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Telecom Big Data Based User Offloading Self-Optimisation in Heterogeneous Relay Cellular Systems

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ABSTRACT

This paper proposes a telecom big data based user offloading self-optimisation (TBDUOS) scheme. Its aim is to assist telecom operators to effectively balancing the load distribution with achieving good service performance and customer management in heterogeneous relay cellular systems. To achieve these objectives, in the cell-level offloaded traffic analysis stage, the optimal offloaded traffic is calculated to minimise the total blocking probability. In the user-level offloading stage, the user portrait is drawn and the K-MEANS algorithm is employed to manage the users clustering in the heavily loaded cell, and finally shifting users to assistant cells. Simulation results show the TBDUOS scheme can effectively reduce the handover failure and call dropping of specific users, especially voice/stream users, high consumption users, high level users. The TBDUOS scheme can also reduce the blocking probability.

KEYWORDS

Relay, Telecom Big Data, Traffic Offloading, User Portrait, Users Clustering

INTRODUCTION

In order to meet the explosive demands on cellular systems coverage by emerging smart terminals and mobile phones, the relay technique is employed (3GPP, 2010). The relay station (RS) can be deployed in wireless-hungry areas to extend the wireless coverage, whilst the base station (BS) focuses on the large coverage in LTE-Advanced heterogeneous relay cellular systems (Zheng, 2011). Due to the service diversity and the user mobility, cellular systems also face the challenge of uneven traffic

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distribution (Cao, 2015). Load balancing is widely used to deal with the uneven load distribution (SOCRATES, 2010; Cao, 2011).

Generally, load balancing can be implemented via two methods. The first method is based on channel borrowing. Under the non-full frequency reuse cellular systems (e.g., GSM), a heavily loaded cell borrows idle spectrum resources from neighbouring cells. Typical channel borrowing schemes includes simple borrowing scheme (Engel, 1973), hybrid assignment scheme (Zhang, 1989), channel borrowing without locking scheme (Jiang, 1994). However, the limitation is that these channel borrowing schemes only suit for cellular systems without employing full frequency reuse. Therefore, this method does not suit the LTE/LTE-Advanced cellular systems (Zheng, 2011; Han, 2012). The second method is via offloading traffic from the heavily loaded cell to less-loaded neighbouring cells.

Many traffic offloading schemes are designed from both academics and industry. In (Nasri, 2007), a heavily loaded cell chooses neighbouring cells, which have lower load, as assistant cells. Then, the heavily loaded cell adjusts handover offset (HO_{off}) to trigger handover between two cells. This work becomes the milestone of mobility load balancing (MLB). In (Zhang, 2010), cell state is categorized into 'light load', 'high load' and 'normal load'. Then the traffic offloading is between the 'high load' and 'light load' cells, according to their load differences. Kwan (2010) studies the precise HO_{off} based MLB mechanism, in which a heavily loaded cell selects all less-loaded neighbouring cells as assistant cells, and then this heavily loaded cell gradually regulates HO_{off} with a fixed step-size to offload serving users. In (Yang, 2012; Yang, 2014), the authors design the cell load based utility function to adjust HO_{off}, in order to offload edge users efficiently. In (Wang, 2010), the neighbouring cell with the lowest load is chosen as the assistant cell in sequence, then the heavily loaded cell shifts users to RSs in assistant cells, thus balancing the traffic distribution evenly. In (Fan, 2011), the load balancing objective is to avoid a cell serving too many users via broadcasting and considering the number of users served by each cell's RS. In (Wu, 2005), the integrated cellular and Ad-hoc relay (iCAR) scheme is designed, in which the mobile ad-hoc relay station (ARS) is employed to relay the traffic from a heavily loaded cell to less-loaded neighbouring cells.

In above mentioned works, cell load is the key factor to decide the traffic offloading direction and to analyse the offloaded user's sequence. Above mentioned load balancing schemes can effectively reduce the load of the heavily loaded cell. However, for telecom operators, traffic offloading should consider comprehensive factors, especially different services' performance degradation under the offloading scenario as well as telecom customers' management requirements.

