Using WLAN/3G Dual-mode Terminals and an Algorithm to Enhance The Performance of Dual-mode Mobile Communication Service

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Abstract: 3G/WLAN dual-mode mobile communication service possesses global mobility and roaming with high transmission rate and low communication cost. However, it confronts the drawbacks of long call-origination delay, heavy vertical handoff (VHO) overhead, and unnecessary battery energy consumption. In this paper, we analyze the mobile and call patterns of users to identify the factors represented the condition of the visited communication environment. We also propose a simple mechanism for dual-mode mobile terminals to determine the network system to adopt to avoid the drawbacks. Our results show that the proposed mechanism can effectively alleviate call-origination delay and VHO overhead. Besides, the grade of service of WLANs in dual-mode environments is enhanced.

Keywords: heterogeneous networks, dual-mode, wireless LAN, UMTS, vertical handoff, energy efficient

1 Introduction

The development of communication systems is oriented toward heterogeneous network integration. Wireless LANs (WLAN) provide high throughput and broad capacity to users and considered a low cost solution for wireless access. The population of WLAN and 3G network systems brings the evolution of WLAN-3G integrated services, where WLAN is regarded as a complementary technology to 3G networks because of the limited coverage and considerable mobility management delay. WLAN-3G integration offers ubiquitous communications in high transmission rate, low communication cost, and also supports greater possibilities and opportunities for communication service providers. The approaches of WLAN-3G integration can be classified into 3 levels: protocol-level interworking [1,2], architecture-level integration [3,4], and terminals- and service-level convergence [5,6,7].

Many protocol-level solutions have been reported on interacting MIP and SIP for mobility management. Traditional hybrid MIP-SIP schemes apply MIP and SIP for TCP and UDP mobility respectively, often results in the problem of redundant mobility messages in use for location updates and handoffs [8]. Full integration of SIP and MIP requires additional effort to modify protocol model to support co-located care of address and extended mobile routing model [9]. The major architecture solutions of interaction between 3GPP and WLAN systems are loose coupling and tight coupling. Loose coupling approach provides separate data paths for WLAN and 3G networks, but tight coupling provides a direct integration by connecting WLAN network directly to the 3G core network. Both loose and tight coupling solutions have the drawbacks of heavy burden imposed to the core 3G network and core Internet, also the high latency and packet loss incurred when binding MIP home agents and foreign agents to achieve the intersystem handoff [10]. Service or terminal-level solutions apply WLAN and the 3G system as underlying transmission networks and utilize service capacities of both WLAN and the 3G system by the development of software and hardware applications to realize service and business models. The operation of signaling messages and transmission control are managed by underlying network systems and are transparent to applications and terminals. Compare with protocol- and architecture-level solutions, service and terminal-level solutions require no modification of existing operating protocols and network architectures [11,12]. The cost and

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time for developing a new user-end software or hardware product is much lower. Service-level solutions are the principal in realizing a service model rapidly.

The development of WLAN/3G dual-mode mobile handsets (DMS) is an implementation of terminal- and service-level heterogeneous network convergence. With the ability to send and receive WLAN and 3G signals simultaneously, DMS combines the benefits of WLAN and ubiquitous 3G communication services in a single terminal. While 3G networks are expensive due to the high cost of spectrum acquisition, and the data rate is limited (up to 2Mbps), a DMS will first adopt WLAN for call origination in a dual-mode communication environment where a WLAN and a 3G network coexist to save communication cost. Besides, the energy for transmission in WLAN is half of that in a 3G network [13], adopt WLAN as the preferred network can extend the standby time of a DMS. When a user moves beyond the coverage of WLAN or when the visited WLAN is congested, the DMS adopts 3G system instead automatically. The determination and alternation of network adoption is transparent to users.

However, when a DMS originates a call via a congested WLAN, the fail of a try in WLAN brings extra effort to set up a call via 3G network and results in a long call-origination delay (COD). In addition, the increased signals and processes consume more battery energy. Dual-mode users who often originate calls via busy WLAN may spend a lot of time waiting on call setup and suffer from short standby time of DMS. To avoid the problems, 3G networks shall be given precedence over WLAN in congested hotspots.

For the sake of small and intermittent WLAN service regions, DMS needs to handoff between the 3G system and WLAN frequently. If a DMS moves out of WLAN coverage and enters a 3G cell, or vice versa, an ongoing connection shall be handed over between different network systems and causes a vertical handoff (VHO) process [14]. VHO is an expensive operation while it requires channel reallocations and information exchanges between heterogeneous network systems. If the dwell time of a DMS in a WLAN is short, the expense of VHO may nullify or exceed the communication profit from the connection in the WLAN. From the aspect of network systems, a dual-mode user who moves fast that the dwell time in a WLAN is too short to cover the cost of VHO shall keep on engaging to the visited 3G network rather than be handed over to the WLAN.

