A Vertical Handoff Algorithm Based on Context Information in CDMA-WLAN Integrated Networks[†]

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Abstract. The integration of CDMA cellular network and wireless LAN (WLAN) has drawn much attention recently. In this integrated architecture, it is required to support a vertical handoff from the WLAN to the CDMA system when a user moves out of the WLAN coverage area and vice versa. We propose a context based handoff procedure and the corresponding mechanism from WLAN to CDMA system, and vice versa, based on wireless channel assignment. In other words, this paper focuses on the handoff decision which uses context information such as dropping probability, blocking probability, GOS, the number of handoff attempts and velocity. As a decision criterion, velocity threshold is determined to optimize the system performance. The optimal velocity threshold is adjusted to assign available channels to the mobile stations with various handoff strategies. The proposed scheme is validated using computer simulation. Also, the overflow traffic with *take-back* technique is evaluated and compared with non-overflow traffics in terms of GOS.

1 Introduction

The demand for better telecommunication services has led to the development of a number of wireless access technologies including Bluetooth, wireless LAN, wireless MAN, and Wireless WAN (2G, 3G, and 4G). They not only provide traditional voice services but also multimedia services with high bandwidth access. Each of these access technologies has a different data rate, network latency, interaction capability, mobility support, and cost per bit because they have been designed with specific services in mind. To meet the diverse and growing needs for telecommunication services, more specific and heterogeneous access technologies must be developed because there is no longer a multi-purpose access technology meeting all user requirements at a reasonable cost. New wireless access networks are required to laid over the existing ones. In such wireless overlay networks, integration of several access networks will effectively support a broad mix of services.

The combination of WLAN and CDMA technology uses the best features of both systems. They nevertheless tend to leverage the high-speed access of WLANs when-

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ever possible. However, CDMA and WLANs are based on different networking technologies. The integration of them, especially seamless roaming, thus becomes one of the critical issues in the ubiquitous environments some of which involve the interworking architecture, authentication, roaming services, seamless handoff, and implementation of a WLAN/CDMA2000 [1]. The motivation behind inter-technology for the hybrid mobile data networks arises from the fact that no one technology or service can provide ubiquitous coverage.

A handoff mechanism in an overlay CDMA and underlay WLAN should perform well so that the users attached to the CDMA just easily check the availability of the underlay WLAN. The decision criteria for handoff (or network selection) can be based on the maximum link speed, reliability, power utilization, billing, cost, user preference, mobile speed, and Quality of Service like bandwidth, delay, jitter, and loss rate, etc [2]. To simplicity, we do only consider the mobile speed in this paper. A good handoff algorithm is to be derived in order to minimize unnecessary handoff attempts. An appropriate handoff control is also an important issue in system management for the sake of the benefits above with the overlaid cell structures. This paper suggests four handoff strategies : a) no-overflow, b) Overflow – From WLAN to CDMA system, c) Overflow – From WLAN to CDMA system and vice versa, d) Take-back.

To efficiently support general applications, we present an optimization scheme which assumes no knowledge about specific channel characteristics. Furthermore this paper considers a mobile speed as a decision criterion and proposes a handoff procedure and the corresponding mechanism from WLAN to CDMA, and vice versa, based on wireless channel assignment. For the speed-sensitive handoff algorithm, different approaches have been proposed in [3]-[6]. In [6], new call and handoff attempts are overflowed from the speed-dependent preferred cell layer (WLAN) to an upper cell layer (CDMA). The overflowed call keeps its connection to the overflowed network in which it is traveling as soon as a channel becomes available in the cell. However, a flexible overflow mechanism with possible take-back of overflow traffic into the preferred cell layer has not been considered.

In short, we first propose a context based handoff procedure and the corresponding mechanism from WLAN to CDMA system, and vice versa, based on wireless channel assignment. Secondly, we present a handoff control scheme for a hierarchical structured network. As a decision criterion, velocity threshold is determined to optimize the system performance. The proposed scheme is validated using computer simulation. Also, the overflow traffic with take-back technique is evaluated and compared with non-overflow traffics in terms of GOS. The simulation results show that take-back strategy performs as good as other handoff strategy.

