A Goodness Based Vertical Handoff Algorithm for Heterogeneous Networks

Shankar K. Ghosh and Sasthi C. Ghosh(✉)

Advanced Computing and Microelectronics Unit,
Indian Statistical Institute, Kolkata 700108, India
shankar.it46@gmail.com,
sasthi@isical.ac.in

Abstract. While moving across heterogeneous networks with strict rate requirement, the possibility of getting the required rate from the target network, depends on the QoS-awareness of the network selection strategy of the concerned vertical handoff (VHO) algorithm. Inclusion of MAC layer scheduling information in the design of different VHO algorithms has previously been very limited though it is important as both user and system performance depend on it. In this paper, we introduce the notion of *goodness* of an access network and based on it propose a goodness based VHO (GVHO) algorithm. The notion of goodness explicitly considers the MAC layer scheduling along with current load and interference of the candidate networks. The GVHO algorithm accounts the goodness values of the candidate networks to select the target network. Simulation results confirm that GVHO algorithm improves both user and system performance compared to RSS and SINR based VHO algorithms.

Keywords: Vertical handoff algorithm · Heterogeneous networks · MAC scheduling · Throughput maximization · QoS

1 Introduction

The modern communication system consists of different types of wireless access networks such as wireless local area networks (WLAN) and 3G cellular networks. The WLAN provides a high data rate with a lower cost over a small coverage area, whereas, cellular networks provides a relatively lower data rate with a relatively higher cost while providing a greater coverage compared to WLAN. Till date, there exists no single radio access technology which can simultaneously provide high data rate, lower cost and high mobility [1]. The next generation (4G) wireless system therefore, focuses on the convergence of existing radio access technologies so that a mobile user, having a multi-mode terminal can access *ubiquitous* and *always the best connected* services while roaming across the heterogeneous networks [1,2].

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Due to the complementary characteristics, integration of 3G cellular networks and WLAN has received much attention from research communities [3]. In 3GPP, an integrated architecture for the 3G cellular network and WLAN has been developed [1,4] and its interconnection specifications have been standardized in 3GPP2 [5]. In this integrated network, a mobile terminal (MT) may perform vertical handoff (VHO) [1] while roaming across the networks. During the handover, an MT uses its network selection strategy (NSS) to select the target network from a set of candidate networks. To get the best connected service, an MT has to rely on the quality of services (QoS) awareness of the network selection strategy of the concerned VHO algorithm. The network selection strategy of a VHO algorithm, therefore plays a crucial role in supporting seamless mobility and guaranteeing the QoS. Consequently, the upper layer application performances are also limited by the choice of the target network. As a result, designing a QoS-aware VHO algorithm is still a challenging problem to the research communities.

To address the above problem, a number of VHO algorithms have been proposed. A detailed survey of the VHO algorithms can be found in [2]. In most of these works, either RSS [6–8] or SINR [9–11] have been used as the fundamental decision indicator. In RSS based approaches, an MT mostly selects the access network having minimum Euclidean distance as the target network. This leads to non-uniform load distribution causing serious degradation of user and system performance. To overcome these drawbacks, SINR based VHO algorithms have been proposed. The SINR based approaches improve both user and system performance as the SINR measurements in wideband code division multiple access (WCDMA) system implicitly considers the network load along with the interference level of the received signal [12]. From the measured value of SINR, an MT can compute the theoretical maximum limit of achievable data rate from a particular access network using shannon's capacity formula. In practice, however much lower rates are achieved [13]. It is to be noted that, the actual physical rate perceived by an MT depends not only on the network load and interference level of the received signal, but also on the medium access control (MAC) layer scheduling algorithm run by the corresponding access network. For example, the effective throughput obtained by an MT from WLAN depends on its MAC scheduling mechanism such as random pooling access and proportional fair access [14]. In random polling access, the individual throughput obtained by all the MTs served by a common access point (AP) is equal. Whereas, in proportional fair access, the obtained throughput by an MT is proportional to the physical rate at which the MT is associated with the concerned AP. In WCDMA systems such as universal mobile telecommunication system (UMTS), an MT can get its requested service if the received energy per bit compared to the spectral noise density is sufficient to get the particular requested service [12].

