A Utility-Based Network Selection Scheme for Multiple Services in Heterogeneous Networks

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Abstract—**It is a trend to integrate different wireless access networks into heterogeneous networks in next generation wireless networks. Network Selection and QoS support for multi-services are two of the most significant issues in heterogeneous wireless networks (HWN). In this paper, we propose a utility-based network selection scheme for HWN, where the price mechanism acting as a lever system guides users to select the most efficient network and controls the allocation of network resources. Simulation results show that the proposed scheme can achieve more total utilities than traditional schemes for the whole networks. The proposed scheme can also balance traffic load between different networks and effectively avoid network congestion while still guarantees QoS for real-time users.**

I. INTRODUCTION

Future wireless networks will be heterogeneous [1]. The heterogeneous wireless networks integrate different access networks, such as IEEE 802.15 WPAN, IEEE 802.11 WLAN, IEEE 802.16 WMAN, GPRS/ EDGE, cdma2000, WCDMA and satellite network, etc. These Pico-, Micro- and Macro-cell and satellites networks often overlap coverage in the same wireless service areas [1]. A typical example is shown in figure.1. In addition, it is a trend that the terminal has multiple radio interfaces for different wireless networks. We call this type of terminal as multi-mode terminal. The user with multi-mode terminal can roam among HWN by seamless handoff.

Therefore, how to select the most efficient and suitable access network to meet a given application's QoS requirement becomes a significant topic in recent years. Traditionally, the network selection is based on the received signal strength (RSS) at the mobile node. Many related works in HWN have been done [2-5]. In [2], there are different signal thresholds for each access network. Mobile node compares the RSS with the signal thresholds and decides handoff procedure. In [3], mobile nodes keep connection with the higher throughput network until RSS goes below a threshold. In [4], service types are considered. Differentiating service is achieved by different levels of RSS. But RSS algorithm is not sufficient to select network in HWN, recent work has already set to study new approaches. In [5], several optimizations are proposed for the execution of vertical handoff decision algorithms, with the goal of maximizing the QoS experienced by each user.

Actually, users in networks are selfish and independent with each other. They do not consider the congestion situation of current network, which may result in overload and affect all users' QoS. Thus, this is a contradiction between limited radio resources of networks and increasing QoS requirements of users. In fact, network selection should depend on some factors, such as availability of network resources, traffic characteristic, radio link quality, and user preferences [5]. In order to enhance the overall utilization and performance of the networks, there must be some mechanisms to guide user's behavior in cooperative ways.

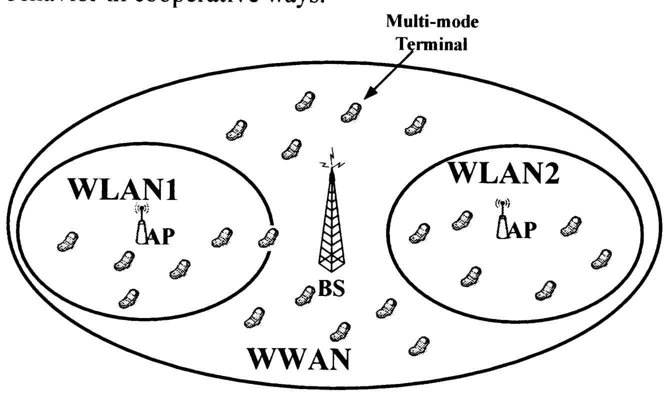

Figure 1. Integrated WLAN/WWAN overlay network

Recently, utility-based microeconomic model as a means has been applied to allocate resources in wire-line networks, e.g. [7] [8]. And they have also been proposed to aid in implementing distributed power control in CDMA wireless networks, e.g. [6] [9]. Generally, these approaches are based on the maximization of the total utilities to efficiently utilize network resource. There is a novel viewpoint that QoS is perception which characterizes the service satisfaction level that a user or upper-layer application obtains from the network [6]. That is, the utility function measures the user's satisfaction level. It is a function of the received QoS. Each service is mapped into a kind of utility function. A "price" mechanism is used to affect users' action. Meanwhile, the "price" can represent the current network condition.

In this paper, our research focuses on a utility-based network selection scheme for multiple services in HWN offering QoS guarantees. In this scheme, based on the microeconomic market theory, utility function represents the satisfaction level of a user or an upper layer application in terms of QoS. The goal of our model is to achieve the optimal resource allocation by maximizing every network's total utilities and efficiently adjusting price to guide user's action.

