Joint Session Admission Control Scheme in Integrated WLAN and 3G Networks

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***Abstract*—As heterogeneous wireless networks are deployed and users need more flexible mobility services, there has been a lot of research work about interworking mechanism between widely deployed 3G network and rapidly boarded WLAN (wireless local area network). On the other side, TD-SCDMA (time division-synchronous code division multiple access), which combines all the advantage of the TDD (time-division deplex) with CDMA (code-division multiple access), is one of the three main standards of third-generation mobile radio system, and is newly commercialized in China. It is expected to provide enough mobility and higher data rate. So the study of the integration between WLAN and TD-SCDMA will be attractive. In this paper, we propose an efficient joint session admission control scheme that maximize overall network revenue with Qos (quality of service) constraints over both the WLAN and the TD-SCDMA cellular networks. Simulation results illustrate that the overall network revenue earned in the proposed scheme is significant larger than that when the individual networks are optimized independently.**

Keywords - heterogeneous wireless network, joint session admission control, integrated system.

I. Introduction

In the past decade, with the fast development of wireless access technologies, several wireless networks have been successfully deployed, such as IEEE 802.11 WLAN, IEEE 802.16 WiMAX, GPRS/EDGE, CDMA 2000, WCDMA and TD-SCDMA, etc. These wireless access networks have different coverage area and load-carrying capability, and usually overlap coverage the same wireless areas. Figure 1 shows the most widely popularized two wireless access networks:cellular networks and WLANs. TD-SCDMA cellular networks support low data rates, but offer a much wider area of coverage that enables ubiquitous connectivity. On the country, WLANs offer relatively high data rates that range from 1 Mbps to 54 Mbps at lower cost, but only cover smaller areas of a few thousand square meters [1], it is often deployed in hot spots such as hotels, airports, campuses and offices, etc. The complementary characteristics of WLANs and TD-SCDMA cellular networks make it attractive to integrate these two wireless access technologies. Users would benefit from the lower overall cost and the enhanced performance of the combined services.

Except the coverage area and the load-carrying capability, the exploitation of radio resource in these two networks is often very much unbalanced. As for WLAN/TD-SCDMA networks, the instable user behavior and the burst traffic usually happen, so the radio resource utilization would be very low due to the requests of peak rate from users [1]–[3].

Integrating heterogeneous networks reveals a lot of difficulties due to their different system specifications, standardization, and service scopes [4]. One major challenge in integrated CDMA/WLAN network is how to realize joint radio resource management to meet the Qos requirements of applications. Some representative methods [1], [5], [6] have been proposed to improve the system performance, but most of these work are focused on interworking mechanism between network elements rather than integrating whole network architectures, and how to utilize the overall radio resource optimally has not been studied in detail in this coupled environment.

In [1], the utilization of radio resource in a heterogeneous integrated system was optimized through joint session admission control, which considers maximizing overall network revenue, but only multimedia traffic was taken into consideration. In [5], a seamless service handoff scheme was proposed, it takes into consideration both the connection duration during the vertical handoff decision and the processing and signaling load during the vertical handoff execution, but it didn't support cooperative session admission control in integrated networks. In [6], it aimed to select the most suitable access network, where the users' Qos requirements can be satisfied and the cost that user paid for is the lowest, but it only considered roaming and vertical handoff, and how to improve the overall system revenue optimally has not been studied.

This paper proposed an optimal joint session admission control scheme using MDP (Markov Decision Process) in integrated WLAN/TD-SCDMA environment, which aims to maximize overall network revenue while satisfying Qos constraints in both the WLAN and TD-SCDMA networks. Compared with the schemes those only support vertical handoff or no joint session admission control is provided in integrated system, proposed scheme obtains higher system throughput revenue gain, and traffic blocking probability is significant lower. In addition, proposed joint session admission control scheme is a randomized policy, i.e., new arrival traffics are blocked with some probabilities when the system is in certain states.

The rest of this paper is organized as follows. In Section II, we describe the integrated WLAN/TD-SCDMA network environment, and the session admission control model is introduced. Then in Section III, we formulate the problem as a joint session admission problem in the integrated networks. In Section IV, some simulation results are presented, system revenue comparison is given at the same time. Finally, Section V concludes this study.