Since, providing the requested rate to an MT having strict rate requirement (e.g., VoIP, Vconf, clinical applications) is one of the major goals of next generation wireless system, design of any VHO algorithm must consider the availability of the requested rate to the user in addition to the overall system performance. To the best of the authors knowledge, till date there exists no VHO algorithm which accounts the MAC layer scheduling details as a decision attribute to select the optimum target network. In this paper, our contributions are threefold:

- We first introduce the notion of *goodness* for an access network. We consider that, at any time while roaming across the 3G-WLAN heterogeneous network with strict rate requirement, an user can stay in one of the two states namely *good state* and *bad state*. The user is considered to be in good state if it gets the requested physical rate from the system and in bad state otherwise. The goodness of an access network is defined as the estimated time an user will get it's requested rate from that particular access network. The notion of goodness explicitly considers the MAC layer scheduling information along with the current load and interference of an access network.
- We propose a goodness based vertical handoff (GVHO) algorithm based on the notion of goodness of access networks. The GVHO algorithm accounts the goodness values of different candidate networks to select the optimum one.
- The performance of GVHO algorithm have been compared with a RSS based VHO algorithm [6] and a multicriteria adaptive SINR based VHO algorithm (MASVH) [9]. It has been shown by simulation results that GVHO algorithm improves both user and system performance compared to the considered RSS and SINR based VHO algorithms.

The rest of the paper is organized as follows. Related works are presented in Sect. 2. Section 3 presents the notion of goodness for access networks. Section 4 presents the proposed VHO algorithm. Section 5 presents results and discussion. Finally, Sect. 6 concludes the paper.

2 Related Works

In most of the previous studies, either RSS or SINR has been considered as the fundamental decision metric in the design of VHO algorithms [6–11]. In RSS based VHO algorithms [6–8], RSS acts as the fundamental decision parameter along with other factors such as available bandwidth, monetary cost and user preference to select the target network from the candidate networks. In [6], a VHO algorithm is proposed based on a cost function which considers traffic load, RSS and variations of RSS (VRSS). The RSS based VHO algorithms proposed in [7,8], uses fuzzy control theory for selecting the target network. Since RSS based algorithms do not consider network load and current interference level of the candidate networks, SINR based VHO algorithms have been proposed to improve the system performance [9–11]. The algorithms proposed in [9,10] consider the combined effect of SINR, user required bandwidth, user traffic cost and utilization from participating access networks to make the handoff decision. In [11], a service adaptive multicriteria vertical handoff (SAMVHO) algorithm has been proposed to improve the performance from system's perspective. The SAMVHO algorithm considers the weighted average of different decision attributes such as SINR, bandwidth utilization, packet loss rate to determine the target network.

Consideration of MAC scheduling, although having a decisive role in both user and system performance, have been very limited previously in the design of VHO algorithms. In this work, we have proposed a goodness based VHO algorithm (GVHO) which explicitly considers MAC scheduling mechanism of the candidate networks for selecting the target network. It has been shown that GVHO algorithm outperforms the considered RSS based [6] and SINR based [9] VHO algorithm.

3 Notion of Goodness for an Access Network

The actual physical rate perceived by an user while roaming across the 3G-WLAN heterogeneous network explicitly depends on the MAC scheduling algorithm run by the corresponding base station (BS) or access point (AP). In WLAN the throughput perceived by an MT from an AP depends on the physical rate at which the MT is associated with the AP and the total number of users associated with that AP. In 3G WCDMA system such as UMTS, an MT can get its requested service if the received energy per bit compared to the spectral noise density is sufficient to get that particular requested service [12]. In this work, we consider only downlink traffic as they require higher bandwidth than that of uplink traffic [10]. We assume that an user while roaming across the 3G-WLAN heterogeneous network with strict rate requirement may be in one of the two states: *good state* or *bad state*. The user is in good state if it gets the requested rate from the system, otherwise, it is in bad state. To judge the serving capacity of the candidate networks, we introduce the notion of goodness for both AP and BS which represents the estimated time of getting the requested rate by an user from the concerned AP or BS.