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To achieve this goal, a set of algorithms are proposed, including network equilibrium price algorithm, network selection algorithm and call admission control algorithm.

The rest of the paper is organized as follows. In Section II, we introduce the utility function of different traffics and formulate the market model to achieve optimal allocation, where resource allocation is controlled by the adjustment of resource price. Then in Section III, a thorough description of the algorithms is given. Section IV simulates the performance of our proposed scheme. Finally, we conclude it in Section V.

II. UTILITY-BASED ECONOMIC MODEL FOR RESOURCE ALLOCATION

A. Utility functions

In terms of microeconomics, utility is a measurement of user's satisfaction level with the perceived QoS. The different forms of utility function characterize different elastic traffics [8]. In this case, the utility function of user i is commonly described by $U_i(R_i)$, which depends on the variable: effective transmission rate. For simple analysis, we neglect some physical layer factors such as channel fading and signal decaying. The form of $U_i(.)$ should be satisfied some features in order to represent the actual satisfaction level. [7], [9] have proposed the following assumptions:

a) $U_i(.)$ is a mono-increment, strictly concave and twice differentiable function, satisfying $U_i(0)=0$ and upper bounded by U_{imax}, the maximal achievable utility of user i.
b) There exists constants k_1, such that for all R, $U'(R) \leqslant k_1$.

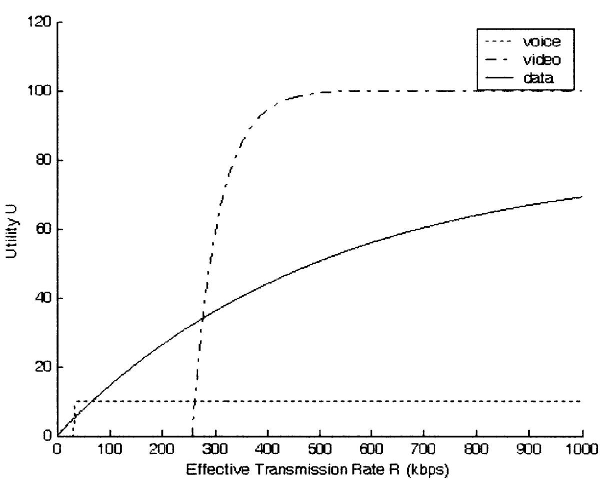

Figure 2. Utility functions of voice, video and data traffic

In some literatures, some kind of utility functions for different traffics have been studied. For example, in [6], it proposed utility functions for three types of applications: voice, video and data. In this paper, voice services is assumed to be CBR (constant bit rate) traffic, its QoS requirements on transmission rate is strict, which can be represented by a step function. To satisfy assumption (a), a steep (high slope) concave function instead of step function are used for voice traffic. Data service is assumed to a type of ABR (available bit rate) and greedy traffic, which means more transmission rate lead higher satisfaction level, an increasing concave function can described its utility. Video service is assumed to be VBR (variable bit rate) traffic, its QoS requirement lie between voice and data, so a slope between voice and data concave utility function is used. Our works follow these utility concepts and build the traffic model with above utility functions, as shown in figure 2.

B. Market model

Assume that the area is covered by several networks, such as WLAN, WCDMA and GPRS, etc. When a user entered this area, its multi-mode terminal can receive several signals which were transmitted by the access point (AP) of WLAN, the base station (BS) of WCDMA or GPRS. Every user or upper layer application subscribes a type of wireless network according to the availability of network resources, traffic characteristic, radio link quality, and user preferences.

Let $y= \{1,...,Y\}$ be a set of wireless networks and $s= \{1,...,S\}$ be a set of services supported by the networks. Considering one class of wireless networks, $\boldsymbol{N_s}= \{N_1,N_2,...,N_S\}$, $\boldsymbol{R_s}= \{R_1,R_2,...,R_S\}$ are two vectors that represent the number of active users and the average data rate for each service, respectively. R is the capacity constraint of the network. $U_s(R_s)$ denotes the utility function of traffic s. We can formulate an optimal problem for maximizing the total utilities over all users as follows:

$$\begin{aligned} &\max_{\mathbf{Rs}} \sum_{s=1}^{S} N_s U_s(R_s) \\ &\text{s.t. } \sum_{s=1}^{S} N_s R_s \le R \end{aligned} \qquad (1)$$

since all of utility functions are assumed to be strictly concave, there must be a unique optimal solution for the rate vector $\boldsymbol{R_s}^*$, which can be found by Lagrangian methods. Lagrange function is defined as

$$\begin{aligned} L(\mathbf{R_s},\lambda) &= \sum_{s=1}^{S} N_s U_s(R_s) - \lambda\left(\sum_{s=1}^{S} N_s R_s - R\right) \\ &= \sum_{s=1}^{S} N_s\left(U_s(R_s) - \lambda R_s\right) + \lambda R \end{aligned} \qquad (2)$$

where λ is Lagrange multiplier, let $\boldsymbol{R_s}^* = \{R_1^*,R_2^*,...,R_S^*\}$ be the optimum rate vector, that the similar method in [6] [7]

$$\mathbf{R_s^*}(\lambda) = \arg\max_{\mathbf{R_s}} L(\mathbf{R_s},\lambda) \quad (3)$$

is employed. To solve (3) problem, let us firstly define the user revenue function as

$$B_s(R_s,\lambda) = N_s(U_s(R_s) - \lambda R_s) \quad (4)$$

Then (3) can reformulate as

$$R_s^*(\lambda) = \arg\max_{R_s} B_s(R_s,\lambda) \quad (s=1,2,\cdots,S) \; (5)$$

Hence, the total utilities maximization problem of the network is spilt into S sub-traffic maximization revenue problems.

In addition, as we know, when $\Sigma^S_{s=1} N_s R_s = R$, there exists optimal solution for the maximization problem in (1), where R

is the overall radio resource that the network can supply, and $\Sigma^{S}_{s=1}N_sR_s$ is the demand of resource that users consume. According to microeconomic theory, if demand meets supply in a market with price λ, it is called the market equilibrium, and the corresponding price λ is the equilibrium price λ^*[10].

C. Revenue maximization for users and market equilibrium for networks

As discussed above, a market model can be divided into two sub-problems by employing pricing between users and networks.

The first sub-problem is how to individually maximize each revenue problem. One user with traffic s is charged a price λ, and is allowed to freely adjust the transmission rate R_s. Then the user revenue maximization problem is as follows

User $(B_s(R_s,\lambda))$*:*

$$\max_{Rs} B_s\left(R_s,\lambda\right) \qquad \left(s=1,2,\cdots,S\right) \quad (6)$$

Note that in this problem the user faces a trade-off between achieving high utilities (by choosing a large transmission rate) and paying low cost (by choosing a small transmission rate). If assumption (a) on utility function holds, the solution must satisfy the first order condition as

$$\frac{\partial B_s\left(R_s,\lambda\right)}{\partial R_s}=0 \quad (7)$$

or

$$U_s'\left(R_s\right)-\lambda=0 \quad (8)$$

To solve (10), we define the demand function D_s.

$$D_s(\lambda)=R_s(\lambda) \quad (9)$$

for $s=1,2,\ldots,S$, let the function $D_s(\lambda)$ be denoted the optimal solution $R_s^*(\lambda)$for the maximization problem (6). $D_s(\lambda)$ can be interpreted as traffic s requests the transmission rate when the price is equal to λ.

Furthermore, if assumption (b) on utility function holds, there exists a constant λ_{smax} for traffic s, such as

$$D_s(\lambda)=0 \quad \forall\lambda\geq\lambda_{s\max} \quad (10)$$

where λ_{smax} is called as the reservation price of traffic s, which means traffic s can afford the highest resource price. In other words, when traffic s is charged more than λ_{smax}, its transmission rate requirement will be zero.

The second sub-problem is to solve the market equilibrium at network side. The goal is to make the resource price λ converge to the equilibrium price λ^*, where supply meet demand for the network resource and the utilization of network is maximized.

Network (λ^*)*:*

$$\lim_{\lambda\to\lambda^*}\sum_{s=1}^{S}N_sR_s=R \quad (11)$$

To obtain the equilibrium price λ^*, we use the fold-half section search. In this market model, the price λ represents the network condition. The price increases as the load gets heavier (restrain user's consumption) and it decreases as the load becomes slighter (encourage use's consumption).