For eliminating the drawbacks of long COD, high VHO overhead, and high energy consumption, DMS shall be able to determine which network system to engage to when originating a call or when entering a dual-mode communication environment. But, without the circumstance information of how busy a WLAN is, how large the coverage of a hotspot is, how fast the user moves, and how long a connection will last, a DMS can not make determination. Network systems did not provide the circumstance information to users, therefore network systems and communication protocols should be modified to come out and to share the information with terminals. It is too expensive and too complicated to be a feasible approach.

Every dual-mode mobile user has his unique mobile and call patterns that can be induced from the history of the user's itineraries and the behavior of call originations [15]. The history data can be utilized to infer the condition of the visited communication circumstance, which is helpful in determining the preferred network to avoid the drawbacks of conventional dual-mode service. In this paper we suggest keeping users' mobile and call patterns in their own DMS, and propose a mechanism for DMS to infer the communication condition of visited WLANs. When enhancing a DMS as an intelligent terminal to adopt the proper network system, the drawbacks of dual-mode services can be alleviated effectively.

The content of this paper is organized as follows: First in section 2, we investigate the factors which affect the rate of successful call-originations in the dual-mode environment, and propose an algorithm to determine which network to adopt for communication. Then, we analyze and evaluate the performance of the proposed scheme in section 3 and 4, respectively. Finally, conclusions are drawn in section 5.

2 Decrease COD and VHO overhead

Whereas the energy consumptions of transmission in WLAN is half of that in 3G system, and the communication cost is much cheaper in WLAN, usually WLAN has precedence over the 3G network when a DMS tends to originate a call in a dual-mode communication environment. But a fail of call origination in WLAN results in a longer COD. In addition, the limited and discontinuous coverage of WLAN results in heavy VHO overhead when DMS moves between WLAN and 3G networks frequently. Battery energy is declined along the prolonged COD and frequent VHO. A user who often originates calls in peak time may confront remarkable total prolonged COD. Also the standby-time of his DMS is obviously shortened.

The drawback of long COD and heavy VHO overhead happens when users enter or reside in dual-mode communication environments where WLAN and 3G networks coexist. The traffic load of calls generated in a congested WLAN eventually offers to the 3G communication system, the call origination delay time and DMS energy spend on failed WLAN calls are losses. We tend to avoid unnecessary attempts on WLAN call-generations in congested WLANs.

The major factor which influences the success of call originations is the traffic intensity (or offered traffic) of a communication environment. A WLAN hotspot can be established in public and strategic areas by cellular operators for extending network coverage, or be established by organizations to facilitate internal communications or save communication costs. The traffic intensity of a WLAN varies with the amount of users, the location of the WLAN, and the observation time epoch. When the offered traffic load exceeds the carried load, new arrived calls are blocked or lost.

To prevent long COD, a mechanism to infer the communication condition of the visited WLAN before call setups is needed for a DMS. In this section we analyze users' mobile and calling behaviors to induce the factors of communication conditions of a communication environment. According to the factors a DMS can infer the condition of the visited WLAN. An algorithm is proposed for a DMS to determine which communication network to use to guarantee the QoS. Based on the method we propose, the drawbacks of the dual-mode communication service can be alleviated effectively.

Here we assume the coverage of WLAN hotspots are a subset of the service areas of 3G networks. The WLAN and the 3G modes are both turned on on a DMS.

Issues and problem analysis

Currently user-ends cannot obtain information about the conditions of the visited communication circumstance. Neither WLAN nor the 3G network system provides a mechanism for sharing the information with user-ends. A DMS can only infer the communication condition of a visited circumstance from the history of a user's mobile and call patterns, including when a user used to visit a specific WLAN and how long he used to dwell in the WLAN; it can also calculate the frequency a user originated calls and the possibility of successful call-originations in a specific WLAN. By the gathered and calculated information, a DMS can determine whether it is proper to originate calls via the visited WLAN.

The possibility of successful call-originations decreases along the increase of the traffic intensity. Users experience the condition of the visited communication circumstance when originating calls. For representing the condition of the visited communication circumstance and how much a user relies on the WLAN, a DMS needs to keep the IDs of the visited WLANs in which calls were originated, the frequencies of call-originations in every visited WLAN, and the probability calls were successfully originated. The probability of successful call-originations in the peak time and the off time can be very different, the observation epoch must also be considered as a parameter of communication conditions.