3.1 Goodness of an AP with Respect to an User

We define the goodness of AP i with respect to user j as the estimated period of time user j will get its requested rate R_j^{req} from AP i. The estimation period is a time varying quantity as it depends on dynamic factors such as user mobility and network traffic load. Clearly, user j will be in good state while associated with AP i at time t if the following is satisfied:

$$r_{ij}(t) \geq R_j^{req} \tag{1}$$

where $r_{ij}(t)$ is the effective throughput perceived by user j from AP i at time t. Assuming that APs are running proportional fair access [14] as the MAC scheduling, $r_{ij}(t)$ can be expressed as:

$$r_{ij}(t) = \frac{b_{ij}(t)}{u_i(t) + 1} \tag{2}$$

where

– $u_i(t)$ denotes the total number of users associated with AP i at time t, and

– $b_{ij}(t)$ denotes the physical bit rate at which user j is associated with AP i at time t. Here $b_{ij}(t) \in \mathcal{C}$, a finite data rate set. This rate set $\mathcal{C}$ depends on the type of network under consideration. As an example, $\mathcal{C} = \{1, 2, 5.5, 11\}$ for IEEE 802.11b network [14].

It is to be noted that, during 3G to WLAN handovers, the information regarding scheduling and load $u_i(t)$ can be obtained from AP i by overloading the service set identifier (SSID) field of 802.11 beacon frame with necessary details [15]. The physical bit rate $b_{ij}(t)$ at which user j can associate with AP i can be derived from the received signal strength indicator (RSSI) values [16]. Accordingly, $r_{ij}(t)$ can be estimated from Eq. (2).

Now, the time average value of the effective throughput, $\overline{r_{ij}}(t)$, can be calculated using the moving average method [2,17] as follows:

$$\overline{r_{ij}}(t) = \frac{1}{\omega} \sum_{x=0}^{\omega-1} r_{ij}(t-x) \tag{3}$$

where ω is the slope estimator window size and can be estimated depending on the user velocity as described in [17]. The rate of change of $r_{ij}(t)$, $S_{ij}(t)$, can be computed as:

$$S_{ij}(t) = \frac{F_{ij}(t) - L_{ij}(t)}{\omega \times T_b} \tag{4}$$

where $F_{ij}(t)$ and $L_{ij}(t)$ are the average RSS measurements performed at user j as received from AP i in first half and last half of the slope estimator window ω. Here $F_{ij}(t)$ and $L_{ij}(t)$ can be measured as:

$$F_{ij}(t) = \frac{2}{\omega} \sum_{x=0}^{\frac{\omega}{2}-1} \overline{r_{ij}}(t-\omega+1+x) \text{ and} \tag{5}$$

$$L_{ij}(t) = \frac{2}{\omega} \sum_{x=\frac{\omega}{2}}^{\omega} \overline{r_{ij}}(t-\omega+1+x). \tag{6}$$

Here T_b denotes the sampling interval of $r_{ij}(t)$. Using Eqs. (3) and (4), the goodness of AP i with respect to user j at time t, $A_i^j(t)$, can be defined as:

$$A_i^j(t) = \frac{\overline{r_{ij}}(t) - R_j^{req}}{S_{ij}(t)} \tag{7}$$

3.2 Goodness of a BS with Respect to an User

The goodness of BS i with respect to user j is defined as the estimated period of time user j will get its requested rate R_j^{req} from BS i. Similar to AP, goodness of a BS is also a time varying quantity. Now, user j will get the requested rate from BS i if, in addition to adequate pilot power, sufficient traffic channel power is allocated by BS i to user j. More specifically, user j will be in good state with BS i at time t if the following is satisfied [12]:

$$\delta_{ij}(t) \geq \left(\frac{E_b}{N_0}\right)_{R_j^{req}} \tag{8}$$

where

- $\delta_{ij}(t)$ is the energy per bit relative to spectral noise density $\left(\frac{E_b}{N_0}\right)$ as received at user j from BS i at time instant t.
- $\left(\frac{E_b}{N_0}\right)_{R_j^{req}}$ is the target threshold of $\left(\frac{E_b}{N_0}\right)$ to get R_j^{req}.

Here, $\delta_{ij}(t)$ can be computed as [12]:

$$\delta_{ij}(t) = \frac{W}{R_j^{req}} \times \frac{p_{ij}(t)}{N_0 + (1-\alpha)\eta_{ij}(t) + \sum_{x \neq i} \eta_{xj}(t)} \tag{9}$$

where

- $p_{ij}(t)$ is the traffic channel power received by user j from BS i at time instant t,
- $\eta_{xj}(t)$ is the total interference received at user j from BS x at time instant t,
- α is the orthogonality factor and N_0 is the thermal noise,
- W is the CDMA chip rate.