The rest of the paper is organized as follows. In Section 2, the system description and the required assumptions are presented. The role of the mobility model is viewed in the design phase of the networks. Section 3 explains the mobility model, performance parameters (i.e. new call blocking probability and handoff call dropping probability), and core part of algorithmic decision procedure for the optimal velocity threshold for the WLAN and CDMA selection schemes. Simulations are performed in Section 4 to validate the proposed approach. Finally, the summary of the result and the future related research topics are presented in the conclusion section.

2 System Description

We consider a large geographical area covered by contiguous WLANs.

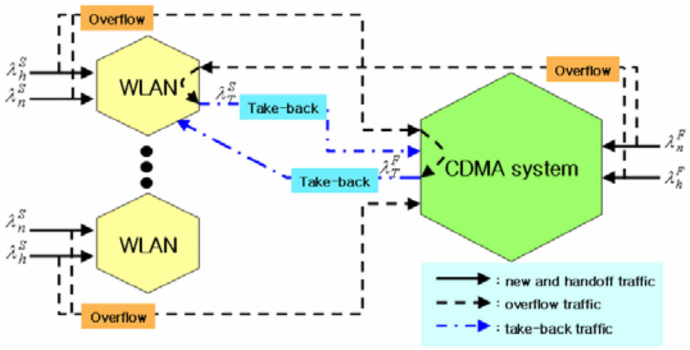

Fig. 1. Management of traffics in integrated system

Fig. 1 shows traffic flows between different wireless networks with related parameters. The WLAN constitutes the lower layer of the two-layer hierarchy. All the WLANs are overlaid by a large CDMA system. The overlaying CDMA system forms the upper cell layer. Each CDMA system is allocated c_0 traffic channels, and the number of channels allocated to the WLAN cell-i is c_i, $i = 1,2,\ldots,N$. All channels are shared among new calls and handoff calls. In our system, mobile stations (MSs) are traversing randomly the coverage area of WLAN and CDMA system. We distinguish two classes of MSs, fast and slow MSs. We further assume that an MS does not change its speed during a call.

The operation of the system can be described as follows (see Fig. 1).

① A new call generated by a slow MS (or a fast MS) in WLAN (λ_n^S) (or CDMA system (λ_n^F)) : A new call is first directed to the camped-on WLAN (or CDMA system). If the number of traffic channels in use in the WLAN i (or CDMA system) is equal to c_i (or c_0), the new call may be overflowed to the overlaying CDMA system (or overlaid WLAN). The overflowed new call will be accepted by the CDMA system (or WLAN) if the number of traffic channels occupied in the CDMA system (or WLAN) is smaller than c_0 (or c_i); otherwise, the call will be lost.

② A handoff request of a slow MS (or a fast MS) in WLAN (λ_h^S) (or CDMA system (λ_h^F)) : A handoff request is first directed to the target WLAN (or CDMA system) independent of whether the current serving network is a neighboring WLAN or an overlaying CDMA system. If all traffic channels in the target WLAN (or CDMA system) are busy, the handoff request may be overflowed to the overlaying CDMA system (or neighboring WLAN). The overflowed handoff request will be served by the CDMA system (WLAN) only if there is any idle traffic channel; otherwise, the handoff request fails and the call is forced to terminate (dropped).

③ A take-back call of a slow MS (or a fast MS) in CDMA system (λ_T^S) (or WLAN (λ_T^F)) : Assume a slow MS (or a fast MS) roaming within a CDMA system (or WLAN) it is traversing. If this slow MS is engaged in a new or handoff call that has been successfully overflowed to the CDMA system (or WLAN), a take-back request is directed to the WLAN (or CDMA system) the MS enters at each border crossing time. This take-back request will be accommodated by the WLAN (or CDMA system) only if there is any idle traffic channel in the WLAN (or CDMA system). If all traffic channels in the target WLAN (or CDMA system) are busy, the slow MS (or a fast MS) will continue to be served in the CDMA system (or WLAN) (See Fig. 2).

