A Study on RAT Selection Algorithms in Combined UMTS/GSM Networks

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ABSTRACT

The future wireless network is expected to be a heterogeneous system, which integrates different Radio Access Technologies (RATs) through a common platform. A major challenge arising from this heterogeneous network is Radio Resource Management (RRM) strategy. Common RRM (CRRM) has been proposed in the literature to jointly manage radio resources among a number of overlapped RATs in an optimized way. Currently, the RAT selection algorithm is one of the key research areas of CRRM. This paper studies RAT selection algorithms in co-located UMTS/GSM networks. In this paper, a three-complex algorithm called IN*VG*Load is proposed based on improvements on the IN*VG algorithm. The simulation results show that the IN*VG*Load algorithm can optimize the system performance in highly loaded combined UMTS/GSM networks. A new algorithm suitable for low to medium loaded UMTS/GSM networks is also proposed and simulation results are presented in this paper.

1. INTRODUCTION

The future wireless network is expected to be a heterogeneous system, which integrates different overlapped Radio Access Technologies (RATs), such as Global System for Mobile Communications (GSM) and Universal Mobile Telecommunications System (UMTS), through a common platform. A major challenge arising from this heterogeneous network is the Radio Resource Management (RRM) strategy. Currently, RRM strategies are implemented independently in different kinds of RATs. Individually, these RRM strategies work well in the RATs that they are designed for. However, none of them is suitable for the heterogeneous network because each RRM only considers the situation of one particular RAT. In order to solve this problem, Common RRM (CRRM) strategy has been proposed in the literature to coordinate radio resource utilization across a number of different RATs in an optimized way. Simulation results in [2, 3] prove that CRRM can significantly improve system performance in terms of blocking/dropping probability and user throughput.

RAT selection algorithm (including initial RAT selection and vertical handover) is one of the key research areas in CRRM. A suitable RAT selection algorithm can maximize system performance by allocating users to the most suitable RAT in the case of two or more RATs located in the same coverage area. A basic RAT selection algorithm proposed in [3] is Load Balancing (LB) based where new arriving users are allocated to the least loaded RAT to reduce blocking/dropping probability. A number of LB based RAT selection algorithms have been studied in the literature including fixed load threshold algorithm [2, 3] and adaptive load threshold algorithms [4, 5]. However, these algorithms improve system performance only when the number of overlapped RATs is three or more [2, 3]. Different algorithms have to be studied where only two RATs overlap in the same coverage area. This paper focuses on the study of RAT selection algorithms in combined UMTS/GSM networks. Based on the existing policy-based RAT selection algorithms introduced in the literature, two improved algorithms have been proposed to enhance system performance for both of high and low to medium loaded combined UMTS/GSM networks.

The rest of this paper is organized as follows. Section II reviews existing RAT selection algorithms for combined UMTS/GSM networks and proposes an improved algorithm suitable for highly loaded combined UMTS/GSM networks. Section III proposes a new RAT selection algorithm that is suitable for low to medium loaded combined UMTS/GSM networks. Section IV describes the simulation environment and Section V compares the performance of different RAT selection algorithms via MATLAB simulations. Finally, conclusions are drawn in Section VI.

2. IMPROVEMENTS ON CURRENT RAT SELECTION ALGORITHMS FOR COMBINED UMTS/GSM NETWORKS

As mentioned in the previous section, LB based RAT selection algorithms are unsuitable for co-located UMTS/GSM networks. So, RAT selection algorithms based on network and service characteristics are studied in the literature. In [1], three basic RAT selection policies are introduced: Voice GSM (VG) policy, Voice UMTS (VU) policy and Indoor (IN) policy. Although these policies are proposed for initial RAT selection, they can be applied to vertical

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handover too. The only difference is to implement them based on predefined time interval rather than on new user's arrival. The VG policy always allocates voice users into GSM and interactive users (e.g. web browsing users) into UMTS. The VU policy works in the opposite manner to VG and allocates voice users to UMTS and interactive users to GSM. The IN policy allocates indoor users to GSM and outdoor users to UMTS.