The target threshold $\left(\frac{E_b}{N_0}\right)_{R_j^{req}}$ can be computed as [13]:

$$\left(\frac{E_b}{N_0}\right)_{R_j^{req}} = \frac{W_{BS}}{R_j^{req}} \times \left(2^{\frac{R_j^{req}}{W_{BS}}} - 1\right) \tag{10}$$

where W_{BS} is the carrier bandwidth of WCDMA. Now, the time average value of $\delta_{ij}(t)$, $\overline{\delta_{ij}}(t)$, can be calculated using the moving average method [2] as follows:

$$\overline{\delta_{ij}}(t) = \frac{1}{\omega'} \sum_{x=0}^{\omega'-1} \delta_{ij}(t-x) \tag{11}$$

where ω' is the slope estimator window size and can be estimated as described in [17]. The rate of change of $\delta_{ij}(t)$, $S'_{ij}(t)$, is given by:

$$S'_{ij}(t) = \frac{F'_{ij}(t) - L'_{ij}(t)}{\omega' \times T'_b} \tag{12}$$

where $F'_{ij}(t)$ and $L'_{ij}(t)$ are the average RSS measurements at user j as received from BS i in first half and last half of the slope estimator window ω'. Here $F'_{ij}(t)$

and $L'_{ij}(t)$ can be measured as:

$$F'_{ij}(t) = \frac{2}{\omega'} \sum_{x=0}^{\frac{\omega'}{2}-1} \overline{\delta_{ij}}(t - \omega' + 1 + x) \text{ and} \tag{13}$$

$$L'_{ij}(t) = \frac{2}{\omega'} \sum_{x=\frac{\omega'}{2}}^{\omega'} \overline{\delta_{ij}}(t - \omega' + 1 + x) \tag{14}$$

Here T'_b denote the sampling interval of $\delta_{ij}(t)$. Using Eqs. (10), (11) and (12), the goodness of BS i with respect to user j at t, $B_i^j(t)$, can be defined as:

$$B_i^j(t) = \frac{\left(\overline{\delta_{ij}}(t) - \left(\frac{E_b}{N_0}\right)_{R_j^{req}}\right)}{S'_{ij}(t)} \tag{15}$$

4 The Proposed Goodness Based Vertical Handoff Algorithm

Our proposed goodness based vertical handoff (GVHO) algorithm consists of three phases namely network discovery, best network determination and target network selection. In network discovery phase, user j periodically determines the set of candidate networks. In the next phase, the best network is determined from the set of candidate networks based on their goodness values. In target network selection phase, user j decides whether the active sessions should be continued with the current network or be switched to the target network.

4.1 Network Discovery

The network discovery phase of GVHO is based on the RSS measurements. Suppose the set of candidate networks N^j for user j found after the network discovery phase include y_j APs and z_j BSs. We represent N^j as:

$$N^j = [\texttt{AP 1}, \texttt{AP 2}, \ldots, \texttt{AP } y_j \; ; \; \texttt{BS 1}, \texttt{BS 2}, \ldots \texttt{BS } z_j]$$

4.2 Best Network Determination

The goodness values of the set of candidate networks N^j for user j at time t can be expressed as:

$$\Omega^{N^j}(t) = [A_1^j(t), A_2^j(t), \ldots A_{y_j}^j(t) \; ; \; B_1^j(t), B_2^j(t), \ldots B_{z_j}^j(t)]$$

where $A_i^j(t)$ and $B_{i'}^j(t)$ are the goodness values of AP i $(1 \le i \le y_j)$ and BS i' $(1 \le i' \le z_j)$ with respect to user j at time t as computed using Eqs. (7) and (15) respectively. The best network $N_{best}^j(t)$ for user j at time t is the AP or BS whose goodness value is maximum among the candidate networks. That is:

$$N_{best}^j(t) = \begin{cases} \texttt{AP } i, & \text{if} \, \texttt{Maximum}(\Omega^{N^j}(t)) = A_i^j(t) \\ \texttt{BS } i', & \text{if} \, \texttt{Maximum}(\Omega^{N^j}(t)) = B_{i'}^j(t) \end{cases}$$