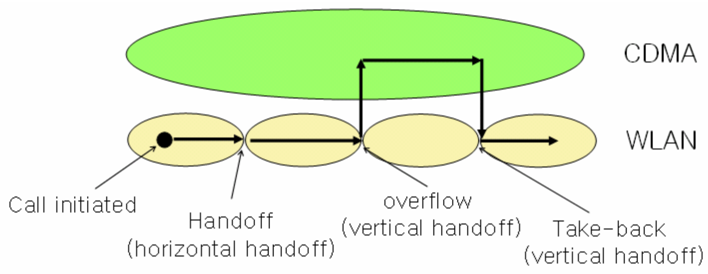

Fig. 2. Examples for take-back strategy

In this paper, all WLANs of the lower layer are treated equally to simplify the overflow and the take-back mechanisms.

3 Performance Measures and Analysis

The mobility models and perspective is given in [7]. We present analytical results for the proposed system. As stated, our objective is to focus on simple and tractable mechanism for which analytical results can give an insight into handoff between different networks. According to the velocity threshold, all the mobile users are divided into two groups; slower moving users (λ^S) and fast moving users (λ^F). In order to determine the value, which is one of the main goals of this study, a few assumptions related to mobility characteristics are made. The assumptions we employ in the mobility models are taken from [6] as cells are circular with radius R, mobiles are uniformly distributed in the system, mobiles making new calls in WLAN move in a straight line with a direction uniformly distributed between $[0,2\pi)$, and mobiles crossing cell boundary enter a neighbor cell with the incident angle θ of distribution:

$f(\theta) = 1/2 \times \cos\theta \ \ for -\pi/2 < \theta < \pi/2$ and $f(\theta) = 0 \ \ for\ otherwise$.

WLAN cells compose of two types of new call traffics, represented by the call arrival rates λ_n^S and λ_h^S, respectively modeled by the Markov Modulated Poisson process (M/M/k/k, in voice traffic model) [8]. Let random variables X and Y denote the straight mobile path for new calls and handoff calls, respectively. With the assumption of the unique WLAN cell size and the same speed of the MS, WLAN cell boundary crossing rate per call (μ_B), provided that no handoff failure occurs [6]:

$$\mu_B = 1 / E[T_Y] = 2E[V] / \pi R \tag{1}$$

Here, T_Y represents the time for a mobile to cross a WLAN cell with radius equivalent to R. $E[T_Y]$ is the cell sojourn time for a constant MS velocity. New calls assume to finish within the average call duration time, $1/\mu$, or the call handoffs to an adjacent cell. The proportion of the channel returned by the handoff is [7]

$$P_h = \mu_B / (\mu + \mu_B) \tag{2}$$

In other words, the rate of channel release and that of the call completion due to handoff are $\mu_B / (\mu + \mu_B)$ and $\mu / (\mu + \mu_B)$, respectively.

3.1 The New Call Blocking Probability of WLAN

We denote the blocking probability of calls from CDMA system and WLAN by P_{B0} and P_{B1}, respectively. And the handoff traffic from slow and fast mobiles is denoted as follows. The λ_{h0}^F and λ_{h0}^S is the rate of fast and slow mobile handoff traffic in a CDMA systems, respectively. The λ_{h1}^F and λ_{h1}^S is the rate of fast and slow mobile handoff traffic in a WLAN, respectively. And we denote the take-back traffic rate to CDMA system and WLAN by λ_{T0} and λ_{T1}, respectively. The P_{T0} and P_{T1} are the take-back probability from CDMA system and WLAN, respectively.

The aggregate traffic rate into the WLAN due to a slow MS is computed as follows:

$$\lambda_1^S = \lambda_{n1}^S + \lambda_{h1}^S + \lambda_{T1}^S \tag{3}$$

where the take-back traffic rate component is given as

$$\lambda_{T1}^S = (\lambda_{n1}^S + \lambda_{h1}^S + \lambda_{T1}^S) P_{B1} (1 - P_{B0}) P_T^S \tag{4}$$

The aggregate traffic rate into the WLAN due to fast MS is expressed as

$$\lambda_1^F = 1 / N \times (\lambda_{n0}^F + \lambda_{h0}^F + \lambda_{T0}^F) P_{B0} + \lambda_{h1}^F \tag{5}$$

The generation rate of the handoff traffic of a slow mobile station in a WLAN is given as follows:

$$\lambda_{h1}^S = P_{h1}^S (\lambda_{n1}^S + \lambda_{h1}^S + \lambda_{T1}^S)(1 - P_{B1}) \tag{6}$$