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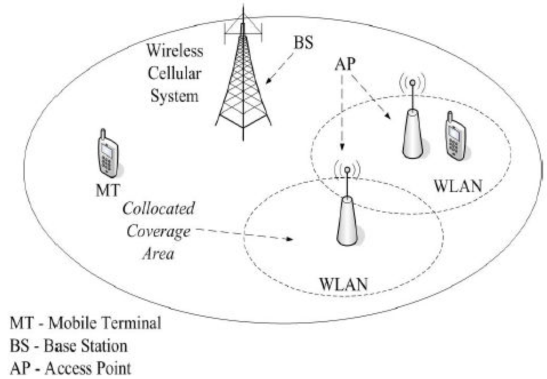

Fig. 1. Heterogeneous wireless network environment.

II. SYSTEM MODEL

In this section, we first introduce the network environment applied with the proposed scheme. Then we present the system model for solving joint session admission problem. The objectives are also introduced.

A. System Architecture

The architecture of the integrated WLAN/TD-SCDMA system is illustrated in figure 1. In this example, the integrated network is comprised of multiple WLAN wireless access points and TD-SCDMA base-stations. Assume that the new calls in a cell arise at an average rate λ(new call arrivals per second per cell) according to a Poisson process. Call duration has a negative exponential probability distribution.

These two wireless access networks have different coverage area and load-carrying capability, and overlap coverage the same wireless areas. In case of a burst traffic which leads to radio resource shortage, they can complement each other to deal the peak request from users.

B. Session Admission Control Model

In this paper, the system reward represents the overall system throughput and the blocking probability of new arrival sessions. For the objective of maximized overall system throughput, assuming the reward to be session saturation of both networks in case of peak user request. The minimized session blocking probability is obtained at the same time.

In the coupled WLAN/TD-SCDMA environment, although the session arrivals in a WLAN coverage area normally connect to the WLAN, there is also the alternative that some session arrivals in the WLAN are admitted to the TD-SCDMA network to avoid the potential congestion in the WLAN. The problem of joint session admission control in integrated WLAN/TD-SCDMA systems is whether or not to admit and to which network(WLAN or TD-SCDMA) to admit a new arrival session. The optimal scheme should maximize the average network revenue and guarantee Qos constraints in both WLANs and TD-SCDMA networks [1].

Suppose that WLAN is saturated or nearly saturated, while TD-SCDMA network is not so heavily loaded. Thus we can do optimal session admission control between these two networks, that is, some of the new arrival sessions in the WLAN can be admitted to the TD-SCDMA network. As a result of joint session admission control, overall system throughput is improved, and traffic blocking probability is decreased. In this joint session admission control scenario, cognitive terminals have multi-homing capability, and pseudo-randomly move within the eoverage area of the integrated WLAN/TD-SCDMA networks. These cognitive terminals perform vertical handoff when required, thus to decrease traffic blocking probability.

In this paper, we consider modeling the new arrival sessions as a continuous time Markov chain by dividing the continuous network states into discrete levels for simplification [7].

Assume that the new arrival session is modeled as a Poisson random process with rate λ_n , and the inter-arrival time is negative-exponentially distributed with mean time $1/\lambda_n$. The departure of the radio system is another Poisson random process with rate μ_i, so the radio system access duration is also negative-exponentially distributed with mean time $1/\mu_i$. The new arrival session rates in the WLAN and the TD-SCDMA areas are $\lambda_{w,n}$ and $\lambda_{t,n}$, respectively. The total new traffic arrival rate in integrated system is $\lambda = \lambda_{w,n} + \lambda_{t,n}$. While session departure rates in the WLAN and the TD-SCDMA network are $\mu_{w,t}$ and $\mu_{n,t}$, respectively.

In this system model, centralized processing method of session admission is adopted, so the information exchange with an associated base-station may be involved. The session management agent is called CPA (centralized processing agent). The base-station checks the cell state timely and share this information with CPA. So the CPA have final session admission decision according to current network states.

C. Objectives and Constraints

Throughput and packet delay are important Qos metrics in WLAN. Throughput should be kept above a target value for a certain class of traffic. While in TD-SCDMA networks, Qos requirements are usually characterized by SIR. However, guaranteeing SIRs of all classes of traffic at all time instants may result in low network utilization for burst traffic [1]. Therefore, instead of guaranteeing the SIR all the time, we can guarantee the SIR outage probability below some target value. In the integrated WLAN/TD-SCDMA system, Qos metrics are overall system throughput and blocking probability of new arrival traffics, which should be guaranteed.