This paper proposes a telecom big data based user offloading self-optimisation (TBDUOS) scheme in heterogeneous relay cellular systems. Its aim is to balance the load distribution, as well as achieve good service performance and benefit customer management. The TBDUOS scheme consists of two stages. Firstly, the heavily loaded cell considers both the cell load and call blocking to analyse the optimal cell-level offloaded traffic. Secondly, we utilize telecom big data to analyse the user portrait (Wang, 2016) and further manage the users clustering (Rekik, 2006), thus deciding the offloaded users.

This paper is organised as follows: Section II introduces telecom big data and presents the system model. Section III describes the cell-level offloaded traffic analysis stage. Section IV presents the user-level offloading stage. Simulation results and conclusions are given in Section V and VI, respectively.

TELECOM BIG DATA AND HETEROGENEOUS RELAY CELLULAR SYSTEMS

In cellular systems, the massive transmitted data contains a huge amount of useful information. Generally, telecom big data includes system related information, for example, system key performance indicator, measurement report, network operating status etc. Telecom big data also includes the user related information, for example, user personal information, user's terminal information, user's location information, user's consumption information, upper-layer service information etc. This information will be discussed in detail in Section IV. Therefore, telecom big data has '4-V' features, namely 'Volume', 'Variety', 'Velocity' and 'Veracity' (Cheng, 2015). '4-V' features describe telecom big data from different perspectives and imply the characteristics of extremely large data volume, distinguished data formats, timely data streaming as well as buried data value. Compared to big data in other industries, telecom big data has dominant advantages, including the large scale of users and the wide coverage area. Besides, the data quality of telecom big data is comprehensive and precise.

This paper considers the telecom big data application in heterogeneous relay cellular systems. Figure 1 shows the simplified system model. In each cell, six RSs are deployed at the cell edge, namely 2/3 of the cell radius (3GPP, 2010). The whole spectrum is shared among BS and six RSs. Full frequency reuse is employed among neighbouring cells (Zheng, 2011). This paper assumes $Cell_h$ serves a large number of users and becomes heavy load. $Cell_h$ has Q neighbouring macro cells indexed with q $\left(q \in \left\{1,2\ldots Q\right\}\right)$. $Cell_h$ chooses J assistant cells from neighbouring cells, indexed with j $\left(j \in \left\{1,2\ldots J\right\}\right)$. Some system parameters and definitions used in this paper are shown in Table 1.

Figure 2 describes the simplified negotiation process of the proposed TBDUOS scheme. In the cell-level offloaded traffic analysis stage, initially, each user served by the heavily loaded cell reports its estimated SINR from each RS in each neighbouring cell. In addition, each neighbouring cell also reports its cell load to the heavily loaded cell via the cell-to-cell X2 interface (Dahlman, 2011). After collecting these reports and information, the heavily loaded cell employs the user-vote based assistant cell chosen algorithm (Xu, 2011) to choose suitable neighbouring cells as the assistant cells. Then, the heavily loaded cell sends the assistant cell request to the selected cells. Each assistant cell will feedback a confirmation message. After the assistant cell chosen, the heavily loaded cell and each assistant cell exchange the cell information. Then, the heavily loaded cell analyses and calculates its optimal offloaded traffic towards each assistant cell.

In the user-level offloading stage, initially, the heavily loaded cell draws each serving user portrait based on the user information (including the user's personal information, terminal information, location information, consumption information, service information). Then, the heavily loaded cell takes the users clustering to segment its serving users into different clusters (Rekik, 2006; Zhang, 2015). Then, the heavily loaded cell selects users in clusters to meet the cell-level required offloaded traffic. Finally, the selected users trigger handover and be offloaded to assistant cells.