The simulation results in [1] show that the VG policy outperforms VU policy when the cell radius is larger than 1km. The main reasons are two-fold. From the voice users' point of view, UMTS users at the cell edge will experience more transmission errors due to the power limitations and the interference-limited nature of WCDMA technology. From the interactive users' point of view, they can get a higher bit rate in UMTS as long as it has sufficient resources.

The simulation results in [1] also show that the IN policy outperforms a reference random policy (where users are allocated randomly to GSM or UMTS with equal probability). This is because indoor users cause higher interference levels than outdoor users in WCDMA systems due to the additional penetration loss, which will degrade the overall system performance [6].

A drawback of the above basic policies is that if the capacity of the preferred RAT is full, the service request will be blocked or dropped even though there are free resources in another RAT. This will cause high blocking/dropping probability and inefficient usage of resources.

In order to solve this problem, a number of two-complex policy-based algorithms are proposed: VG*IN, IN*VG and VG*VU [1]. They are defined as a combination of two basic policies. The general format is Policy 1*Policy 2. Service sessions are allocated based on Policy 1 first. If the capacity of the preferred RAT is full, service sessions will be assigned according to Policy 2. For example, under the VG*IN algorithm, an outdoor voice user will be allocated to GSM according to the VG policy. If the capacity of GSM is full, the user will be assigned to UMTS according to the IN policy. In these two-complex algorithms, a service request is blocked or dropped only when both Policy 1 and Policy 2 are violated. So the blocking/dropping probability can be significantly reduced compared to the basic policies. Table I compares the differences of the three two-complex algorithms in terms of RAT selection priority.

From Table I, it can be seen that for VG*IN and IN*VG algorithms, indoor voice users and outdoor data users still only can be assigned to one particular RAT. They can be further improved by allowing them to be allocated to another RAT when the capacity of the preferred one is full. Table II shows the improved VG*IN and IN*VG algorithms.

Table 1: *COMPARISON BETWEEN VG*IN, IN*VG AND VG*VU ALGORITHMS*

Service type	VG*IN	IN*VG	VG*VU
Voice and indoor	Select GSM only	Select GSM only	Select GSM first and then UMTS
Voice and outdoor	Select GSM first and then UMTS	Select UMTS first and then GSM	Select GSM first and then UMTS
Data and indoor	Select UMTS first and then GSM	Select GSM first and then UMTS	Select UMTS first and then GSM
Data and outdoor	Select UMTS only	Select UMTS only	Select UMTS first and then GSM

Table 2: *IMPROVED VG*IN AND IN*VG ALGORITHMS*

Service type	Improve VG*IN	Improve IN*VG
Voice and indoor	Select GSM first and then UMTS	Select GSM first and then UMTS
Voice outdoor	Select GSM first and then UMTS	Select UMTS first and then GSM
Data and outdoor	Select GSM first and then GSM	Select GSM first and then UMTS
Data and outdoor	Select UMTS first and then GSM	Select UMTS first and then GSM

From Table II, it can be seen that the improved VG*IN algorithm becomes the same as VG*VU. The improved IN*VG algorithm becomes a three-complex policy-based algorithm: IN*VG*Load. The Load policy allocates users to the least loaded RAT. For example, for indoor voice users, if the capacity of GSM is full, they can be allocated to UMTS according to the Load policy. In a highly loaded combined UMTS/GSM network, the IN*VG*Load algorithm is expected to optimize system performance by minimizing the number of indoor users in UMTS. However, it is not expected to work well in a low loaded combined UMTS/GSM network. The main reasons are two-fold. First of all, allocating indoor data users to GSM is not a good choice when there are sufficient resources in UMTS. Secondly, allocation of outdoor voice users to UMTS may decrease the throughput of data users in UMTS. A new algorithm aiming to optimize system performance in a low to medium loaded combined UMTS/GSM network will be introduced in the next section.