Suppose k denotes traffic type, $k = 1$ means real-time traffic and $k = 2$ means non-real-time traffic. During inter-time from i to j, the new arrival k type traffic number is denoted by $d_{k,i,j}$, and the system revenue gain is $R_{k,i,j}$. Assume the number of k type traffic sessions admitted at l time is $C_{k,l}$, and the k type traffic sessions admitted from i time to j time is $X_{k,i,j}$, then we get the overall system throughput objective:

$$max \sum_{k,i,j} R_{k,i,j} X_{k,i,j} \tag{1}$$

$$s.t. X_{k,i,j} \le d_{k,i,j}, k = 1, 2; i, j = 1, 2, 3, \ldots \tag{2}$$

$$s.t. \sum_{i,j:(k,i,j)\in S(k,l)} X_{k,i,j} \le C_{k,l}, \quad (3)$$

$$S(k,l) = (k,i,j) \mid i \le l \le j, k = 1,2; l = 1,2,3,\ldots,$$

$$X_{k,i,j} \ge 0, k = 1,2; i,j = 1,2,3,\ldots$$

The first constraint shows that the admitted session numbers of both type of traffics should not be greater than arrived, while the second constraint limits the number of admitted sessions to be less or equal than network's supported numbers at any time.

III. Joint Session Admission Control Scheme

In this section, we will introduce the joint session admission control scheme in detail, and give the process method.

A. Qos Metrics Over Integrated System

In this paper, we take into consideration both overall system throughput and traffic blocking probability to find out the optimal session admission control policy. The optimization objectives can be summarized as maximized overall system throughput and minimized session blocking probability.

B. Optimal Algorithm

In dynamic session admission scenario, supported-load within heterogeneous wireless network are dynamically changed. When a new session arrives, a decision must be made whether or not to admit and to which network. The action chosen is based on the current state of the integrated system. The state information includes the session numbers of each type of traffic in both the WLAN and the TD-SCDMA network. Assume that WLAN network can support up to C sessions, and current idle load carrying ability is C_i. When the new sessions arrive with the rate λ_i, the CPA makes an admission decision. If C_i is less than certain value(here we set $C_i = C * 5\%$), some of the new arrival sessions will be blocked with a certain probability, and CPA should admit the others session to TD-SCDMA network if it is not over-loaded. And vice versa.

In the integrated WLAN/TD-SCDMA system, the joint session admission control problem can be modeled as a continuous time Markov chain.

Define row vector

$$s_w(t) = [n_{w,1}(t), n_{w,2}(t), \ldots, n_{w,J}(t)] \quad (4)$$

where $n_{w,j}(t)$ denotes the number of j type sessions in WLAN. Define row vector

$$s_c(t) = [n_{c,1}(t), n_{c,2}(t), \ldots, n_{c,J}(t)] \quad (5)$$

where $n_{c,j}(t)$ denotes the number of j type sessions in the TD-SCDMA cell. The state vector of the system at time t is given by

$$\begin{aligned} s(t) &= [s_w(t), s_c(t)] \\ &= [n_{w,1}(t), \ldots, n_{w,J}(t), n_{c,1}(t), \ldots, n_{c,J}(t)] \end{aligned} \quad (6)$$

The state space S of the system comprises of any state vector such that the throughput and average packet delay constraints in the WLAN cell and the SIR outage probability constraint in TD-SCDMA cell can be met. Therefore, the state space of markov chain can be defined as

$$S = s = [s_w, s_c] = [n_{w,1}, \ldots, n_{w,J}, n_{c,1}, \ldots, n_{c,J}] \quad (7)$$

Given the traffic arrival rates and occupying time, we can define an infinitesimal generator matrix A. Then, by solving the following equation we can get the state probabilities:

$$\Pi A = 0 \quad (8)$$

where $\Pi = [\Pi_1, \Pi_2, \ldots, \Pi_K]$ is the steady-state probability vector and Π_i represents the probability of being in state i, and K is the number of states in the Markov chain. The generator matrix A is singular so we cannot solve the state probability vector directly. But with the condition that the sum of all the steady-state probabilities should be one, we can put these two conditions into the following compact equation [8]:

$$\begin{bmatrix} A^T \\ 1_{1\times K} \end{bmatrix} \Pi^T = \begin{bmatrix} 0_{K\times 1} \\ 1 \end{bmatrix} \quad (9)$$

