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ANALYSIS OF MULTI-TIER OVERLAY-BASED NEXT GENERATION WIRELESS NETWORKS

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This paper analyzes the overlay model for ubiquitous networking over variety of networks. It proposes architecture for Wireless Overlay Network (WON) supporting seamless mobility across multiple heterogeneous networks. It has proposed a *Layer Manager* supporting Mobile IP (MIP) protocol for interlayer connectivity. It presents a mathematical model to analyze the handoff delay and call blocking probability in the WON. The proposed architecture is extendable as global WON (GWON) considering true heterogeneity. Finally, the key performance issue, the vertical handoff (VHO) has been discussed and analyzed for the system evaluation.

Keywords*:* Vertical Handoff, Wireless Overlay, Mobile IP, Layer Manager

1. INTRODUCTION

Nowadays we find coexistence of worldwide deployed dissimilar networks such as LAN, WLAN, Cellular ATM, ISDN and PSTN. IP networks are rapidly expanding because of its transmission ability over heterogeneous networks. Wireless and IP integration makes wireless mobile networks simpler, efficient and user-friendly [1]. However, interconnection of heterogeneous networks enhances handoff latency due to mismatch in protocols which poses deep concern to the researchers. Our aim is to propose a generalized system architecture and protocol suit for heterogeneous networks that would minimize the handoff delays to ensure seamless communication. We have adopted overlay model to analyze heterogeneous networks. A wireless overlay network (WON) may be logically constructed over a mix of heterogeneous underlay wireless networks, where low bandwidth networks with wider coverage areas are layered on top of high-bandwidth, smaller-coverage area networks. Mobile wireless devices with interfaces for each layer are used to dynamically switch to upper layer for connectivity when lower layers are unavailable. Single or multiple overlays for specific functions may be created over a common base network to provide network or application services for the base network terminal users. In this work we propose an overlay network model to simulate arbitrary set of heterogeneous networks that would minimize the overall handoff latency. Rest of the paper is organized as follows. In Section 2 we have focused on the related work. The proposed architecture is depicted in Section 3. In Section 4 we present an analytical model of the proposed architecture. Section 5 concludes with future direction of studies.

2. BACKGROUND AND RELATED WORK

In homogeneous cellular systems, the handoffs are intercells and known as horizontal handoff. In WONs users handoff both horizontally among cells within an overlay and vertically among network service overlays. Horizontal handoff in WONs is the same as normal handoff in homogeneous cellular systems. Vertical Handoff (VHO) in WONs is between different networks that use different type of wireless interface. Mobility during inter-cell or horizontal movement is known as micro mobility whereas that during inter-network or vertical movement is known as macro mobility. Inter-domain handoff between the overlays may be considered as global mobility. Stemm *et al* [3] first proposed wireless overlay architecture to integrate diverse wireless networks towards seamless communication. They originated and implemented the idea of vertical handoff. It allows users to roam between cells in wireless networks in order to provide the best possible connectivity with the minimum handoff disruption. Thereafter, a lot of proposals were published to improve the vertical handoff latency. An analysis of the proposals is presented in [4].

We propose all-IP network with micro-mobility protocol for intra-layer mobility during horizontal handoff

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and Mobile IP for inter-layer mobility during vertical handoff. When the mobile node (MN) moves into the new layer, it performs Mobile IP vertical handoff through the cross-layer switch. In the new layer, a MN is assigned a layer specific IP address, as its care of address (COA) from which, layer specific multicast address is inferred using algorithmic mapping [5]. The packets destined to the MN are tunneled to it through a multicast tree under tight coupling owing to the heterogeneity. As the MN moves horizontally, the multicast tree is extended to the new Access Point (AP) or base station (BS) by sending join messages to that multicast group.