From another point of view, the drawback of high VHO overhead results from the small and intermittent WLAN service regions. A connecting DMS moves across the border of 3G and WLAN networks causes VHO process to hand over an ongoing connection to a heterogeneous network. The WLAN communication profit from a user depends on how long the communication holds in the WLAN. If a hotspot is small, or a dual-mode user moves fast, the dwell time in the WLAN could be too short to cover the VHO cost. A connection shall not be handed over to WLAN when the VHO overhead is expected to be heavy. For users who have routine itineraries, DMS can learn the average call-holding time in a specific WLAN, and determine if VHO overhead is heavy. DMS can learn the average VHO overhead from users' moving patterns. A DMS notes VHO and the call lasting time in WLANs as information to denote the VHO overhead.

As a result, the parameters which represent the call and mobile patterns of dual-mode users, and the communication conditions of the visited WLAN can be concluded as the following:

1. The identifiers of visited WLANs (*SSID*). Every WLAN has a unique service set identifier (SSID).
2. DMS keeps SSIDs of WLANs via which calls were originated.
3. The average call holding time in a WLAN (*t_call*).
4. The epoch to visit a WLAN ($epoch_i$). The grade of service (GoS) of a WLAN differs from the observation epoch. The time of a day can be divided into several epochs to distinguish the communication circumstances of every WLAN.
5. The frequency a DMS originated calls in the communication circumstance ($call_i$).
6. The frequency of successful call-originations ($scall_i$).

Table 1. An entry of circumstance record on a DMS

<table>
<tr><td rowspan="2">WALN ID ($SSID_i$)</td><td rowspan="2">Call lasting time (t_call_i)</td><td>$epoch_1$</td><td>$call_1$</td><td>$scall_1$</td><td>lmt_1</td></tr>
<tr><td>$epoch_2$</td><td>$call_2$</td><td>$scall_2$</td><td>lmt_2</td></tr>
</table>

The last modified time of an entry (lmt_i) is aim for management purpose.We propose to maintain these parameters in users' DMS to log users' call and mobile habits, and to estimate the condition of the visited communication circumstance. The parameters relate to every communication circumstance are listed in Table 1. Since the memory of a DMS is limited, the oldest entry of the record will be removed when the memory runs out.

For avoiding long COD and frequent VHO, a set of rules to determine which network system to adopt in dual-mode environments is important.

Algorithm design

There are two reasons to give precedence of WLAN over 3G for dual-mode communication: The trials of call-originating in a congested WLAN must fail and must be regenerated via 3G network. That is, the traffic load generated by the calls happened in congested WLAN finally is offered to 3G networks, no matter WLAN or 3G is given precedence. Besides, the power consumption of DMS transmission in WLAN is half of that in 3G, WLAN is the preferred network of DMS in dual-mode communication environment.

Based on the concept of saving communication cost, a DMS adopts a WLAN for communication if the WLAN is first-time visited, and adds the circumstance information of the WLAN to DMS record. A modest communication circumstance represents high possibility of successful call originations, users are encouraged to utilize it for communication. In other respects, a user who often originates calls in a specific communication circumstance is considered as strongly relies on the circumstance. Even in the peak time, the user may like to originate calls via the WLAN to take chance. However, when users suffer from the frequent fails of the try, they are suggested adopting 3G network directly for shortening COD.

The coverage of WLAN is limited. While VHO is costly, frequent VHO is a notable drawback of dual-mode communication service. When the expected profit from a user will not exceed the operation cost of VHO, an ongoing call shall not be handed over to the visited WLAN. For a WLAN, the profit relates to the call holding time in the WLAN, which grows linearly as the total call lasting time. For users whose dwell time in WLAN is short shall adopt 3G network for communication. Thus the communication resource of WLAN and the 3G network can be utilized more efficiently.

The procedure of determining which network system to adopt is shown in Fig.1.