As above analysis mentioned, the optimal resource allocation can be obtained by every user maximizing own revenue, which is a distributed and parallel computing process. Thus, the computational complication of central control node such as AP or BS is significantly alleviated, which make the scheme easily apply to the real systems.

III. Algorithms Description

In this section, equilibrium price algorithm, network selection algorithm and call admission control algorithm are presented. The signal detection module of each terminal is assumed to simultaneously detect the signals of diverse networks. The radio resource management modules of each network store some system and traffic parameters, such as the network capacity constraint R, utility functions $U_s(R_s)$, demand functions $D_s(\lambda)$ and the reservation price λ_{smax} of each traffic.

In addition, different networks have their own characteristics for suitable services. For example, users prefer to access WLAN to download large data files, but would select cellular network to carry on voice calls. So we define p_{sx} $(0< p_{sx}<1)$ to characterize user preference, where index s and x represent the type of service and network, respectively.

A. Equilibrium price algorithm

Since the price λ can represent the utilization of network resources, we design the equilibrium price algorithm to dynamically adjust price λ to the equilibrium price $\lambda*$, which make the utilization of network maximized. The convergence accuracy of algorithm is defined to be ε.

Step1: *Initialize resource price.*
Network initializes λ_{max} *and* λ_{min} *to the maximal and minimal possible price, respectively, and set* $\lambda_{initial} = 0.5(\lambda_{max}+\lambda_{min})$;
Advertise the initial resource price $\lambda_{initial}$.
Step2: *Adjust transmission rate.*
Each user adjust transmission rate R_s *according to the advertising resource price* λ *and the demand function* $D_s(\lambda)$.
Step3: *Adjust price.*
Network make a census of network total throughput $\Sigma^{S}_{s=1}N_sR_s$;
While $(\Sigma^{S}_{s=1}N_sR_s! =R$ *or* $\lambda_{max} - \lambda_{min} > \varepsilon)$
  If $(\Sigma^{S}_{s=1}N_sR_s<R)$
    $\lambda_{max}=\lambda_{current}$; *(fall the price)*
  Else
    $\lambda_{min}=\lambda_{current}$; *(rise the price)*
  End
  Update the current price $\lambda_{current} = 0.5(\lambda_{max}+\lambda_{min})$;
  Advertise the current price $\lambda_{current}$;
  Return to step2;
End
Advertise the equilibrium price $\lambda^*=\lambda_{current}$.

B. Network selection algorithm

Network selection algorithm is designed to guide user's behavior in cooperative ways, and used the parameter of user preference to reduce network congestion and the ping-pong effect during handoff process. User terminal selects the most efficient network according to RSS, resource price and user preference. Three predefine parameter sets are stored in user terminal: $y=\{1,\ldots,Y\}$ is a set of wireless networks, $x=\{1,\ldots,X\}$ is a set of candidate wireless networks (RSS higher than its threshold) and $T=\{T_1,T_2,\ldots,T_Y\}$ is a set of RSS thresholds.

Step 1: *Detect RSS.*
For $y = 1: Y$
Detect the RSS of network y *in a gliding window with length* t_1*;*
Calculate the average value of RSS(y);
If (RSS(y) > T(y))
Network y become candidate network, add it to set x;
End
End
Step 2: *Select network.*
Select the network with the lowest price among candidate network set x, denoted by $x_{min}=argmin_x \lambda_x$*, its price is* $\lambda_{x,\,min}$*;*
If (the call is new call)
Access the network x_{min}*,* $x_{access}= x_{min}$*;*
Else (the call is handoff call)
If $(x_{current} = x_{min})$
Break;
Else
Calculate the ratio of differing on price for two networks as $v = (\lambda_{current} - \lambda_{x,\,min})/\lambda_{current}$*;*
Select user preference parameter p_{sx} *according to service s and handoff target network* x_{min}*;*
Decide to handoff to the target network x_{min} *with the probability* vp_{sx}*;*
End
End

C. Call admission control algorithm

Call admission is based on concept of reservation price $\lambda_{reservation}$ profile, which can guarantee QoS of the end users who have already set up the connection. There are three types of calls, including new call, price handoff call (handoff is aroused by resource price) and mobile handoff call (handoff is aroused by mobility, e.g. users roam from WLAN to WWAN). Different calls have different priorities when accessing.