3. A PROPOSED RAT SELECTION ALGORITHM FOR COMBINED UMTS/GSM NETWORKS

The purpose of proposing a new algorithm is to minimize the blocking/dropping probability of voice calls while maintaining a high throughput for interactive users in a low to medium loaded combined UMTS/GSM network. The proposed algorithm is summarized in Fig. 1.

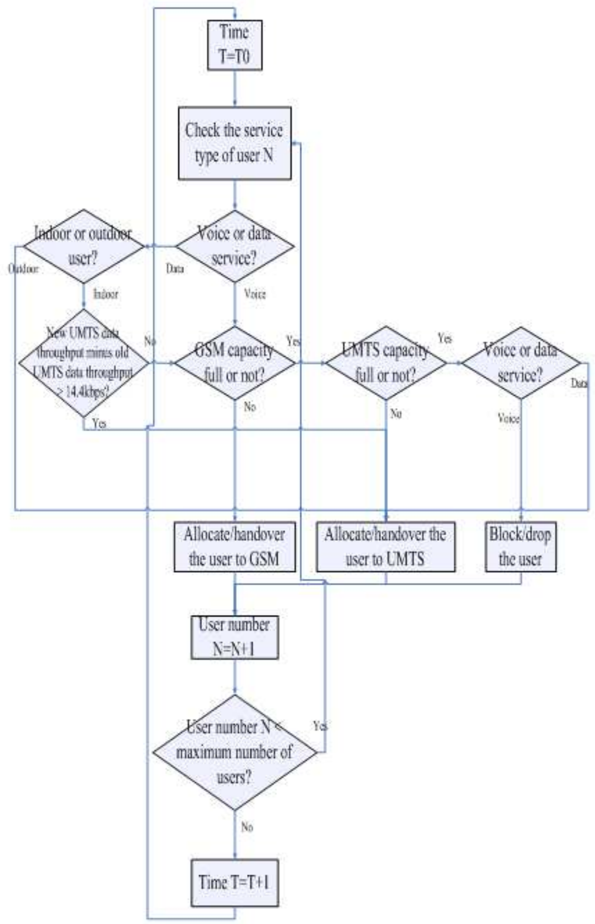

Fig.1: *Proposed RAT selection algorithm*

The proposed algorithm considers all of the VG, IN and Load policies. It also makes RAT selection decisions based on the difference between new and old UMTS data throughputs. In this algorithm, voice calls are allocated to GSM first. If the capacity of GSM is full, they will be served by UMTS. This is because allocation of voice calls into UMTS may decrease the throughput of interactive users serving by UMTS. Data and outdoor services are allocated to UMTS because they satisfy both VG and IN policies. For data and indoor services, if the new data throughput of UMTS (the data throughput of UMTS including the new arriving data user) minus the old data throughput of UMTS (the data throughput of UMTS before adding the new arriving data user) is larger than 14.4 kbps, it is allocated to UMTS. Otherwise, if the capacity of GSM is not full, it is allocated to GSM. If the capacity of GSM is full, it is allocated to UMTS. The rationale of the new algorithm is as follows. In GSM, data services can obtain a bit rate up to 14.4 kbps. If a new arriving data user is allocated to GSM, the overall data throughput will be increased by 14.4 kbps. If the new UMTS data throughput is larger than the old one plus 14.4 kbps, it means that allocating the new arriving data user into UMTS can obtain a higher overall throughout of data services than allocating it to GSM. So, the new data user should be allocated to UMTS. Otherwise, it should be allocated to GSM. This proposed algorithm is expected to maximize the overall data throughput in a low to medium loaded combined UMTS/GSM network by using the throughput comparison function. Simulations will be down to prove our expectations.