The generation rate of the handoff traffic of a fast moving MS in a WLAN is characterized as follows:

$$\lambda_{h1}^F = P_{h1}^F \{1 / N \times (\lambda_{n0}^F + \lambda_{h0}^F + \lambda_{T0}^F) P_{B0} (1 - P_{B1}) + \lambda_{h1}^F (1 - P_{B1})\} \tag{7}$$

The parameter ρ is the actual offered load to a WLAN from the new call arrival and the handoff call arrival. Invoking this important property, we can use

$\rho_1 = \lambda_1^S / \mu_1^S + \lambda_1^F / \mu_1^F$ as the offered load to the WLAN, the Erlang-B formula calculates the blocking probability with the traffic ρ_1 and the number of channels c_1 [8]

$$P_{B1} = B(c_1, \rho_1) \tag{8}$$

where

$$P_B = B(c, \rho) = (\rho^c / c!) / (\sum_{i=0}^{c} \rho_i / i!)$$

3.2 The New Call Blocking Probability of CDMA System

The aggregate traffic rate into the CDMA system due to a slow MS is computed as follows:

$$\lambda_0^F = \lambda_{n0}^F + \lambda_{h0}^F + \lambda_{T0}^F \tag{9}$$

Here the take-back traffic rate component is given as

$$\lambda_{T0}^F = (\lambda_{n0}^F + \lambda_{h0}^F + \lambda_{T0}^F) P_{B0} (1 - P_{B1}) P_T^F \tag{10}$$

Thus, the aggregate traffic rate into the CDMA system due to a fast MS is given as

$$\lambda_0^F = N(\lambda_{n1}^S + \lambda_{h1}^S + \lambda_{T1}^S) P_{B1} + \lambda_{h0}^S \tag{11}$$

The generation rate of the handoff traffic of a slow MS in the CDMA system is calculated as

$$\lambda_{h0}^F = P_{h0}^F (\lambda_{n0}^F + \lambda_{h0}^F + \lambda_{T0}^F)(1 - P_{B0}) \tag{12}$$

The generation rate of the handoff traffic of a fast MS in the CDMA system is computed as

$$\lambda_{h0}^S = P_{h0}^F \{ N(\lambda_{n1}^S + \lambda_{h1}^S + \lambda_{T1}^S) P_{B1} (1 - P_{B0}) + \lambda_{h0}^S (1 - P_{B0}) \} \tag{13}$$

The probability of call blocking is given by the Erlang-B formula because it does not depend on the distribution of the session time. Invoking this important property, we can use $\rho_0 = \lambda_0^S / \mu_0^S + \lambda_0^F / \mu_0^F$ as the offered load to CDMA system, and blocking probability can be written as

$$P_{B0} = B(c_0, \rho_0) \tag{14}$$

3.3 The Handoff Call Dropping Probability of WLAN and CDMA System

Slow MSs are supposed to use WLAN channels. However, since handoff to CDMA system is also allowed, the probability of handoff call drop in WLAN can be calculated as follows. Let P_{10} denote the probability that a slow MS fails to be handoffed to a near WLAN. The probability of the calls, P_{B0}, in a WLAN denotes the probability of failed hand-up to the overlaying CDMA system due to the channel shortage. Then the handoff call dropping probability is

$$P_D^S \approx P_{10}P_{B0} + P_{10}(1-P_{B0})P_{F0}^S \tag{15}$$

Here P_{F0}^S is the probability that a slow MS handoff to CDMA system fail. The P_{10} is defined in such a way that the i th handoff request is successful but the $(i+1)$ th request is dropped:

$$P_{10} = f_1 + s_1 f_1 + s_1^2 f_1 + \hbar \; = f_1 / (1-s_1) \tag{16}$$

where $f_1 = P_{h1}P_{B1}$, $f_0 = P_{h0}P_{B0}$, $s_1 = P_{h1}(1-P_{B1})$, and $s_0 = P_{h0}(1-P_{B0})$. f_i describe the probability that handoff fails due to channel shortage and the s_i is the probability of successful handoff. The overall probability of either dropping or handoff failure is

$$PD = R_S P_D^S + R_F P_D^F \tag{17}$$

where R_S and R_F is fraction of slow and fast MSs , respectively.