Step1: *Estimate effect.*
Calculate a temp resource price λ_{temp} *if the network admits new calls or handoff calls.*
Step2: *Compare price and reestimate effect*
If $(\lambda_{temp} < \lambda_{reservation})$
Admit all calls;
Else
Reject the new calls;
Recalculate the temp resource price as λ'_{temp} *if the network admits all handoff calls;*
If $(\lambda'_{temp} < \lambda_{reservation})$
Admit all handoff calls;
Else
Reject the price handoff calls;
Recalculate the temp resource price as λ''_{temp} *if the network admits all mobile handoff calls;*
If $(\lambda''_{temp} < \lambda_{reservation})$
Admit all mobile handoff calls;
Else
Reject the mobile calls;
End
End
End

Let t_1 denote the period of algorithm1 and t_2 denote the period of algorithm2 and 3. Generally, since the algorithm1 can converge a better equilibrium price λ^* in iterated ten times for smaller convergence precision ε, we let $t_2=10\ t_1$. In addition, every algorithm is assumed to work at the beginning of each period.

IV. NUMERICAL RESULTS

In this section, we simulate above algorithms in an integrated cellular and WLAN networks. The simulation scenario consists of one cellular network and two hotspot WLANs. The overlay structure is shown in Figure.1. WLAN1 and WLAN 2 represent 802.11b wireless LANs and WWAN is modeled as a cellular network. Users' roaming [11] is model as the mobile state transition diagram, as shown in Figure.3. It is assumed that the arrival process of users is independent Poisson and the service holding time is exponential distribution. The price advertisement information can be transmitted over the WLAN beacon channel and the cell broadcast channel, respectively.

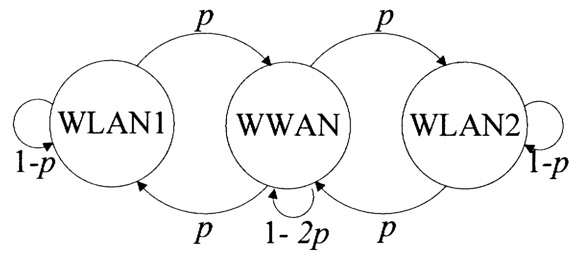

Figure 3. User mobile state transition diagram

Each user carries one type of traffic among voice, video and data. Their utility functions are given in figure.2. For clarity, traffic parameters and system parameters are summarized in Table1 and Table2, respectively. We simulate 1000 seconds in real time. The working period of signal detection module and handoff module of user are both 1 second. The call admission control module and the radio resource management module of networks work 1 time and 10 times per second, respectively. According to above simulation parameters, we compare the traditional RSS algorithms [2] with our algorithms to analyze the performance of our scheme. Figure.4-.8 record a typical simulation process.

TABLE I. PARAMETERS FOR VOICE, VIDEO AND DATA TRAFFIC

Traffic type	Voice	Video	Data
Maximum Utility (utility function)	10	100	80
Displacement (utility function)	32	256	——
Pitch (utility function)	1	0.02	0.002
Reservation Price	17.18	2.02	0.16
Minimum Rate requirement (kbps)	32	256	0
Mobile Parameter *P*	0.05	0.005	0.005
User Preference (WWAN to WLAN)	0.2	0.7	0.9
User Preference (WLAN to WWAN)	0.8	0.3	0.1

TABLE II. SYSTEM PARAMETERS IN OUR SIMULATION

Networks Type	WLAN1	WWAN	WLAN2
Bandwidth (Mbps)	11	4.3	5.5
Arrival Rate	0.25	Departure Rate	0.2
Simulation Time(second)	1000	Converged Precision	0.001
t_1(second)	0.1	t_2(second)	1

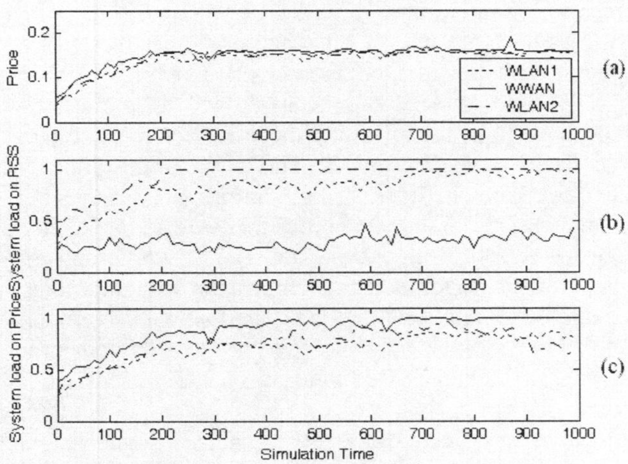

Figure 4. The variation traces of price and network load in WLAN1, WWAN and WLAN2