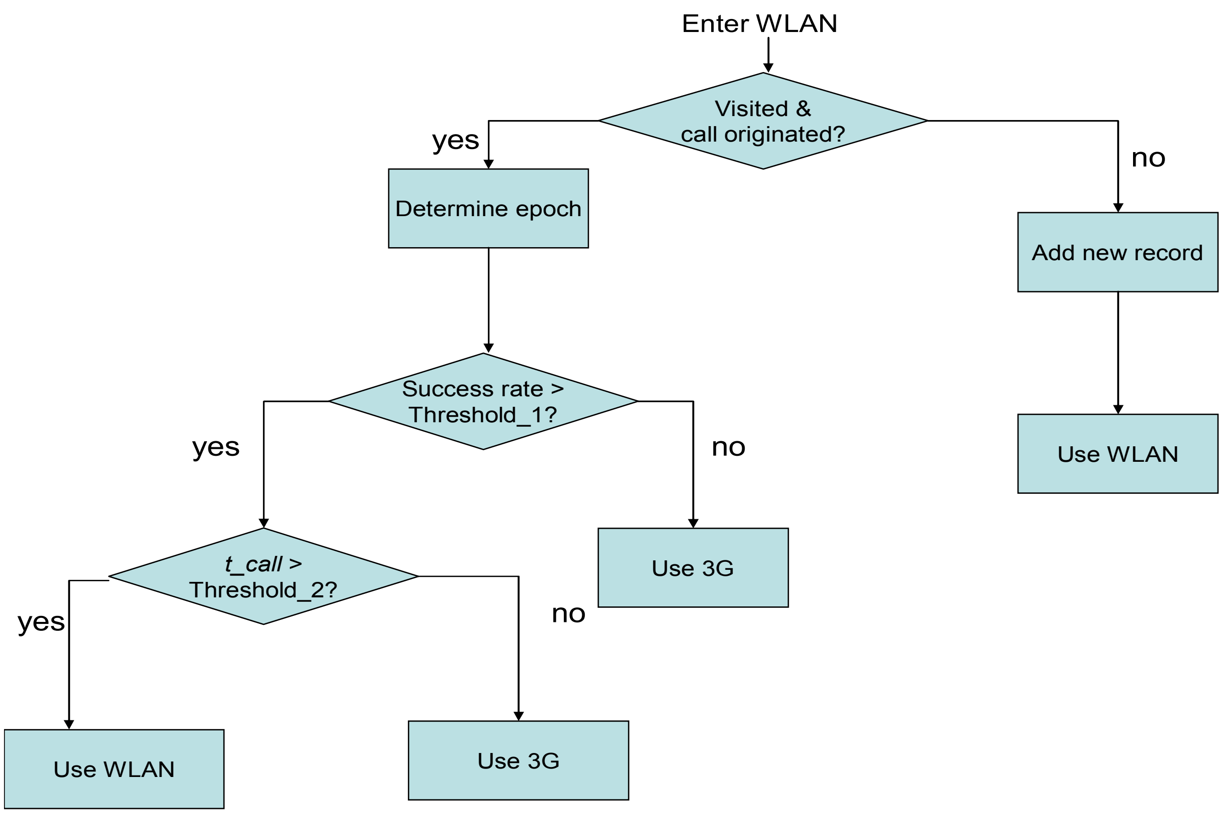

Fig.1. The procedure for choosing a communication network

- Step 1: initialization

  A DMS checks the SSID of a WLAN after receiving the characteristics beacons of a WLAN and try to originate a call. The DMS increases the call-origination frequencies of the WLAN when a corresponding record exists; otherwise, it adds a new record for the WLAN.

```
If (ssid_i exists) {
  determine epoch j;
  call_j++;
} else {
      create a record of ssid_i;
      determine epoch j;
      call_j++;
}
```

- Step 2: determination:

  The rate of successful call originations represents the communication condition of a WLAN. In a modest WLAN, users are encouraged to utilize WLAN for communication. If a user often originated calls via the WLAN, it implies the user strongly relies on the WLAN. Even if the WLAN is busy, users may like to try the WLAN. In the two cases, WLAN is given precedence of call originations.

  From WLAN operators' viewpoint, if the expected revenue from a user may exceed the cost of VHO, the user is welcome to use the WLAN. For a user whose dwell time in a WLAN is too short to generate profit, the user shall keep on engaging to the 3G network rather than be handed over to the WLAN.

  The algorithm for determining which network system to adopt is depicted in the following:

```
If ((visit_i == 1) && (call_j >0)) {
  // The first time the user visit WLAN in epoch j, and the user has stayed for a long time
  Use WLAN to make a call;
  call_j ++;
} else if ((scall_j/call_j) > threshold_1) {
  // the rate of success-calls is high
  Use WLAN to make a call;
  call_j ++;
} else if (t_call_i > threshold_2)          {
  // the call lasting time in this WLAN is long enough to cover VHO cost
  Use WLAN to make a call;
} else {
  Use 3G to make a call;
}
```

- Step 3: adaptation:

  After a call originated via WLAN is terminated, the DMS recalculate the average call holding time in the WLAN. Besides, an adaptation mechanism is invoked to update the record to present the condition of the communication circumstance.

```
If (success) {
      scall_j ++;
} else {
      // a chasten mechanism
      call_j --;
      scall_j --;
}
```

  While $call_j \geq scall_j$, according to the inequality $(y/x) \geq (y-1)/(x-1)$, where $x,y>0$ and $x>y$, decrease the value of ($scall_i$ /$call_i$) also decrease the opportunity of originating calls via WLAN.