Figure 1. Structure and frequency planning of relay cellular systems

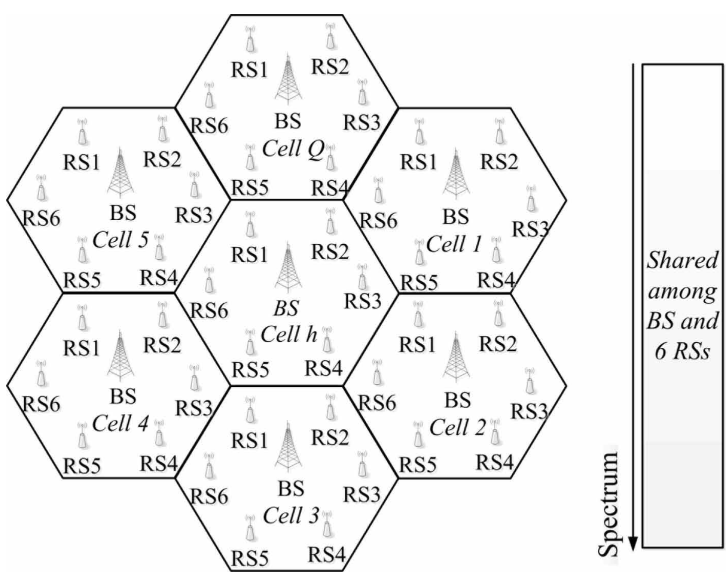
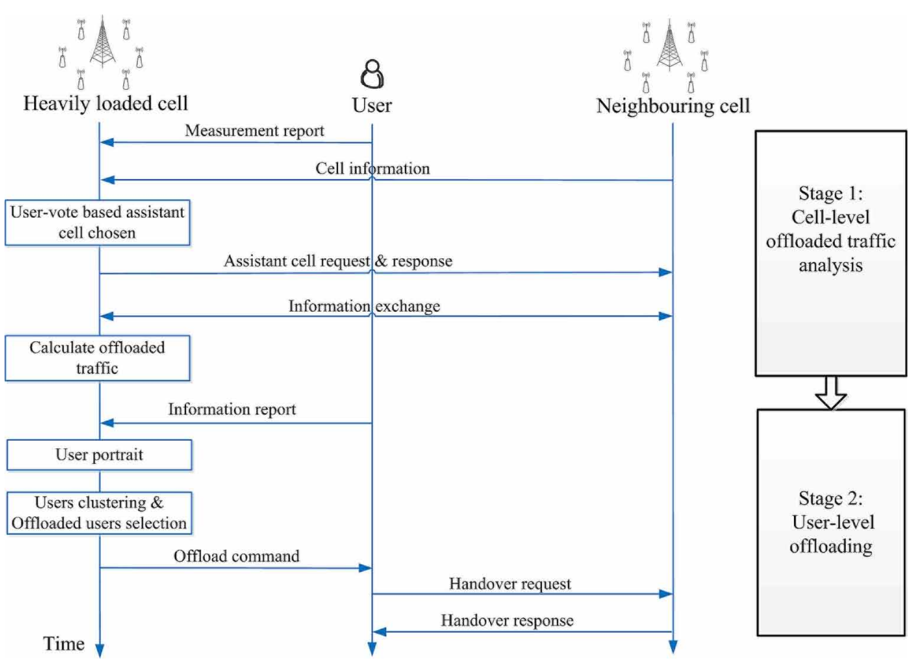


Table 1. List of system parameters and definitions

$Cell_h$: Heavily loaded $Cell_h$.
$Cell_q$: Neighbouring $Cell_q$. We assume $Cell_h$ has Q neighbouring cells indexed with q $\left(q \in \left\{1,2\ldots Q\right\}\right)$.
$Cell_j$: Assistant $Cell_j$. Assistant cells are a subset of neighbouring cells to offload traffic. This paper assumes heavily loaded $Cell_h$ has J assistant cells indexed with j $\left(j \in \left\{1,2\ldots J\right\}\right)$.
M: Total number of subcarriers available in each cell.
M_{use}: The number of subcarriers in use in a cell.
L: Cell's load. Cell's load is defined as the ratio of the number of subcarriers in use to the cell's total number of subcarriers (Ramiro, 2012). $L = M_{use} / M$ and $0\% \le L \le 100\%$.
L_{hot}: The load threshold of a hot-spot/heavily loaded cell, e.g., L_{hot}=80% (Ramiro, 2012).
$RS_{sev,h}$: The serving RS, and $RS_{sev,h}$ is in heavily loaded $Cell_h$.
$RS_{r,q}$: RS_r in neighbouring $Cell_q$ ($r \in \left\{1,2,3,4,5,6\right\}$).
$M_{off\ j}$: The offloaded traffic from $Cell_h$ to assistant $Cell_j$.
$\tilde{B}_h$: Blocking probability of $Cell_h$ after offloading.
$\tilde{B}_j$: Blocking probability of assistant $Cell_j$ ($j \in \left\{1\ldots J\right\}$) after offloading.
ARPU: Average revenue per user.
MOU: Minutes of usage for a user.
PI: Personal information, including the user level, the user age, the user gender etc.
CI: Consumption information. User's consumption information includes ARPU, MOU etc.
TI: Terminal information, including the terminal brand, the terminal model and the terminal price etc.
LI: Location information, including the location based signal strength, the user trace etc.
SI: Service information, including the service type, the service usage time, the service name etc.