3.4 The Number of Handoffs

We will use the term handoff rate to refer to the mean number of handoffs per call. We use geometric models to predict handoff rates per call as cell shapes and sizes are varied. Approximating the cell as a circle with radius R and the speed of the mobile station with V, the expected mean sojourn time in the call initiated cell and in an arbitrary cell can be found [6], respectively

$$E[T_X] = 8R/3\pi E[V] \qquad E[T_Y] = \pi R/2E[V] \tag{18}$$

A user will experience a handoff if he moves out of the radio coverage of the base station with which he currently communicates. The faster he travels, probably the more handoffs he experiences. Using result from renewal theory, the expected number of handoffs given the speed of the user can be found.

$$E[N_h] = \frac{\pi E[V]}{4\mu R}\left(1 + \frac{4\mu R}{3\pi E[V] + 8\mu R}\right) \tag{19}$$

3.5 Grade of Service (GOS) and Network Selection

Among many system performance measures, GOS is most widely used. In fact users complain much more for call dropping than for call blocking. It is evaluated using the prespecified weights, PB and PD ,

$$GOS = (1-\alpha)PB + \alpha PD \tag{20}$$

where PB and PD represent the blocking and dropping prob. of systems, respectively. The weight α emphasizes the dropping effect with the value of larger than one half.

A proposed perspective network selection procedure together with a few of preprocessing is shown in Fig. 3. For the estimation of the mobile speed, Global Positioning System (GPS) or Differential GPS can provide adequate location information. Using GPS and Time-of-Arrival (TOA) information from the user signal, we can estimate for user's velocity. We develop the selection algorithm based on an optimal velocity threshold. The problem here is to find V_T improving the GOS and decrease the number of handoff attempts (N_h) with the given traffic parameters and MS mobility; $f_\Lambda(\lambda)$ and $f_V(v)$. We have to find the velocity threshold satisfied the following equation.

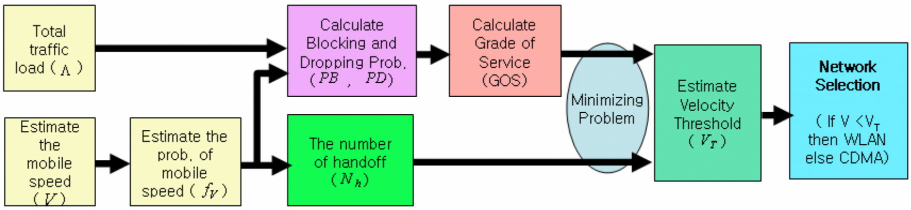

Fig. 3. Network selection Scheme

$$\min_{V_T}\{GOS(V), N_h(V)\} \tag{21}$$

The procedure is now concerned with the GOS in which the system wide new call blocking probability PB and the handoff call dropping probability PD are weighted to be averaged as in Equation (20). The GOS can be written as a function of V_T , and hence finding the optimum value of V_T minimizing the value of GOS and N_h is a typical minimization problem.

4 Numerical Examples

The proposed procedure is tested with a number of numerical examples for the overlaid structure. The test system consists of 10 WLANs in the CDMA system. The total traffic $\Lambda = \lambda_0 + n\lambda_1$, where λ_0 and λ_1 are the new call arrival rate for the CDMA system and the WLAN, respectively. The radius of the WLAN and the CDMA system are assumed 300m and 1000m, respectively. The average call duration is $1/\mu = 120$ sec. The number of channels in each CDMA system and WLAN is $c_0 = 30$, $c_1 = 10$ for the total $\Lambda = 60$ Erlang. Assume the traffic mobility distribution same as [6] .

In operation phase use can draw a histogram to estimate the $\hat{f}_V(v)$, and the expected value of the mobile speed can be calculated by averaging the mobile speeds monitored by the system. Analytically we can obtain $E[V]$ for such a simple hypothetical velocity distribution [7]. And we consider four handoff strategies for comparison as follows.

a) No overflow : A reference system where the two layers are kept completely independent.
b) Overflow – From WLAN to CDMA system : A system where only overflow of new and handoff traffic for a slow MS to the CDMA system is allowed.

c) Overflow – From WLAN to CDMA system and vice versa : A system where overflow of new and handoff traffic for both slow and fast MS is allowed.
d) Take-back : Overflow of new or handoff traffic and take-back of both slow and fast MS to their appropriate layers.