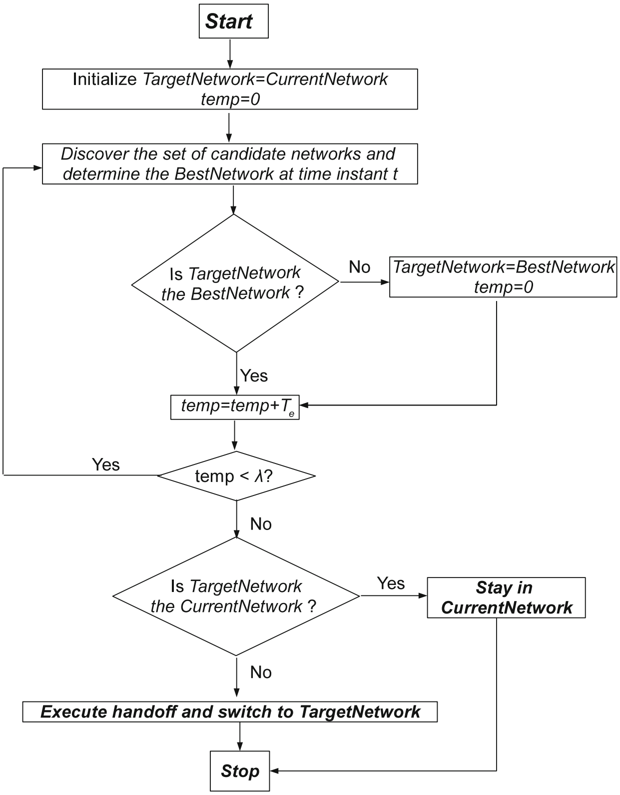

Fig. 1. Flowchart of GVHO algorithm

4.3 Target Network Selection

The target network selection algorithm finds the best network at every time interval T_e. A network is selected as the target network if it is continuously the best for larger than λ time. The active sessions are then switched to the target network. Note that λ is a predefined threshold used here to avoid the ping-pong effect. The proposed GVHO algorithm in the form of a flowchart is presented in Fig. 1.

5 Results and Discussions

5.1 Performance Evaluation Metrics

We have considered the user and system throughput as the metrics for evaluating the performance of different VHO algorithms. *User throughput* measures the mean data rate perceived by an user while roaming across the heterogeneous network. *System throughput* measures the absolute amount of data communicated by the users per unit time. Note that user throughput measures the performance from user's perspective while, system throughput measures the performance from system's perspective. According to our considered application scenario the users have strict rate requirement. So, it is important to measure how long an user is in good state, i.e., getting its requested rate and what fraction of users are in good state. Clearly, these can not be captured by user and system throughput as they are concerned only about the absolute amount of data communicated per unit time. To capture this effect, we introduce two other metrics namely *user goodness* and *system goodness*. We define *user goodness* as the expected time an user is in good state while roaming across the heterogeneous network. *System goodness* is defined as the ratio of mean number of users in good state to the total number of users in the system.

5.2 Simulation Setup

To evaluate the performances of different VHO algorithms, we have used the simulation environment similar to that of [9]. In our simulation environment 7 BSs and 13 APs are placed in a 4000×4000 m^2 area where APs are placed at the boundary points of the BSs. The BSs are assumed to provide ubiquitous coverage. We have considered all kind of overlapping: BS $\leftrightarrow$ BS, AP $\leftrightarrow$ AP, and AP $\leftrightarrow$ BS. The BS coverage radius is set to 1200 m [9]. The physical rate obtained by the users from their respective serving APs is derived based on their received signal strength indicator (RSSI) values as described in [16]. Users are assumed to be uniformly distributed and moving according to smooth random way point mobility model [19] with velocity v km/hr and acceleration $f\ m/s^2$ where $v \in \{0, 20, 60\}$ and $f \in \{0, 10, 20\}$. An user accelerates or decelerates depending on its current and target velocity. The slope estimator windows ω and ω' has been estimated depending on the velocity of the user as described in [17]. The sampling intervals T_b and T'_b have been set to 0.01 s [17]. We have assumed the log linear path loss model with shadow fading as [18]: $RSS = P_T - L - 10nlog(d) + f(\mu, \sigma)\ dBm$ where P_T denotes the transmitted power, L is the constant path loss, n is the path loss exponent and $f(\mu, \sigma)$ represents shadow fading modeled as a Gaussian variable with zero mean and standard deviation σ ranging from 6 to 12 dB. The maximum transmitting power of BS and AP are set to 43 and 20 dBm respectively [9]. The different parameter values considered in our simulation are depicted in Table 1.