Figure 2. Simplified negotiation of TBDUOS scheme



CELL-LEVEL OFFLOADED TRAFFIC ANALYSIS

Section III introduces the cell-level offloaded traffic analysis stage of the proposed TBDUOS scheme.

Assistant Cell Chosen

The TBDUOS scheme utilizes the user-vote based assistant cell chosen algorithm. This algorithm is proposed in our previous work (Xu, 2011) for single-hop cellular systems. Then, we enhance this algorithm to fit in relay cellular systems. In the enhanced assistant cell chosen algorithm, each user, which is served by the heavily loaded $Cell_h$'s RSs, estimates its $SINR^{est}_{RS_{r,q}}$ from each RS_r ($r \in \{1,2...6\}$) in each neighbouring $Cell_q$ $\left(q \in \{1,2 \ldots Q\}\right)$. Then, this user reports its estimated $SINR^{est}_{RS_{r,q}}$ to the serving $Cell_h$. Based on the estimated $SINR^{est}_{RS_{r,q}}$ and the serving $SINR_{RS_{sev,h}}$, the heavily loaded $Cell_h$ calculates this *user's vote*.

Then the heavily loaded $Cell_h$ collects and calculates the total votes TV_q of neighbouring $Cell_q$, according to each user's *vote*. TV_q indicates the capability of neighbouring $Cell_q$, decided by users' channel condition from RSs in neighbouring $Cell_q$.

In order to choose appropriate assistant cells, the heavily loaded $Cell_h$ also considers the load of neighbouring $Cell_q$. Cell load indicates the idle subcarriers of neighbouring $Cell_q$ to serve offloaded users. In the modified user-vote based assistant cell chosen algorithm, the above two factors, including *total votes* and *cell load*, have the same weight to calculate the selection priority of neighbouring $Cell_q$. Then, $Cell_h$ chooses the high priority neighbouring cells as its assistant cells.

Aim of Cell-Level Traffic Offloading Optimisation

According to Section II, this paper assumes that the heavily loaded $Cell_h$ selects J assistant cells indexed with j ($j \in \{1 \ldots J\}$). This paper assumes $Cell_h$ tries to offload $M_{off\,h}$ traffic from $Cell_h$'s RSs to the assistant cells' RSs, and $Cell_h$'s load reduction is denoted as ΔL_h. Hence, $\Delta L_h = M_{off\,h} / M$. After traffic offloading, $Cell_h$'s load $\tilde{L}_h = L_h - \Delta L_h$. The offloaded users will be served by its assistant cells' RSs. This will increase the load of its assistant cells, which will increase their call blocking probability. Therefore, the proposed algorithm is aimed to analyse and optimise $Cell_h$'s offloaded traffic to each assistant cell, in order to minimise the total blocking probability of $Cell_h$ and its assistant cells.

After receiving *$Cell_h$'s* traffic, we define assistant *$Cell_j$'s* load as $\tilde{L}_j$. $\tilde{L}_j$ equals the sum of its initial load L_j and *$Cell_h$'s* offloaded traffic. Hence, all assistant cells' total load after traffic offloading $\sum_{j=1}^{J} \tilde{L}_j$ is as Equation (1a):

$$\sum_{j=1}^{J} \tilde{L}_j = \Delta L_h + \sum_{j=1}^{J} L_j \tag{1a}$$

$$\overset{\Delta L_h = L_h - \tilde{L}_h}{\Rightarrow} L_h + \sum_{j=1}^{J} L_j - \tilde{L}_h - \sum_{j=1}^{J} \tilde{L}_j = 0 \tag{1b}$$

where ΔL_h is the load reduction of $Cell_h$. Hence, ΔL_h equals the load difference between $Cell_h$'s initial load L_h and its load after offloading $\tilde{L}_h$. Namely, $\Delta L_h = L_h - \tilde{L}_h$. Then Equation (1a) can be derived as Equation (1b).