4. SIMULATION ENVIRONMENT

MATLAB simulations have been done to compare the performance of three RAT selection algorithms: VG*VU, IN*VG*Load and the one proposed in Section III. It is assumed that a UMTS cell and a GSM cell overlap in a square area of 1*1km2. The border effect is alleviated by using the wrap-around method. The left and right borders and top and bottom borders are connected to each other. Both GSM and UMTS Base Stations (BSs) are located at the centre of the cell. The other cells to own cell interference ratio is considered for UMTS. In order to simplify the problem, it is assumed as a fixed value during the simulation period.

Four types of users are defined: voice indoor, voice outdoor, web browsing indoor and web browsing outdoor users. The simulation time is 20 minutes. During the simulation time, every voice user makes one call. The call duration is 2 minutes. Web browsing users are continuously downloading during the whole simulation period. It is assumed that the locations of indoor users are fixed while the outdoor users are moving within the simulation area randomly at a speed of 3km/hour. It is also assumed that the indoor users have an additional penetration loss of 20dB compared to outdoor users.

For GSM, it is assumed that there are three carrier frequencies in the cell. Each of them can be divided into eight time slots. So, the GSM cell has 24 physical channels. Each service will be allocated to one channel. The bit rate of voice service in GSM is 12.2 kbps and the bit rate of web browsing service is 14.4 kbps. A service request is rejected or transferred to UMTS if all the GSM channels are occupied. Voice services have higher priority over web browsing services.

For UMTS, a single FDD carrier frequency of 1950 MHz is considered. Voice services are served at a bit rate of 12.2 kbps and have higher priority over web browsing services. A voice service will be rejected or transferred to GSM if the capacity of UMTS is full. Web browsing users are served in best effort. All web browsing users in UMTS share the capacity not used by voice users. If there are sufficient resources available, they can obtain a maximum throughput up to 64 kbps in uplink and 128 kbps in downlink respectively. If the resource is not enough, they will be delayed or served by a lower throughput.

In terms of blocking/dropping probability, all three algorithms (VG*VU, IN*VG*Load and the one proposed in Section III) will obtain the same performance because a voice call will be rejected only when both GSM and UMTS networks are fully loaded. These algorithms will be compared in terms of average downlink data throughput.

UMTS admission control algorithms used in this simulation are introduced in [7]. In UMTS networks, load factor is introduced to measure the system load. When a UMTS network is fully loaded, its load factor is one. Because a UMTS system will be unstable if it is fully loaded (the powers of all users will reach to the maximum level in this case), a safety margin is required. In this simulation, the maximum allowed load factor value (load factor threshold) is set to 0.75. In UMTS networks, the uplink and downlink load factors should be calculated separately. The uplink load factor can be calculated by Equation (1) [7]:

$$\eta_{UL} = (1+f)\cdot\sum_{j=1}^{N}\frac{1}{1+\dfrac{W}{(E_b/N_0)_j\cdot R_j\cdot v_j}} \quad (1)$$

where η_{UL} is the uplink load factor, f is the other cells to own cell interference ratio, N is the number of service connections, W is the WCDMA chip rate, E_b/N_0 is the signal energy per bit to noise spectral density ratio, R_j is the bit rate and v_j is the activity factor of a service at the physical layer. The downlink load factor is given in Equation (2) [7]:

$$\eta_{DL} = \sum_{j=1}^{N} v_j\cdot\frac{(E_b/N_0)_j}{W/R_j}\cdot[(1-\bar{\alpha})+\bar{f}] \quad (2)$$

where η_{DL} is the downlink load factor, $\bar{\alpha}$ is the average orthogonality factor in the cell and $\bar{f}$ is the average other cells to own cell interference ratio. A new service request is accepted if in uplink:

$$New\_\eta_{UL} < \eta_{UL\_threshold} \quad (3)$$

and the same in downlink:

$$New\_\eta_{DL} < \eta_{DL\_threshold} \quad (4)$$

where New_η_{UL} and $New\_\eta DL$ are the uplink and downlink load factors after accepting the new service request respectively and $\eta_{UL-threshold}$ and $\eta_{DL-threshold}$ are the uplink and downlink load factor thresholds respectively.