3. SYSTEM ARCHITECTURE AND MATHEMATICAL ANALYSIS

Our system architecture consists of four different WONs as shown in Fig.1. Let NW_n be the wireless network that contains homogeneous cells in level n ($1 \leq n \leq 4$). Note that, NW_1, NW_2 and NW_3 are in the coverage area of NW_2, NW_3 and NW_4 respectively. The bandwidth of NW_1, NW_2, NW_3 and NW_4 are 54Mbps, 2Mbps, 180Kbps and 9Kbps respectively. The number of channels for cells of NW_1, NW_2 NW_3 and NW_4 are B_1, B_2, B_3 and B_4 respectively, where $B_1 \leq B_2 \leq B_3 < B_4$ as shown in Fig. 4. We propose a *Layer Manager* (LM) to manage and connect inter-layer base stations over heterogeneous networks [6,7] with additional support of inter-layer mobility, accessibility and QoS. When it decides to handoff a user from one network to another network, it also directs subsequent packets to the new base station. It is also capable of decision making in packet transfer between different heterogeneous networks. We assume that there are some areas that are only covered by NW_2 and/or NW_3 and/or NW_4, therefore, we are forced to handle cases where lower overlay (NW_1 and/or NW_2 and/or NW_3) become unavailable and users must perform vertical handoff. We have used mobile IP protocol to implement the roaming function amongst NW_1, NW_2, NW_3 and NW_4 networks for interlayer communication.

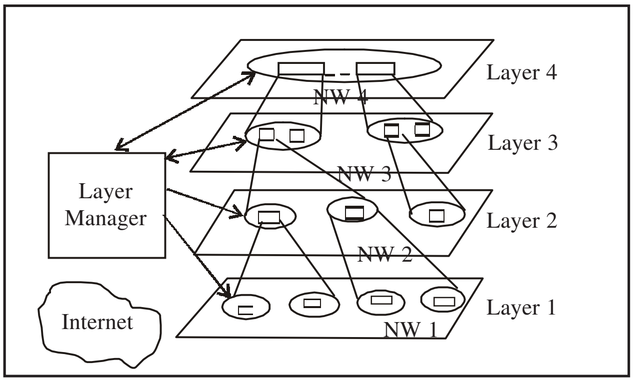

Figure 1: Proposed Multi-layer WON

We consider an analytical model for the vertical handoff in overlay networks. A handoff is processed sequentially through handoff detection and execution procedures, thereby contributing delay. We may consider provision of a buffer to minimize the handoff latencies for lossless communication. We first find out optimum buffer size using M/M/B/B queuing model. We analyze call blocking probability (P_n) and the handoff dropping probability (P_h) for calls originated in each cell in NW_1 to deduce the buffer size. Then we use M/M/1/K queuing model and repeat the analysis for the same parameters to find out the buffer size.

3.1 Analysis with M/M/B/B Queuing Model

We use the birth-death process in order to determine the required circular buffer size. Since for each overlay network, the inter-arrival time of packets is deterministic (CBR traffic) and the service time of a cell is also deterministic, therefore the buffer occupancy distribution can be determined by finite D/D/1 queuing model. However, the call duration in each of the four networks is assumed to be exponentially distributed for developing an analytical model. Let $T_{X \to Y}$ denotes the handoff interval for moving from a channel in any cell in Network X (NW_X) to a channel in any cell in Network Y (NW_Y) and ($\lambda_{1,i}$) be the new calls arrival rate to cell $C_{1,1,1,\,i}$, where $1 \leq i \leq L$, and L is the maximum number of homogenous cells in the coverage area of the corresponding cell in NW_2. Then the required buffer size to prevent packet loss is given by,

$$S_{X \to Y} = \lambda_{1,i} \cdot T_{X \to Y} \tag{1}$$

Since our system consists of four different WONs with different bandwidths, we investigate the required size for each WON individually under different traffic load. A channel assigned to a new call is released if the call is completed or the user leaves the cell of the current network. The mean channel holding time (dwell time) of a call in NW_i is T_i, where T_i is exponentially distributed. Taking into account that connecting to a lower layer is more desirable (because it is bandwidth efficient, cost effective, power efficient and reduces interference in the mobile network), we took T_i's with means $T_1 = 0.30T$, $T_2 = 0.2T$, $T_3 = 0.3T$ and $T_4 = 0.2T$ for calls in NW_1, NW_2, NW_3 and NW_4 respectively where T is the total duration of the call in the system and is defined as,