Fig.4 (a) describes the adaptation of resource price in three networks with varying load in a typical simulation scenario. The results of fig.4 indicate that the trends of traffic load traces in (c) and resource prices fluctuating traces in (a) are similar. It is can be explained as follows. When the network load is enhanced, the resource price will increase. Each user has to consume less resource according to the price or handoff to another available network that the price is lower than current network's price. Thus, the current price will be decreased and the network can provide high quality of service to all users simultaneously or admit more users' access. Another phenomenon is that there exist some sharp values in the price trace in fig.4 (a), which means that the current price is higher than their reservation price sometimes, so that some new arrival users or handoff users are rejected. From fig.4 (b) and (c), we compare network load based on RSS versus Price. After 200 seconds, WLANs traffic load is almost near to 1 by RSS scheme, but WWAN traffic load is always lower, its network utilization only fluctuates at about 30%. Clearly, the network load of different networks is unbalanced when using the RSS scheme. On the other hand, the traffic load based on our proposed price scheme often keep high level, but less overload situations occurs in overall networks. The results indicate that our scheme can rationally use the network resource, effectively avoid networks congestion and balance traffic load between different networks.

Fig.5 compares the total utilities between different networks supported by our proposed scheme with RSS scheme. Obviously, our proposed price mechanism can achieve more total utilities than RSS scheme in every network. Especially, in WWAN, the achieved utilities of price scheme get over 70% gains more than RSS policy. The reason why our scheme attained better utilities is that our scheme sufficiently makes use of WWAN resource, which simultaneously alleviates other networks traffic load. Thus, most real-time users meet high level QoS. The total utilities of WLANs are added.

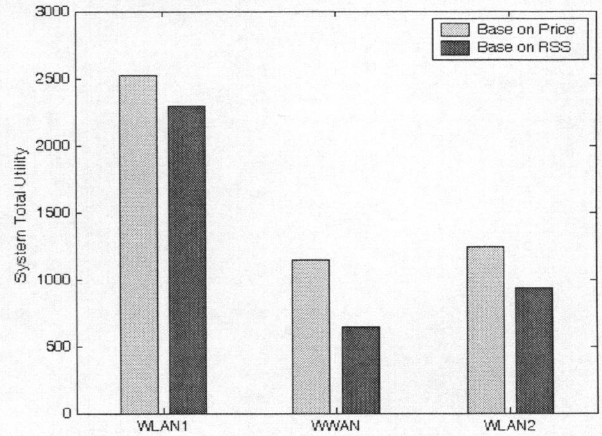

Figure 5. Total utilities in WLAN1, WWAN and WLAN2

Figure 6, 7 and 8 show the achieved utilities trace of voice, video and data users in WLAN1, WWAN and WLAN2, respectively. It can be obvious as follow.

For voice traffic, its achieved utilities keep high level at different network load for both our price scheme and conventional RSS algorithm. This phenomenon can be interpreted that transmission rate demand of voice traffic is lower than that of video traffic and it has highest priority among the traffics. So the network will take precedence to decrease other traffics' rate when the network load is heavy.

For data traffic, since the traffic load is stronger after 200 seconds in WLAN, the utilities of data users keep lower degree. RSS algorithm leads the network load of cellular network being always slight, which results in data users obtaining superior utilities than our scheme. Although data service is always at lower level and even cut off in our scheme under heavy network load, little QoS effect will occur on the whole network because data application is insensitive to delay. From the viewpoint of economics, sacrificing some data users' utilities means a cost to guarantee real-time services.

The main improvement of our scheme versus traditional algorithm is exhibited on the video traffic. The video services often experience jitter and cut off phenomena after about 760 seconds in WLAN1 by RSS scheme, which will result in intolerant intermittent and stagnant image. This case becomes even worse in WLAN2 because its capacity is smaller and the situation of overload frequently appears. As a whole, when using conventional RSS algorithm, although utilities of all users are high in WWAN network, video users are often jittering and shut down in WLAN networks under heavy traffic load, which is intolerant. Conventional RSS algorithm will cause the different network loads unbalanced (e.g. WLAN is congested, while WWAN is idle) and affect all user's QoS.