5.3 Simulation Results

Figures 2 and 3 depicts the effect of total number of users on user goodness and system goodness respectively. Here all users are assumed to have a typical data rate request for video traffic (384 Kbps). Total number of users in the system varies from 100 to 700 with a step of 100 users.

Figure 2 shows that GVHO significantly improves user goodness compared to MASVH (9–17 % approximately) and RSS based VHO (21–28 % approximately). The underlying impetus of this phenomenon is the better QoS-awareness of GVHO

Table 1. Parameter settings

Parameter	Value	Parameter	Value
W_{BS} [9]	5 MHz	T_e	0.01 s
n [18]	2	λ	0.1 s
σ [18]	7 dB	W [12]	3840000 Kbps
α [12]	0.5	N_0 [9]	−99 dB

compared to MASVH and RSS based approach. It is to be noted that, the user goodness depends on the user perceived throughput, which in turn depends on the interference, user density and the MAC scheduling. In RSS based approaches, the users always select the nearest BS or AP, which may lead to choose a highly loaded target network causing serious degradation of user throughput. Increasing traffic load in WCDMA system causes degradation of user throughput due to self interference. User perceived throughput in WLAN decreases with increasing load as depicted in Eq. (2). On contrast, the MASVH approach considers the current interference level while selecting the target network. The SINR measurements in WCDMA system implicitly considers the network load [12]. As a result, user perceived throughput increases compared to RSS based approach. Although MASVH increases the user mean throughput, it can not guarantee whether an user will get its requested data rate from the target network. From the measured SINR values, an user can determine the theoretical maximum limit of achievable data rate from a channel. Practically, however much lower rate are achieved [13]. A user in WCDMA system can get its requested service if the received energy per bit compared to the spectral noise density $\left(\frac{E_b}{N_0}\right)$ is sufficient to get that particular requested service [12]. Clearly, MASVH algorithm do not consider this MAC layer details. The proposed GVHO algorithm while selecting the target network considers goodness of the participating access networks which accounts MAC scheduling information in addition to the current load and interference level. As a result, the selected target network in GVHO is more reliable to provide the requested data rate.

Figure 3 depicts the effect of total number of users on system goodness. Simulation results show that GVHO significantly improves the system goodness compared to MASVH (1–20 % approximately) and RSS based approach (2–24 % approximately). System goodness depends on total number of users associated with the system, which in tern depends on load balancing among different access networks. System goodness in MASVH is better than RSS as MASVH leads to a fairer load distribution among different access networks in comparison to RSS. Since MASVH is cost aware, this is effectively a WLAN-first strategy under moderate traffic load. It is important to note that, unlike BS, in case of AP, nothing can be predicted regarding the user density from the received SINR. As a result, load under APs quickly reach the maximum limit of allowable traffic load as depicted in Eq. (2) and all subsequent calls are dropped. Being equipped with the scheduling details,

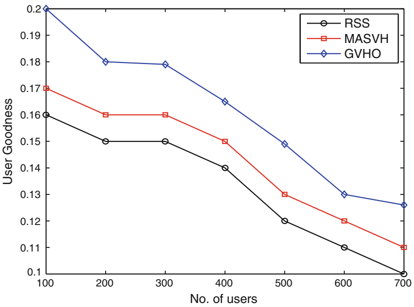

Fig. 2. User goodness vs. No. of users

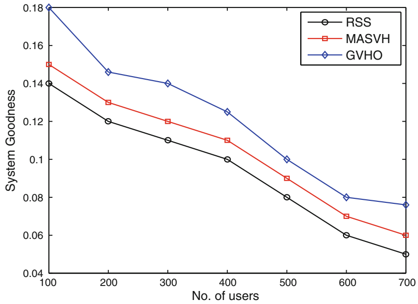

Fig. 3. System goodness vs. No. of users

GVHO can have better insight regarding achievable data rate in APs. In WCDMA system, whether an user will be able to associate with a particular BS depends on the power availability in the corresponding BS, which can not be estimated only from the received SINR values. The power availability can be closely estimated from $\left(\frac{E_b}{N_0}\right)$ values which the notion of goodness explicitly considers. As a result, GVHO outperforms the SINR based MASVH approach.