$$T = T_1 + T_2 + T_3 + T_4 \tag{2}$$

This reflects a possible situation that a user who started his application (call) in his office in a hotspot area and liked to continue that on his way to home through the services of the upper layers in the overlay network. The value of T varies according to the application and considered as exponentially distributed with a mean of 10 min. The average service rate for all WONs is obtained as,

$$\mu_{avg} = (\mu_1)(T_1 /T) + (\mu_2)(T_2/T) + (\mu_3)(T_3/T) + (\mu_4)(T_4/T) \tag{3}$$

where μ_1, μ_2, μ_3, μ_4 are the service rates representing the bandwidth for each channel in cells of NW_1, NW_2, NW_3 and NW_4 respectively. In our model, channel service rate of a cell in NW_1 is 27 times that of NW_2, 30 times of NW_3 and 6000 times of NW_4, i.e. $\mu_1 = 27$ frames/sec, $\mu_2 = 11$ frames/sec, $\mu_3 = 20$ frames/sec, and $\mu_4 = 1$ frame/sec which may be considered to be fixed during a particular period. Since we have concentrated on calls that are originated in $C_{1,1\ 1,1}$ we can define the traffic intensity as $\rho = \lambda_{1,1}/\mu_{avg.}$

However, it should be noted that the effects of other calls (in cells of NW_1 NW_2, and NW_3) on calls originated in $C_{1,1\ 1,1}$ have been taken into account in the analysis. Using equation (1), the required circular buffers sizes for $T_{1\to 2}$= 100 ms $T_{2\to 3}$ = 200 ms and $T_{3\to 4}$ = 200 ms are given in Table-1.

Table I
Buffer Size with Variable Traffic Intensity

Traffic Intensity (ρ)	*Buffer Size (In frames)*		
	$L_{1\to 2}$	$L_{2\to 3}$	$L_{3\to 4}$
0.1	0.165	0.33	0.33
0.3	0.495	0.99	0.99
0.5	0.825	1.65	1.65
0.7	1.155	2.31	2.31
0.9	1.485	2.97	2.97

3.2 Analysis with M/M/1/K Queuing Model:

Since infinite buffer length is not realistic, we consider the case of a queuing system with finite buffer size to hold the message. The M/M/1/K queue is a model of a system, which can hold up to K messages including the one being received. Thus, the system will deny entry of $(K+1)^{th}$ message at any point of time. Assuming that messages arrive and are processed at Poisson's rates, the transition-rate coefficients are given by,

$\lambda_n = \{\lambda, 0\}$ for $n = 0, 1, 2, 3, \dots, K-1$ for $n \geq K$ and

$\mu_n = \{\mu, 0\}$ for $n = 1, 2, \dots, K$ for $n > K$

$$\sum_{n=0}^{K} P_n = 1 \Rightarrow P_0 \sum_{n-1}^{K} \rho^n = 1 \Rightarrow P_0 \frac{1-\rho^{K+1}}{1-\rho} = 1 \Rightarrow P_0 = \frac{1-\rho}{1-\rho^{K+1}}$$

The steady state call blocking probabilities are given by,

$$Pn = P_0 \prod_{i=0}^{n-1} \lambda_i/\mu_i = \rho^n P_0 = \frac{1-\rho}{1-\rho^{K+1}} .\rho \qquad \text{for } n \leq K$$

and $\quad P_n = 0 \qquad$ for $n > K$

The average number of messages N_q waiting in the queue is given by, $N_q = N - N_s$

where N = Expected number of messages in the system, and $N_s = 1 - P_{0.}$

We use Little's formula to find the parameters N, T, N_q and T_q. Blocking Probability i.e, probability that an arriving message finds the buffer full is given by,

$$P_B = \frac{(1-\rho)\rho^K}{1-\rho^{K+1}}$$

For $\rho < 1$, expected number of messages in the queue is given by,

$$N = \frac{(1-\rho)}{1-\rho^{K+1}} \sum_{i=0}^{K} i\rho^i = \frac{(1-\rho)\rho}{(1-\rho^{K+1})} \sum_{i=0}^{K} \frac{d\{\rho^i\}}{d\rho} = \frac{\rho}{1-\rho} \quad . \tag{4}$$
$$-(K+1)\rho^{K+1} / (1-\rho^{K+1})$$