For dual-mode users who have routine mobile and call patterns, the inferred possibility of successful call-originations and the call lasting time are close to the realities, thus the circumstance information will be really helpful. In some special cases such as parades or festivals, the traffic intensity increases suddenly that can not be inferred from the history data, and the algorithm will not be helpful.

3 Analysis model

The algorithm is applied to DMS to shorten COD in dual-mode communication environments, to decrease VHO overhead for communication systems, and to alleviate energy decline of DMS. The proposed algorithm benefits the users who usually originate calls successfully or have long dwell time in WLAN. But it is unfavorable to the users who have short dwell time or who often visit WLAN in busy periods. By preventing call-originations that attempt to be failed in WLAN, the grade of service of WLAN is improved. Meanwhile, the algorithm avoids unnecessary VHO, thus the available channels can be utilized to higher profit communications.

In this section we analyze the benefit of the proposed mechanism by evaluating the shortened COD and prevented unnecessary VHO.

3.1 Shortened COD in the user-end

Assume in the observation period of time t a WLAN is in the steady state. The average amount of users in the WLAN in (0, t) is m, and the call-origination rate of the i_{th} user is λ_i.

When the traffic intensity exceeds the carried load of a WLAN, new arrived calls will be blocked or lost. Without the record in DMS and the algorithm we proposed, the rate of successful call-originations in the WLAN is p_1, $0\le p_1 \le 1$. Let the duration a user dwell in a WLAN is generally distributed. Let $g(x)$ denote the density function of the dwell time in a WLAN. The average dwell time of the i_{th} user is $t_{dwell}=\int_{x=0}^{t} xg(x)dx$. In this analysis, all the users are considered to generate the same pattern of traffic. The average traffic a user generates in a time unit is Erl. The carried load of the WLAN is $\sum_{i=0}^{m} p_1 \cdot \lambda_i \cdot t_{dwell} \cdot Erl$. (1)

The calls failed to be originated via WLAN will be re-originated via a 3G network. The amount of re-originated calls (lost calls) is $\sum_{i=0}^{m} (1-p_1) \cdot \lambda_i \cdot t_{dwell}$ (2)

By applying the proposed method to DMS, p_2 of the calls are originated via 3G network directly, where $0\le p_2 \le 1$. The new traffic intensity of the WLAN becomes

$$\sum_{i=0}^{m} (1-p_2) \cdot \lambda_i \cdot t_{dwell} \cdot Erl \quad (3)$$

When the offered traffic load exceeds the carried load of the WLAN, the excess traffic load will be lost. The amount of lost calls can be represented as

$$\sum_{i=0}^{m} (1-p_1-p_2) \cdot \lambda_i \cdot t_{dwell} \quad (4)$$

Let the response time of call-origination in WLAN be t_{WLAN}, the total shortened COD = (reduced number of lost calls) × t_{WLAN} = $(\sum_{i=0}^{m} \lambda_i \cdot p_2 \cdot t_{dwell}) \times t_{WLAN}$. (5)

3.2 Avoided VHO and broadened serviceable carried load in a WLAN

The proposed algorithm can effectively avoid unnecessary VHO when dual-mode users have routine itineraries and call patterns. In addition, the transmission resources can be applied to high profit communications. In this section we investigate the amount of avoided VHO and the alleviated traffic intensity of WLAN to show the benefit of the proposed method.

Call arrivals and departures in a WLAN in the dwell time of an observer (t_{dwell}) are Poisson processes with call arrival rate λ and departure rate μ, respectively. When the offered traffic exceeds the capacity of a WLAN, the WLAN becomes congested, and new arrived calls will be blocked or lost. We use ρ to represent the utility of the WLAN, $\rho = \max(\lambda/\mu, 1)$. In a WLAN, the offered traffic load is λt_{dwell}, and the carried load is ρt_{dwell}.

According to the proposed algorithm, a user whose dwell time in a WLAN which is too short will not be handed over from a 3G network to the WLAN. Assume the traffic load which can be alleviated by the algorithm is $\lambda_1 t_{dwell}$ in average, the offered traffic load becomes $(\lambda-\lambda_1)t_{dwell}$, and the number of lost or blocked calls can be represented as $(\lambda-\lambda_1-\rho)t_{dwell}$.