A drawback of the above UMTS admission control algorithm is that it does not consider the BS transmission power limitation. In UMTS, the BS transmission power is limited and part of the power is reserved for common channels. The downlink transmission power calculation is given in Equation (5) [8]:

$$P_{DL} = \frac{P_N\cdot\sum_{j=1}^{n}\dfrac{(E_b/N_0)_j\cdot R_j\cdot v_j}{W}\cdot L_j}{1-\eta_{DL}} \quad (5)$$

where P_{DL} is the BS transmission power for traffic channels, P_N is the thermal noise power and L is the loss between BS and UE (including path loss and penetration loss). The path loss can be calculated by Equation (6) by assuming that the BS antenna height is 30m and the mobile antenna height is 1.5m [7]:

$$L_{path} = 137.4 + 35.2\log_{10}(d) \quad (6)$$

If a service request wants to be accepted, in addition to meet the load factor requirements, it also should meet the following power requirement:

$$New\_P_{DL} < P_{DL\_max} \quad (7)$$

where New_PDL is the BS transmission power after accepting the new service request and PDL_max is the maximum BS transmission power allocated to traffic channels. A service request is admitted only when it meets all requirements described by Equations (3), (4) and (7).

Because of the asymmetric property of web browsing services, only the downlink throughput is measured in this simulation. The web browsing downlink bit rate in GSM equals to the number of web browsing users served by GSM multiplies by 14.4 kbps. The web browsing downlink bit rate in UMTS is calculated as follows. According to Equation (2):

$$R = \frac{\eta_{DL\_data}\cdot W}{v_{data}\cdot(E_b/N_0)_{data}\cdot[1-\bar{\alpha}+\bar{f}]} \quad (8)$$

where R is the total downlink bit rate of web browsing services, $\eta_{DL-data}$ is the downlink load factor of web browsing services, which can be calculated as follows:

$$\eta_{DL_data} = \eta_{DL\_threshold} - \eta_{DL\_voice} \quad (9)$$

where $\eta_{DL-voice}$ is the downlink load factor of voice services. According to Equation (5), the total downlink web browsing bit rate in UMTS can be calculated by Equation (10):

$$R = \frac{P_{DL\_data} \cdot W \cdot (1-\eta_D L)}{P_N \cdot (E_b/N_0)_{data} \cdot \upsilon_{data} \cdot \bar{L}} \quad (10)$$

where $\bar{L}$ is the average loss of all served users and $P_{DL-data}$ is the power left for web browsing services. $P_{DL-data}$ can be calculated by Equation (11):

$$P_{DL\_data} = P_{DL\_max} - P_{DL\_voice} \quad (11)$$

where $P_{DL-voice}$ is the power allocated to voice users. The downlink bit rate of web browsing users in UMTS is the minimum one calculated from Equations (8) and (10). The throughput then can be calculated by Equation (12):

$$Throughput = R \cdot (1 - BlER) \quad (12)$$

where BLER is the block error rate. The detailed UMTS network simulation parameters are summarized in Table III.

Table 3: *UMTS NETWORK SIMULATION PARAMETERS*

Parameters	Voice	Data
Activity factor v_j	Uplink: 0.67 Downlink: 0.58	1
E_b/N_0	7 db	5 db
Block error rate BLER	1%	10%
Bit rate of User R_j	12.2 kbps	Uplink: up yo 64kbps Downlink: up to 128kps
Uplink load factor threshold	0.75	
Downlink load factor threshold	0.75	
WCDMA chip rate W	3.84 Mcps	
Average orthogonality $\bar{\alpha}$	0.5	
Other cells to own cell interference ratio f	0.65	
Maximum base station transmission power	20 W	
Common channel power allocation	3W	
Base station antenna height	30 m	
Mobile antenna height	1.5m	
Carrier frequency	1950 MHz	
Thermal noise power	-108dbm	

5. SIMULATION RESULTS AND EXPLANATIONS

It is assumed that the total number of users is 200. Five scenarios are defined in this simulation, which are summarized in Table IV. The three algorithms (VG*VU, IN*VG*Load and the one proposed in Section III) are compared in terms of average downlink web browsing throughput. The simulation results are shown in Fig. 2 to Fig. 6.