Fig. 4 shows the plot of Equation (19) for the mobility distributions [6] of the MS in the system. As the velocity threshold increases, the number of handoff attempts in the system also increases. To achieve the goal of minimizing N_h, we want to place more users in the CDMA system, because crossing the boundaries of large cells becomes less frequent. However, this may overload the CDMA system. Many calls may be blocked due to the lack of channels and have to be handed down to WLAN. This imposes an extra cost. Therefore, it is desirable to keep the GOS in the system.

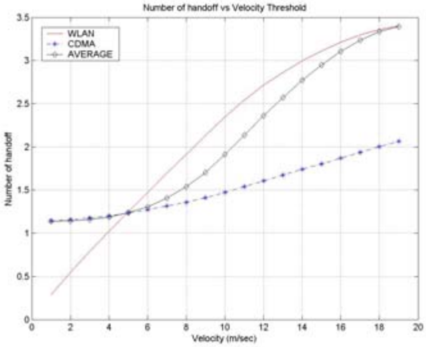

Fig. 4. The number of Handoff vs. velocity threshold

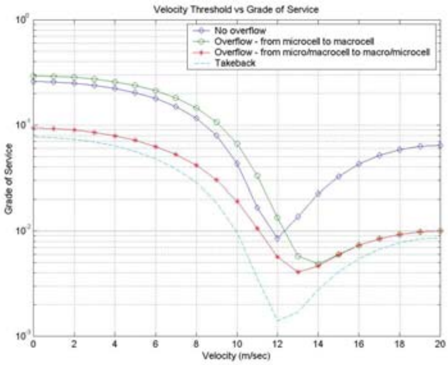

Fig. 5. Grade of Service vs. velocity threshold

We investigate the GOS, which is a function of both the traffic load and mobility distribution. Fig. 5 shows the plot of Equation (20) for the mobility distributions of the MS in the system. The vertical arrows in the figure show the range of the possible velocity thresholds at a certain load level. The lowest point in the range corresponds to the maximum allowable and optimal velocity threshold. Optimal V_T is 12m/sec, 14m/sec, 13m/sec, 12m/sec for case a), b), c) and d), respectively. Here the GOS of case c) and d) have minimums of nearly equal values, but V_T does different cases. Case d) is favorable (See Fig. 4) since V_T in the case d) is smaller than that of case c) and thus more users are serviced in the CDMA system while the WLAN serves the fewer users. As a results, the WLAN will give rise to a higher number of handoff requests for high-mobility users, and the corresponding number of handoff requests of the calls in progress may cause an excessive processing load in the network.

For the range exceeding the threshold, as V_T is smaller, more traffics can be accommodated for the increased P_{B1} for which more traffics are allocated to the WLAN. As the traffic increases, the V_T corresponding to the minimum P_{B0} becomes higher; more traffics should be assigned to the WLAN. For example, if the number of faster moving MS are more than those of the slower moving, the optimal V_T (in terms of GOS) lies in the relatively higher position of the region. From the mentioned figures above, when the overflow is likely to reduce the PD, we note that the traffic should be small enough as compared to the case without the overflow.

The take-back strategy provides the value of GOS nearly equal to case c) while it has the optimal velocity threshold smaller than that of case c). With all the observations in mind, the strategy we proposed has desirable characteristics, i.e., finding the optimal value of GOS and the number of handoff rate (See figure 4 and 5).

5 Conclusion

We have presented a handoff procedures with network selection deciding the optimal velocity threshold in order to improve the GOS and minimize the number of handoff attempts with the given traffic volume and four handoff strategies in WLAN and CDMA system. The simulation results show the dependency of the system performance upon the velocity threshold, V_T. The velocity threshold has shown to be an important system parameter that the system provider should determine to produce better GOS and lower handoff rate. From the simulation results we were able to validate the procedures determining the optimal V_T in which depends upon PD and PB as well as the number of handoff attempts. Furthermore, the take-back strategy is more favorable than other handoff strategies in this simulation environment.

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