Then, by defining

$$A' = \begin{bmatrix} A^T \\ 1_{1\times K} \end{bmatrix}, b = \begin{bmatrix} 0_{K\times 1} \\ 1 \end{bmatrix} \quad (10)$$

we have:

$$A'\Pi = b, \pi_j^* = \frac{\lambda_j \pi_j}{\sum_{k=0}^{s} \lambda_k \pi_k} \quad (11)$$

By using minimum mean-squared error(MMSE) criterion [9], we obtain the following unique solution:

$$\Pi^T = \left(A'^T A'\right)^{-1} A'^T b \quad (12)$$

Despite the fairness concerns, another important metric wireless users care about is the blocking probability. We can compute the state probability seen by an arriving call as follows:

$$\pi_j^* = \frac{\lambda_j \pi_j}{\sum_{k=0}^{s} \lambda_k \pi_k} \quad (13)$$

In above equation, $s+1$ is the total number of states. Considering a long period of time T, on the average the system spends in state j the time $\pi_j T$. During this time, there are on the average $\lambda_j \pi_j T$ calls arrive which find the system in state j. The total number of calls arriving in time T is on the average:

$$T \sum_{k=0}^{s} \lambda_k \pi_k \quad (14)$$

Then, the proportion of calls which find the system in state j is as given by above expression. When the random access probability is p_i , the blocking probability experienced by the integrated system is:

$$P_{Block} = 1 - p_i \left[1 - \sum_{j:blockedstates} \pi_j^* \right] \qquad (15)$$

Note that, the above blocking probability constraints is derived under the assumption of a saturated network, in which the maximum load is carried in the system in stable conditions [10]. In practice, however, this assumption may not hold. Nevertheless, the joint session admission control scheme proposed in this paper is also applicable to other Qos constraints as long as the admissible set can be expressed explicitly.

C. Session Admission Control Process

The joint session admission control process allows new sessions to be admitted to the other network in a joint way. Suppose that current network's available load-carrying ability is denoted by C_k, the session admission process is as follows.

1) When a new session arrives, the CPA executes an admission decision to find whether network's current load exceed it's load-carrying ability, and admit it in case of not over-loaded (that is, C_k is larger than C_i).

2) If current cell is saturated or nearly saturated ($C_k \leq C_i$), CPA judges session type. If it is real-time session, admit it to current network. If failed ($C_k = 0$), CAP will admit this session to the other network.

3) If new arrival session is non-real-time, CPA computes the Markov Chain states and block it with some probability.

4) For those not blocked non-real-time sessions, CPA admits them to current network or the other network.

5) If both of the WLAN and TD-SCDMA networks are saturated, the new arrival session will be blocked.

6) Go to step 1.

IV. Simulation Results

In this section, we simulate the proposed joint session admission control scheme and compare it with other schemes. Since previous work [11]–[13] does not consider the integrated problem, we assume single network rewards in these schemes.

To illustrate the performance of the proposed scheme, in this simulation, we assume that there are at most 100 users, and employ the session admission strategy in central control manner. We show that the proposed scheme can achieve significant performance improvement over other two WLAN/TD-SCDMA integration schemes.

In the scheme without handoff between WLAN and TD-SCDMA, session admission is done independently in individual networks, so the WLANs and TD-SCDMA networks are two isolated networks, when a mobile user with a WLAN session moves out of the WLAN area, it will be dropped because there is no vertical handoff mechanism between these two networks. While in the scheme vertical handoff between these two networks is supported, mobile users can handoff to the other network if it is not saturated. Compared with above two schemes, proposed scheme adopts joint session admission management, and QoS in different networks can be guaranteed at the same time.

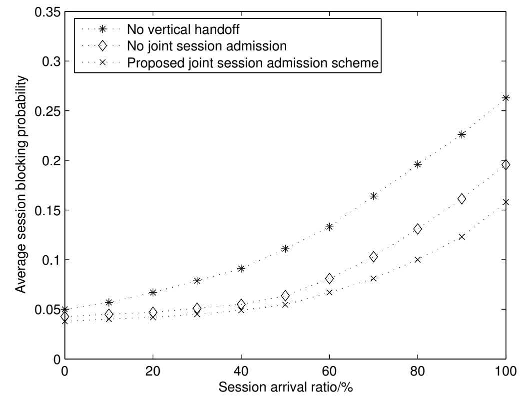

Fig. 2. Session blocking probability versus session arrival ratio.