Table 4: *PERCENTAGE OF HIGH SIMILARITY*

Scenario numbers	Voice user%	Web browsing user%	Indoor user%	Outdoor user%
1	50%	50%	50%	50%
2	75%	25%	50%	50%
3	25%	75%	50%	50%
4	50%	50%	75%	25%
5	50%	50%	25%	75%

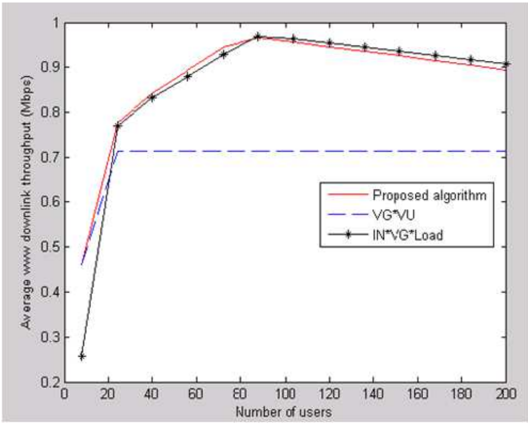

Fig.2: *Simulation results of scenario 1*

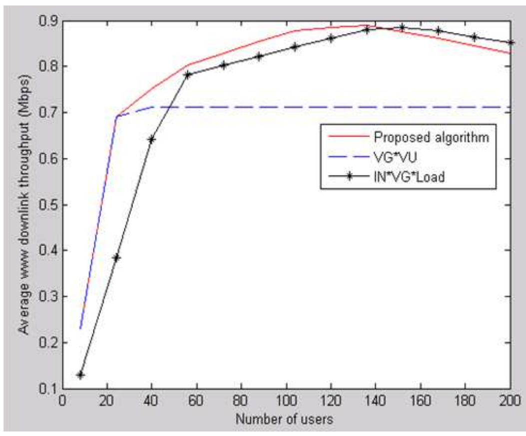

Fig.3: *Simulation results of scenario 2*

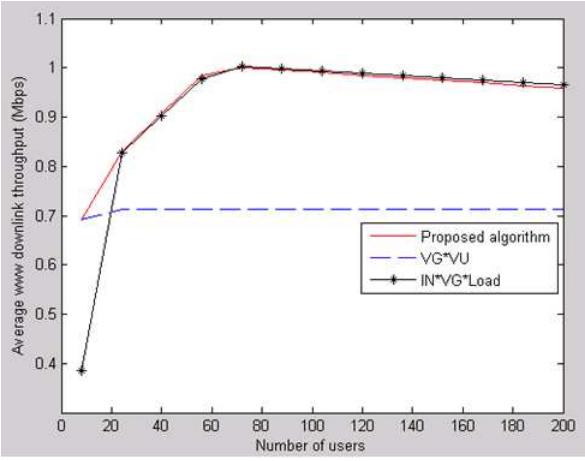

Fig.4: *Simulation results of scenario 3*

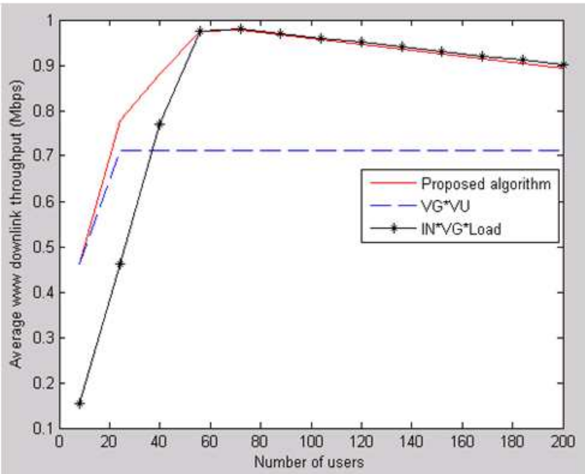

Fig.5: *Simulation results of scenario 4*

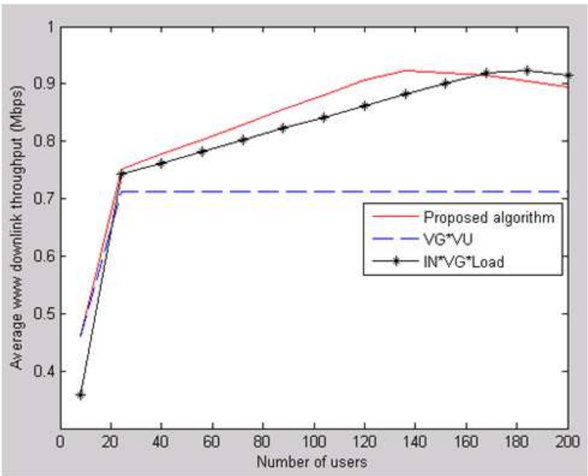

Fig.6: *Simulation results of scenario 5*

From Fig. 2 to Fig. 6, it can be seen that the IN*VG*Load algorithm performs worse than the other two when the system load is low in all of the five scenarios. The main reasons are two-fold. Firstly, the IN*VG*Load algorithm allocates indoor web browsing users into GSM, where only 14.4 kbps bit rate is available for every web browsing user. However, these web browsing users can get a higher bit rate in UMTS when the network load is not high. Another reason is that it allocates outdoor voice users into UMTS, which reduces the throughout of web browsing users served by UMTS. However, the other two algorithms allocate voice users to GSM and web browsing users to UMTS so that web browsing users can obtain a higher throughput.

When the system is highly loaded, the IN*VG*Load algorithm outperforms the other two. The main reasons are also two-fold. Firstly, applying IN policy at the highest priority can minimize the number of indoor users in UMTS. On the other aspect, in a highly loaded UMTS network, due to the increased number of users, the throughput per web browsing user can be even lower than the one in GSM. The advantage of VG policy over VU policy no longer exists.