We now like to evaluate the quality of service i.e. the probability of loss of call due to handoff with varying buffer size (K) in terms of number of massage frames the buffer may hold. From equation (4) we calculate the number of expected messages N for various buffer sizes as tabulated in Table 2.

Table 2
Message Numbers for Various Buffer Sizes

Buffer Size (K) in frames	*Expected No. of messages (N)*
1	0.3333
3	0.7333
5	0.9000
10	0.9946
100	0.9998

The table shows that as the buffer size K increases beyond 5, the expected number of messages N in the system increases towards 100% thereby eliminates handoff delay. The average no. of messages N_q waiting in the queue is given by,

$N_q = N - N_s$, where $N_s = 1 - P_0$

Since the average number of messages being serviced is merely the probability that the system is non empty ($1-P_0$) times the average number of messages that are received under this condition. If it is considered that the nonempty probability of the system is 0.0000001, then the average number of messages waiting in the queue is also negligible.

3.3 Probability of Call Blocking and Inter-Layer Handoff Call Dropping

We assume the number of channels in each cell as B_1 =10 (of NW_1); and $B_2 = B_3 = B_4 = 20$ (of NW_2, NW_3 and NW_4 respectively) in order to analyze the traffic model numerically. New calls coming to the layer may be dropped in case no serving channel is available. The probability of blocking for the new arriving calls given by Erlangs B formula with channel capacity $B_1\rho$ is given by,

$$Pn = [(B_1\rho)^{\mathrm{B}1} / \mathrm{B}_1 !] \Big/ \sum_{q=0}^{B1} (B_1\,\rho)^q q! \tag{5}$$

From (5), we determine the handoff probability for different values of P_n considering number of WLAN channels $B_1 = 10$. We now determine hand off probability P_h for inter-layer vertical transition within four cells NW_1, NW_2, NW_3 and NW_4 approximated by M/M/B/B queuing system as,

$$P_{h_{n-1}} = [(B_n\rho)^{\mathrm{B}n} / \mathrm{B}_n !] \Big/ \sum_{q=0}^{Bn} (B_n\,\rho)^q q! \tag{6}$$

We can calculate the value of overall handoff probability for four networks with the help of the equation:

$$P_h = P_h1 + (1 - P_h1)\,P_h2 + (1 - P_h1 - P_h2)\,P_\mathrm{h}3 \tag{7}$$

The handoff latency can be calculated from the knowledge of traffic intensity and channel width. We calculate P_h1, P_h2, and P_h3 from equation (5) and (6) to find the overall P_h and then use equation (7) to find the handoff latencies for average traffic intensities of 0.1, 0.3, 0.5, 0,7 and 0.9. Different values of Call blocking probability (P_n) and hand off probability (P_h) against various values of traffic intensity (ρ) are shown in Table 3.

Table 3
Handoff Call Dropping Probability

Traffic Intensity(r)	*Call blocking probability (P_n)*	*Handoff Dropping Probability (P_h)*
0.1	0.160×10^{-8}	5.7×10^{-14}
0.3	0.31596×10^{-2}	1.1×10^{-5}
0.5	0.185×10^{-1}	5.593×10^{-3}
0.7	0.7882×10^{-1}	0.1380
0.9	0.1679	0.2194
1.0	0.2145	0.2427
1.5	0.4103	3.96×10^{-2}
2.0	0.5379	5.6×10^{-4}

The results show that hand-off dropping probability is not a concern for a typical four-layer overlay network.