Another important factor for measuring the performance of dual-mode service is the VHO overhead. As shown in Fig.2 (a)-(c), a VHO (the shadows in Fig.2) occurs when an ongoing call lasts to different network systems. Where ts_i and tt_i denote the time the i_{th} call began and terminated, to_i and th_i denote the time the observed DMS entered and left a WLAN, respectively. Calls arrive randomly in the observation period of time, thus the call holding time in a WLAN is proportional to the dwell time in a WLAN. Without applying the proposed algorithm, VHO occurs when a call lasts to the service region of another communication system. The

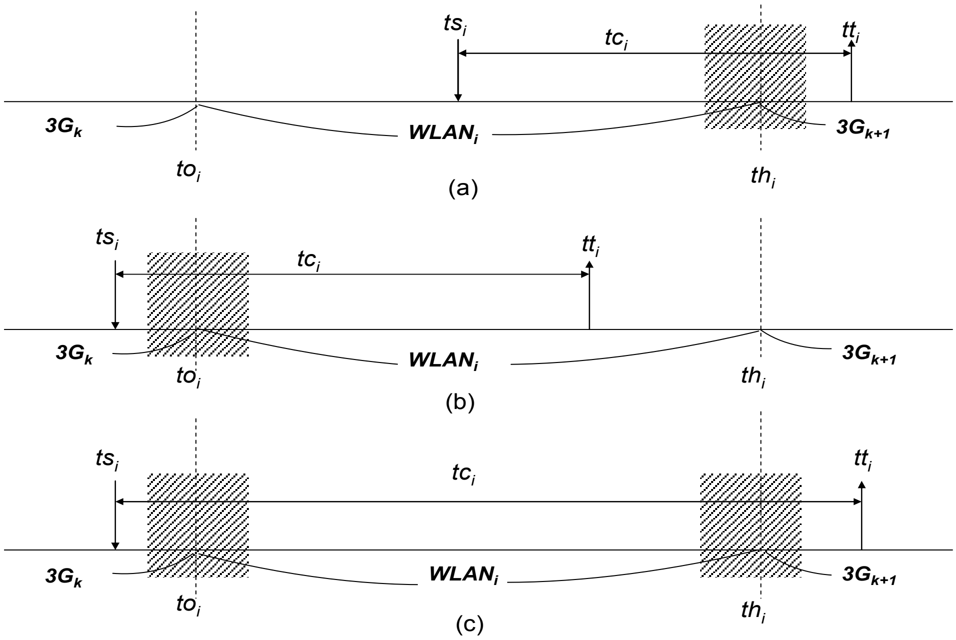

Fig.2. VHO timing diagram

probability of VHO is $p_{vho}= P\{call\ lasting\ time > call\ holding\ time\ in\ a\ WLAN\} \cong P\{(tt_i - ts_i) > (th_i - to_i)/2\} = P\{tc_i > (th_i - to_i)/2\}$.

By applying the proposed algorithm, when the average call holding time in a WLAN is inferred to be less than a threshold, the call will not be handed over to a WLAN. The amount of avoided VHO is $\lambda_1 t_{threshold}$. As a consequence, the potential traffic offered by the users is left out from the WLAN, and the extra transmission resource can be applied to other connections.

4 Performance evaluation

The proposed method allows DMS to infer the condition of a communication circumstance by the maintained history data, and to adopt the proper communication systems to shorten COD and to avoid unnecessary VHO. Thus, the WLAN communication resource can be utilized more effectively. For evaluating the performance of the proposed method, we estimate the amount of VHO and shortened COD when applying the purposed method, and compare the call loss rate of the purposed method and the conventional dual-mode communication service.

