavpur University, Kolkata, India and M.Tech. degree in Telecommunication Engineering in 2008 from NIT Durgapur. He received his Ph. D. degree from NIT Durgapur in 2011. He worked for Koshika Telecom Ltd. from 1997 to 2000. After that he joined the Department of Electronics and Communication Engineering, National Institute of Technology Durgapur as a Lecturer in 2000 and is currently an Assistant Professor there. His research interests include Radio Resource Management, Handoff, and Cognitive Radio Networks. As of today, he has published fifty (50) research papers in various journals and conferences. Dr. Dhar Roy is a member of IEEE (Communication Society) and is a reviewer of IET Communications, Electronics Letters and Journal of PIER, IJCS, Wiley, International Journal of Electronics, Taylor & Francis.