4. DELAY AND COST ANALYSIS

Vertical Handoff (VHO) latency may be determined [8] by $T_h = T_d + T_c + T_r$, where T_d = Hand-off detection latency, T_c = Hand-off configuration latency & T_r = Hand-off registration latency. Experimental measures of Total handoff latency T_h is considered as 3775ms, T_d = 808ms, T_c = 1ms and T_r = 2997ms for WLAN → GPRS hand-off. The VHO delay for the proposed GWON system shown in Fig. 2 depicts the protocol indicating the handoff delay. Also, performance is considered as proportional to cost. The general form of the cost function [4] may be given by,

$$f^n = \Sigma\ \Sigma w_{s,i} \cdot P^n_{s,i} \tag{8}$$

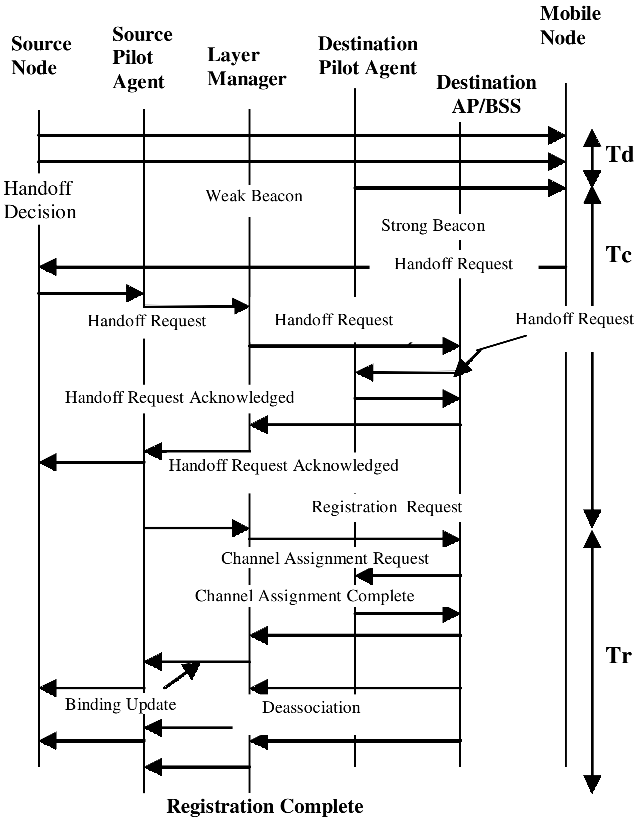

Figure 2: VHO Timing Diagram for the GWON Protocol

where $P^n_{s,i}$ represents the cost in the i^{th} parameter to carry out service s on network n and $w_{s,i}$ represents the weight assigned to using the i^{th} parameter to perform services, where the weight assigned may be related to a level of importance the user assigns to a particular service. If a user wishes to make handoff choices based on bandwidth and monetary cost for data service, the cost function can be calculated as,

$$f^n = w_b\ .\ ln\ (1/B_n) + w_c \cdot ln\ (C_n) \tag{9}$$

where B_n represents the cost in bandwidth for network n to support the handoff call, and C_n represents the monetary cost to support the handoff call. The weights assigned to each parameter are w_b for the bandwidth and w_c for the monitory cost, such that $\Sigma_i\ w_i = 1$.

Fig. 3 shows the variation of cost function with the bandwidth cost and handoff cost. It is interesting to find the break even point at cost function of 1.2 where both bandwidth cost and handoff cost are equal.