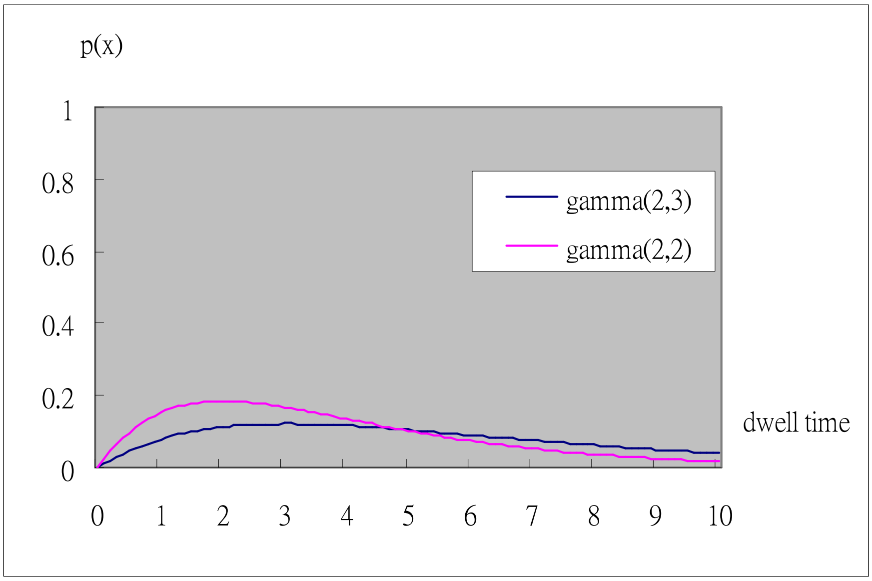

Fig.3. Probability intensity function of users' dwell time

Mobile users may move through the coverage of a WLAN on foot or by vehicles. The resident time of a user in a WLAN ranges from seconds when moving by a high speed train to minutes for pedestrians, even lasts for hours in an office building. To represent the resident time of different kind of users in a WLAN, the distribution of a user's resident time is represented by a gamma distribution function. The probability intensity function is shown as in Fig.3.

The proposed method sets a threshold of call holding time in a WLAN for preventing unnecessary VHO, where the value of threshold is set based on the average VHO delay or the accounting policy between WLAN and the 3G networks (e.g., 2 times of the VHO delay). When the average call holding time in a WLAN is too short to bear the VHO cost, the visited 3G network is adopted for call origination to prevent VHO. While a call in a WLAN is randomly started, the call holding time in a single WLAN is proportionally depends on the dwell time of a user in a WLAN.

The amount of traffic load which is generated by the avoided unnecessary VHO is shown in Fig.4 and Fig.5. Users whose average call holding time in a WLAN didn't exceed the threshold will not be handed over to the WLAN; thus, 10.5% and 28.2% of VHO can be avoided during off time and peak time, respectively.

Users who adopt 3G network directly need not to wait for the fail of call-originations in WLAN, thus the COD can be shortened. Assume the response time of call-origination in WLAN (t_{WLAN}) is 1 second. The average amount of users in a hotspot of a train station is 30000 in peak time, the calling rate of a user in the WLAN is 30% in average, and the rate of successful call origination is 70% without applying the proposed method. The success rate of call originations increases along the adaptation of the proposed algorithm. When the 30%

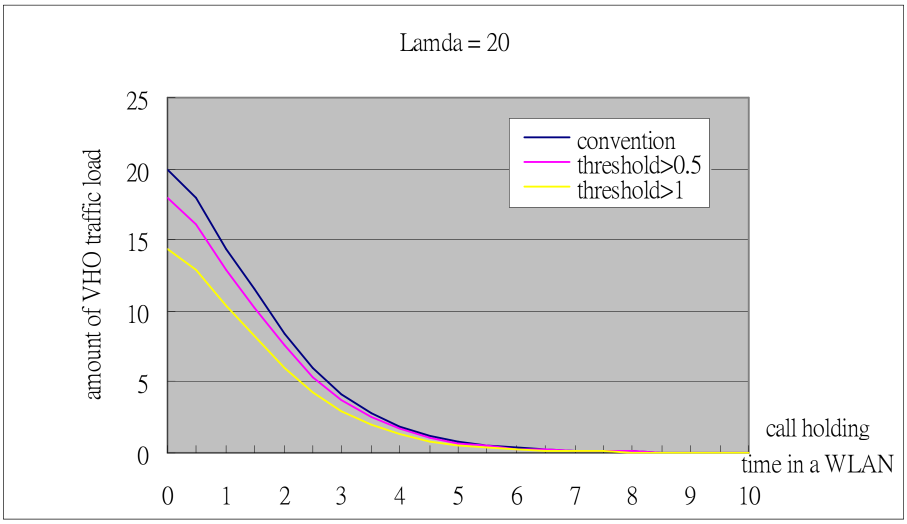

Fig.4. The amount VHO traffic load (off time)