Erlang-B model is widely utilised for the call blocking probability evaluation (Goldsmith, 2005). By applying this model, the blocking probabilities of the heavily loaded $Cell_h$ and the assistant $Cell_j$ $\left(j \in \left\{1 \ldots J\right\}\right)$ after offloading, can be expressed as $\tilde{B}_h$ in (2) and $\tilde{B}_j$ $\left(j \in \left\{1 \ldots J\right\}\right)$ in Equation (3), respectively:

$$\tilde{B}_h = \frac{(\tilde{L}_h \times M)^M \; / \; M!}{\sum_{m=0}^{M} (\tilde{L}_h \times M)^m \; / \; m!} \tag{2}$$

$$\tilde{B}_j = \frac{\left(\tilde{L}_j \times M\right)^M \Big/ M!}{\sum_{m=0}^{M} \left(\tilde{L}_j \times M\right)^m \Big/ m!} \; j \in \left\{1 \ldots . J\right\} \tag{3}$$

After traffic offloading, this paper denotes the total blocking probability of $Cell_h$ and its assistant cells as $\tilde{B}_{total}$. $\tilde{B}_{total}$ equals the sum of each cell's load times each cell's blocking probability, namely, $\tilde{B}_{total} = \tilde{B}_h \times \tilde{L}_h + \sum_{j=1}^{J} \tilde{B}_j \times \tilde{L}_j$. According to Equation (4), the TBDUOS scheme aims at minimising $\tilde{B}_{total}$. The load constraint of Equation (5) is from formula (1b). After offloading traffic to the assistant $Cell_j$ ($j \in \left\{1 \ldots J\right\}$), the heavily loaded $Cell_h$'s load $\tilde{L}_h$ is lower than its initial load L_h. Therefore, $\tilde{L}_h - L_h < 0$, as shown in constraint Equation (6). After receiving $Cell_h$'s traffic, the assistant $Cell_j$'s load $\tilde{L}_j$ is higher than its initial load L_j. Hence, $L_j - \tilde{L}_j < 0$, as shown in constraint Equation (7):

$$\underset{\tilde{L}_h, \tilde{L}_j}{MIN} \; \tilde{B}_{total} = \underset{\tilde{L}_h, \tilde{L}_j}{MIN} \; \tilde{B}_h \times \tilde{L}_h + \sum_{j=1}^{J} \tilde{B}_j \times \tilde{L}_j \tag{4}$$

$$\text{s.t. } L_h + \sum_{j=1}^{J} L_j - \tilde{L}_h - \sum_{j=1}^{J} \tilde{L}_j = 0 \tag{5}$$

$$\tilde{L}_h - L_h < 0 \tag{6}$$

$$L_j - \tilde{L}_j < 0 \;\; j \in \{1 \ldots . J\} \tag{7}$$

Theoretical Analysis and Solution

This paper employs the Lagrange multipliers method (Chiang, 2006) to address the optimisation problem formulated in Equations (4)-(7). The local minimal $\tilde{B}_{total}$ of Equation (4) with constraints in Equations (5)-(7) are found via four steps. Firstly, the Lagrangian function is designed via employing constraint functions in Equations (5)-(7) weighted times Lagrange multipliers, together with $\tilde{B}_{total}$ of Equation (4). Secondly and thirdly, the partial derivatives of Lagrangian function are calculated, and then we design the equation group of above partial derivatives equaling zero. Finally, we solve above equation group to find the local minimal $\tilde{B}_{total}$ of Equation (4) with constraints in Equations (5)-(7):