The VG*VU algorithm performs worse than the other two when the system load is medium to high. The reason is that it does not consider the IN policy at all so that a large number of indoor users are allocated to UMTS, which significantly degrades the system capacity. Under the VG*VU algorithm, all web browsing users are allocated to UMTS. When the UMTS capacity reaches to its upper bound, arrival of a new web browsing user will decrease the throughput per web browsing user while the total throughput of web browsing users in UMTS will remain at the same or similar value as before. This is why the throughput line of VG*VU levels out from medium to high system load.

The proposed algorithm outperforms the other two under a low to medium system load situation because the throughput comparison function of this algorithm maximizes the overall web browsing service throughput.

6. CONCLUSION

This paper compares the performance of different RAT selection algorithms in combined UMTS/GSM networks. It was found that the proposed algorithm in Section III outperforms the others in a low to medium system load case while the IN*VG*Load algorithm is the best choice for highly loaded networks. Network operators can select the most suitable solution according to system load estimation. For example, during busy hours, the IN*VG*Load algorithm can be used while the proposed algorithm in Section III can be used at other times. In our future work, more types of users and services will be considered in the simulation model and more simulation scenarios will be considered.

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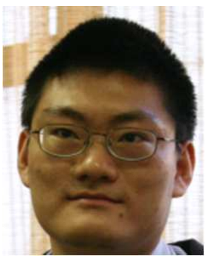

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