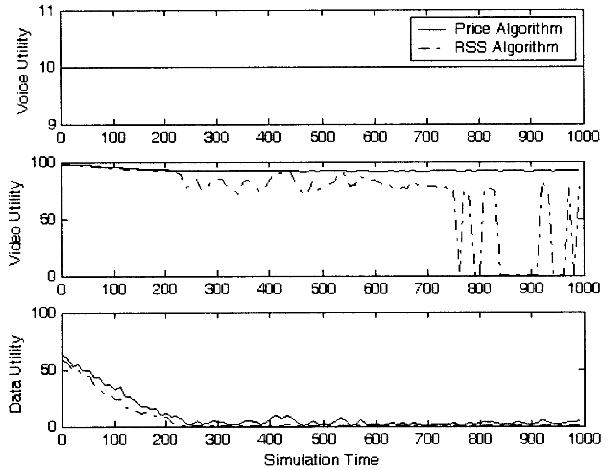

Figure 6. Simulation traces of the achieved utilities of voice, video and data users in WLAN1

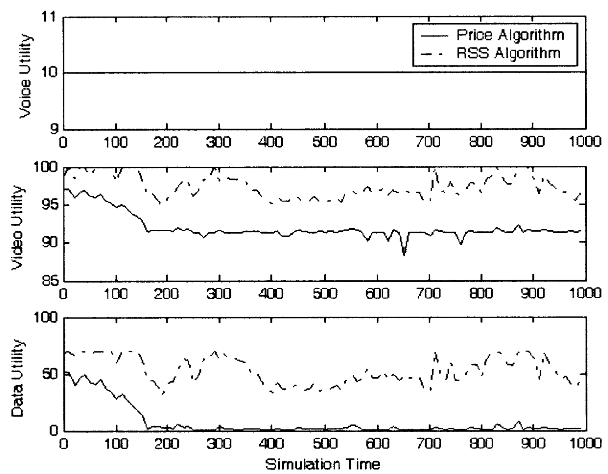

Figure 7. Simulation traces of the achieved utilities of voice, video and data users in WWAN

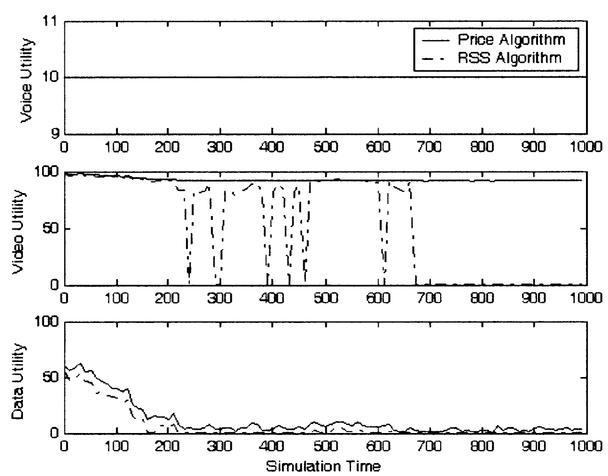

Figure 8. Simulation traces of the achieved utilities of voice, video and data users in WLAN2

In our scheme, although it sacrifices some data users' utilities in WWAN network, it guarantees all real-time users' high level QoS in overall networks. This has shown that our algorithms have a good capability to balance traffic loads between different networks.

V. CONCLUSIONS

In this paper, an optimization radio resource management framework for efficient network selection in HWN was presented. In this framework, the well-known utility functions are used to represent the satisfaction degree of a user or an upper layer application obtaining QoS. The price is considered as a lever to guide user's behavior and to control resource allocation. In order to utilize the microeconomic theory, we formulated a market model. The goal of this model is to maximize the network's total utilities by adjusting the resource price. To implement this model, a serial of integrated network selection algorithms for HWN was proposed. We compared the performance of our scheme with traditional RSS scheme by simulation in an integrated networks composed of WLAN and cellular network. Results show that our proposed scheme can achieve more total utilities than RSS scheme in overall networks, balance the network load and effectively reduce network congestion. The main improvement is that guarantee the real-time services' QoS under heavy traffic load.

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