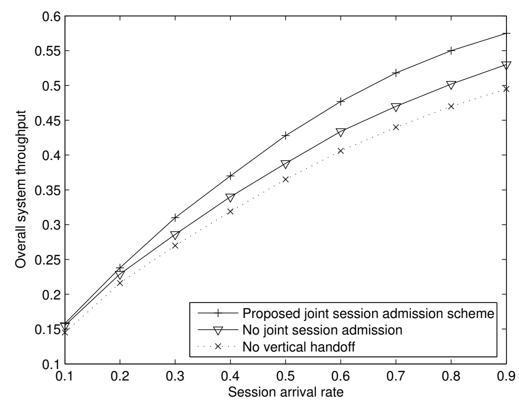

Fig. 3. Overall throughput versus session arrival rate.

Real-time video traffic is considered in integrated WLAN/TD-SCDMA system with a single WLAN cell and a single TD-SCDMA cell. Each video flow is 1.17 Mbps in the WLAN, and video packet size is set to be 1464 bytes. Assume that real-time traffic is 50 percent of total traffic. Only one request will be dealt at a certain moment. Transmission rate for video traffic in the TD-SCDMA is set to be 240 Kbps.

We compare the average reward from the proposed scheme to those of the other two WLAN/TD-SCDMA integration schemes. In case of high loaded, CPA will admit some of the new arrival traffic to WLAN/TD-SCDMA network while TD-SCDMA/WLAN is saturated or nearly saturated, and the other one is light-loaded.

Figure 2 and figure 3 show the average rewards earned in different schemes. We can conclude that in case of fast session growing, the proposed scheme can efficiently decrease session blocking probability compared to other two schemes, and the best overall system performance is earned. While in case of low traffic, the proposed scheme isn't so much better than other

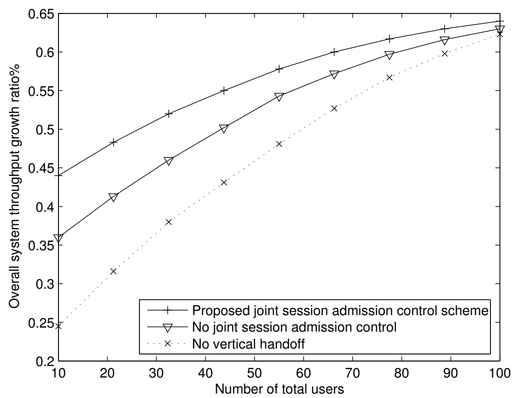

Fig. 4. Overall system throughput growth ratio versus user number.

two schemes. This is because proposed scheme has a joint session management between WLAN/TD-SCDMA networks, all sessions are judged and admitted in an unified way. On the other hand, centralized manage strategy demands AP(access point) and BS(base-station) to report their status periodically, this will consume some of the system radio resource. So in case of low traffic environment, the proposed scheme couldn't earn the best overall system performance.

Figure 3 shows the overall system throughput reward gain with different session arrival rates in integrated system. It is observed that the proposed scheme is more effective than the other two integration schemes. The higher the session arrival rate, the higher overall system throughput gain in the proposed scheme. This is because our scheme can optimally admit some sessions to the other network, thus enhance overall system throughput performance.

We compare the overall system throughput from the proposed scheme to the other integration schemes. Figure 4 shows the system throughput earned in different schemes. We see that overall system throughput earned in the proposed scheme is always higher than the other two schemes, and the least is gained when vertical handoff is not supported. It is observed that the larger user number, the less system throughput growth ratio. This is because both of the WLAN/TD-SCDMA networks become saturated when the user number grows higher enough, and all new sessions will be blocked. Nevertheless, the throughput reward earned in the proposed scheme is much higher than the other two schemes even when the system is high loaded.

V. Conclusions

This study mainly considers how to maximize the overall system throughput and minimize the session blocking probability in integrated WLAN/TD-SCDMA environment. In this paper, we propose an optimal joint session admission control scheme using MDP, which adopts centralized session admission management strategy, and executes automatic session admission control between WLAN/TD-SCDMA networks, so as to ensure higher overall system performance and network revenue gain.

Simulation results show that the proposed scheme can efficiently enhance the performance of heterogeneous wireless networks. Compared with legacy algorithm, proposed scheme can reach higher overall system throughput and lower session blocking probability. Simulation results also indicate that the proposed scheme is applicable in high loaded environment. While in low loaded environment, it's not the optimal one. In addition, the proposed scheme is effective to solve hot spot problem, and is feasible to other heterogeneous wireless network environments, too.

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