Figures 4, 5, 6 and 7 shows the effect of requested data rate on different performance evaluation metric. We vary the requested data rates from 64 to 640 Kbps with a step of 64 Kbps. Total number of users are kept fixed to 300.

Figure 4 depicts the effect of requested data rate on user goodness. The results show that GVHO outperforms MASVH (8–12 % approximately) and RSS based approach (11–14 % approximately) because of its better Qos-awareness as explained earlier. As the requirement for system resources increases with increasing data rate, the user goodness decreases while increasing the requested data rate. The user goodness degrades drastically as soon as the requested rate become more than 384 Kbps (approximately). The differences among different VHOs become narrower as the data rate request increases beyond 384 Kbps. This intuitively suggests that for the considered number of user (300), the system reaches the saturation point when the data rate request per user is 384 Kbps.

Figure 5 depicts the effect of requested data rate on system goodness. Here also GVHO have been found to outperform MASVH (3–7 % approximately) and RSS based approach (10–15 % approximately). It may be noted that system goodness decreases with increasing user requested data rate. This is because, the maximum number of users that can be associated with an AP in good state decreases with increasing the requested data rate as depicted in Eq. (2). On the other hand, the power requirement for an user to stay in good state with a BS increases exponentially with the requested data rate as depicted in Eq. (10).

Figures 6 and 7 depict the effect of requested data rate on user mean throughput and system throughput. It can be seen that GVHO outperforms MASVH (performance gain is 2–7 % approximately for user throughput and 1–15 % approximately for system throughput) and RSS based approach (5–25 % approximately

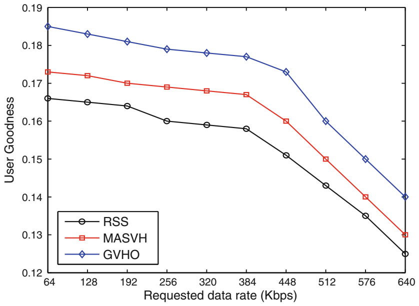

Fig. 4. User goodness vs. requested rate

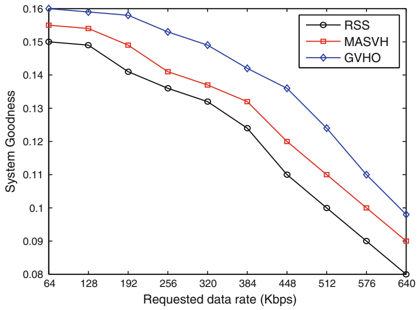

Fig. 5. System goodness vs. requested rate

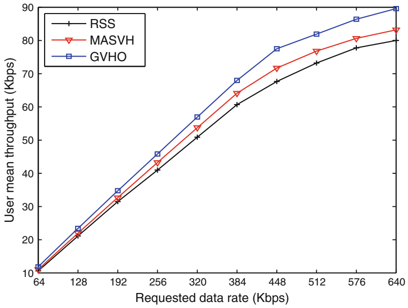

Fig. 6. User mean throughput vs. requested rate

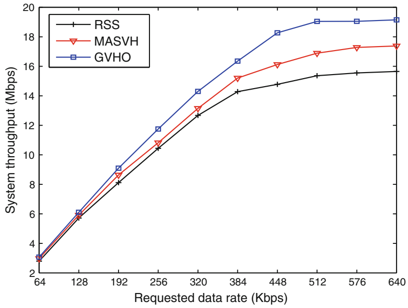

Fig. 7. System throughput vs. requested rate

for user mean throughput and 2–25 % approximately for system throughput). The reason behind is the advanced Qos-awareness of GVHO as described earlier.

6 Conclusions

We have introduced the notion of goodness for access networks and based on it proposed a goodness based vertical handoff (GVHO) algorithm which explicitly considers the MAC scheduling information along with the current load and interference. We have compared the performance of GVHO with an SINR based and a RSS based approach from the existing literature. It has been shown that GVHO significantly improves both user and system performances compared to the considered SINR and RSS based approaches.

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