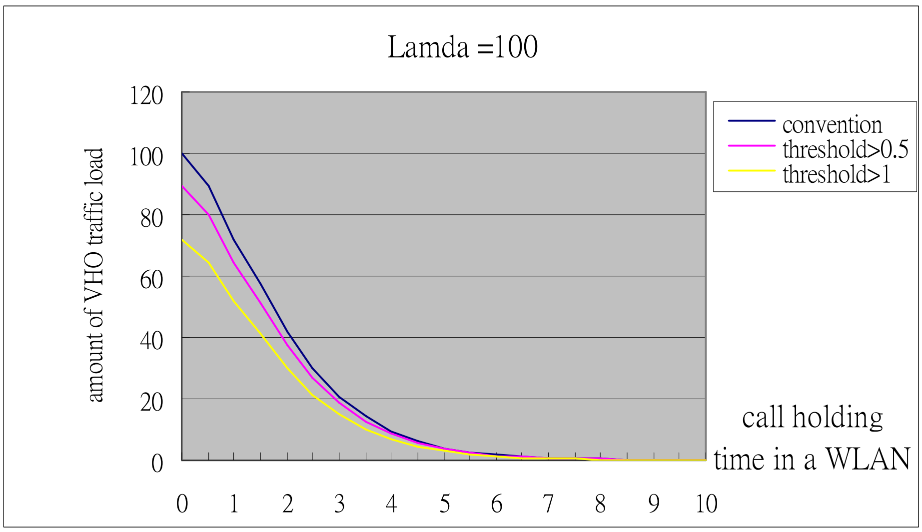

Fig.5. The amount VHO traffic load (peak time)

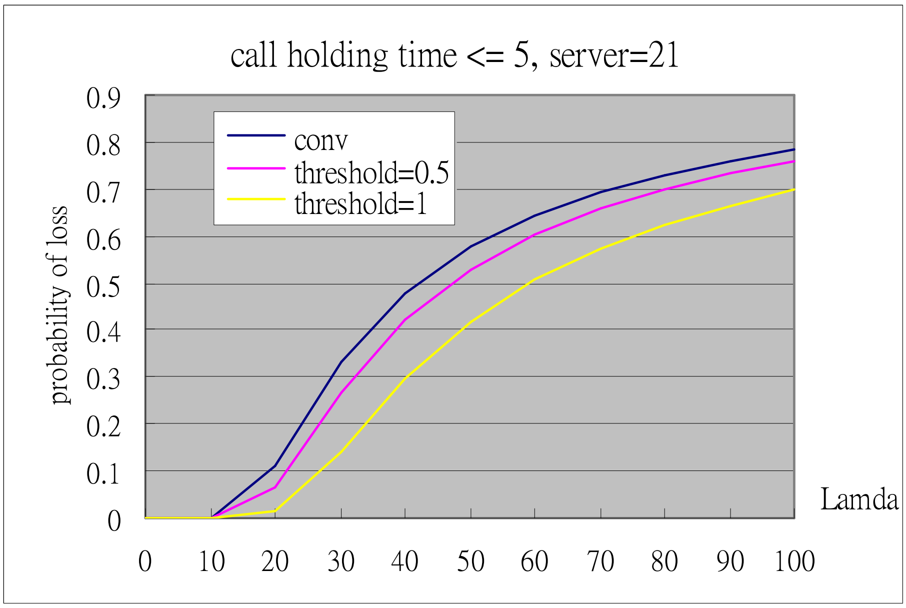

Fig.6. The probability of loss

unsuccessful calls are originated from 3G network directly, the total shortened COD is 2700 seconds (45 minutes) during a single peak time period. For users who have routine itineraries and call patterns, the proposed method can save them remarkable waiting time and battery energy.

Users who often fail to originate calls via WLAN, or the call holding time in a WLAN is too short will be forced to adopt 3G network directly for communication by the algorithm. Thus, the congestion of busy WLAN can be alleviated and the call block and loss rate can be reduced. As shown in Fig.6, the proposed algorithm effectively reduces 10% of call losses in the peak time (100 call arrivals per sec), and 24.83% in the off time (50 call arrivals per sec).

5 Conclusion

Long call-origination delay (COD) and high VHO overhead are the common drawbacks of WLAN/3G dual-mode mobile communication service. The drawbacks results in more battery energy consumption and shortened the standby time of dual-mode mobile handsets (DMS). In this paper we proposed a service and terminal level solution to overcome the drawbacks. We study the mobile and calling behavior of dual-mode users to analyze the factors represented the condition of the communication environment and proposed to keep the factors in DMS. Also we propose a very simple algorithm, which is easy to implement on DMS, to infer the condition of the visited communication circumstance and to determine the preferred network to avoid the drawbacks of dual-mode services. Without changing existing communication architecture and protocols, the proposed method has the advantages of low complexity, easy to develop and implement, and the development cost is low.

We also evaluated the efficiency of the proposed method by establishing a simulation model to show that COD and VHO overhead of dual-mode communication service are alleviated effectively. Accordingly, the communication resource of WLAN and the 3G network can be utilized more efficiently, and the battery energy consumption is alleviated that the standby time of DMS is extended.

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