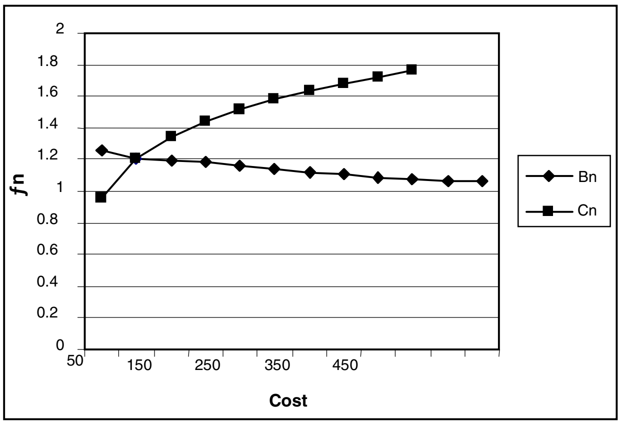

Figure 3: Variation of Cost Functions with Bandwidth and Handoff Costs

5. GLOBAL WON FOR FUTURE NETWORKS

It is expected that the current networks will continue to survive along with future networks. We also assume that our analysis of 4-layer WON in the previous section can be easily extended to validate other 4-layer WON's retaining the same basic overlay principles. For a futuristic global logical network, we propose MIP-based global overlay architecture GWON consisting of four layers as depicted in Fig.4. Layer-1 contains the core network of WLANs/ WiMAXs. Layer-2 contains 3G (UMTS/CDMA2000) systems overlaid on the base network. Layer-3 contains mostly deployed cellular systems GPRS and GSM overlaid on top of 3G. Considering the wide difference in bandwidth, we subdivide layer-3 with GPRS as layer-3L (lower end) and GSM as layer-3U (upper end). Layer-4 contains Satellite system. The bandwidth of the networks are 54Mbps (L-1), 2Mbps (L-2), 180Kbps (L-3L), 10Kbps,(L-3U) and 3-64kbps (L-4).

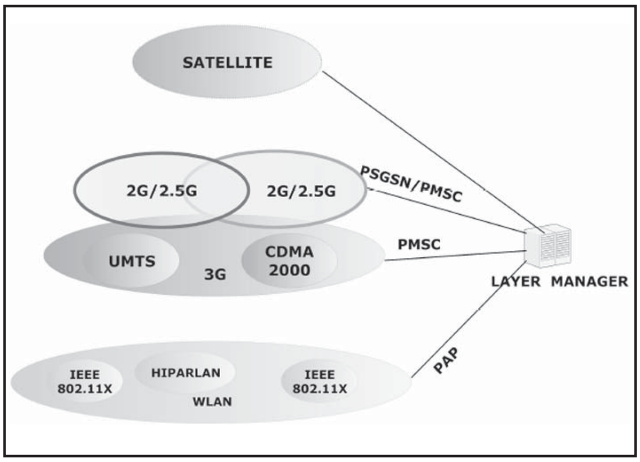

Figure 4: GWON Structure

We consider the basic Mobile IP (MIP) protocol to support seamless mobility over heterogeneous networks although many variants of basic MIP with improved performance are available. As proposed earlier, Layer Manager (LM) with functionalities of layer-3 switch will manage and connect inter-layer base stations over heterogeneous networks. Each network would identify a Pilot Access Point (PAP) or Pilot MSC (PMSC) that links the LM. The LM is equipped with a high-speed server to store database containing packet formats, routing information (for PAP/PMSC/GGSN etc). When an IP packet arrives at LM, it forwards the packet as per routing decision to the destination network using proper link. Packet format may be changed if tight coupling method is used. For example, a packet destined for UMTS, involves loose coupling and enter into the network through pilot GSSN (PGSN) without change of format. But packet destined for CDMA2000 needs tight coupling and its format needs to be changed.

6. CONCLUSION

It is well anticipated that all the communicating services as well as networks will converge in to all-IP based services in the future generation of networks. Our proposal for overlay based model follows that direction only. Our analytical analysis has shown that a four-layer overlay can be efficiently implemented within tolerable limit of handoff latency and call blocking probability. Our proposed a multi-layer global overlay GWON with dissimilar networks will contain all the present and future networks such as WLAN, WiMAX, GSM, GPRS, UMTS, CDMA2000 etc along with satellite system for interconnecting continental overlays. Our basic mathematical analysis is also applicable to the proposed GWON system. Our proposed GWON, supports seamless mobility globally across multiple heterogeneous networks using MIPv6. Our analysis based on recent research proposals and simulation results establishes the performance of the scheme. However, this model is preliminary work and is still under refinement, improvement and standardization.

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