1. Initially, the Lagrangian function is formulated as Equation (8), by introducing Lagrange multipliers η, μ_h, β_j $\left(j \in \{1 \ldots J\}\right)$ for the constraint in Equations (5), (6), (7), respectively (Bhatti, 2000; Chiang, 2006):

$$Lag\left(\tilde{L}_h, \tilde{L}_j\right) = \tilde{B}_h \tilde{L}_h + \sum_{j=1}^{J} \tilde{B}_j \tilde{L}_j - \eta\left(L_h + \sum_{j=1}^{J} L_j - \tilde{L}_h - \sum_{j=1}^{J} \tilde{L}_j\right) + \mu_h\left(\tilde{L}_h - L_h\right) + \sum_{j=1}^{J} \beta_j\left(L_j - \tilde{L}_j\right) \tag{8}$$

For the *Karush-Kuhn-Tucker (KKT)* condition (Nering, 1993), it requires $\mu_h(\tilde{L}_h - L_h) = 0$ and $\beta_j\left(L_j - \tilde{L}_j\right) = 0$ for $j \in \{1 \ldots J\}$. Besides, Equation (6) shows $\tilde{L}_h - L_h < 0$, and (7) shows $L_j - \tilde{L}_j < 0$ for $j \in \{1 \ldots J\}$. Hence, the Lagrange multiplier $\mu_h = 0$, $\beta_j = 0$ $\left(j \in \{1 \ldots J\}\right)$.

2. Then, the partial derivatives $\frac{\partial Lag}{\partial \tilde{L}_h}$, $\frac{\partial Lag}{\partial \tilde{L}_j}$ $\left(j \in \{1 \ldots J\}\right)$ are Equation (9) and (10), respectively:

$$\frac{\partial Lag}{\partial \tilde{L}_h} = \frac{\left(\tilde{L}_h \times M\right)^M / M!}{\sum_{m=0}^{M}\left(\tilde{L}_h \times M\right)^m / m!} \times \left\{M + 1 - \frac{\sum_{m=0}^{M}\left(\tilde{L}_h \times M\right)^m \times m / m!}{\sum_{m=0}^{M}\left(\tilde{L}_h \times M\right)^m / m!}\right\} + \eta \tag{9}$$

$$\frac{\partial Lag}{\partial \tilde{L}_j} = \frac{\left(\tilde{L}_j \times M\right)^M / M!}{\sum_{m=0}^{M}\left(\tilde{L}_j \times M\right)^m / m!} \times \left\{M + 1 - \frac{\sum_{m=0}^{M}\left(\tilde{L}_j \times M\right)^m \times m / m!}{\sum_{m=0}^{M}\left(\tilde{L}_j \times M\right)^m / m!}\right\} + \eta \tag{10}$$

3. Therefore, we design the *Equation group* Equation (11) to get the solution of $\frac{\partial Lag}{\partial \tilde{L}_h} = 0$, $\frac{\partial Lag}{\partial \tilde{L}_j} = 0$ $\left(j \in \{1 \ldots J\}\right)$:

$$\begin{cases} \frac{\partial Lag}{\partial \tilde{L}_h} = \frac{\left(\tilde{L}_h \times M\right)^M / M!}{\sum_{m=0}^{M}\left(\tilde{L}_h \times M\right)^m / m!} \times \left\{M + 1 - \frac{\sum_{m=0}^{M}\left(\tilde{L}_h \times M\right)^m \times m / m!}{\sum_{m=0}^{M}\left(\tilde{L}_h \times M\right)^m / m!}\right\} + \eta = 0 \\ \frac{\partial Lag}{\partial \tilde{L}_j} = \frac{\left(\tilde{L}_j \times M\right)^M / M!}{\sum_{m=0}^{M}\left(\tilde{L}_j \times M\right)^m / m!} \times \left\{M + 1 - \frac{\sum_{m=0}^{M}\left(\tilde{L}_j \times M\right)^m \times m / m!}{\sum_{m=0}^{M}\left(\tilde{L}_j \times M\right)^m / m!}\right\} + \eta = 0 \\ \ldots\ldots\ldots\ldots\ldots\ldots \\ \frac{\partial Lag}{\partial \tilde{L}_J} = \frac{\left(\tilde{L}_J \times M\right)^M / M!}{\sum_{m=0}^{M}\left(\tilde{L}_J \times M\right)^m / m!} \times \{\left\{M + 1 - \frac{\sum_{m=0}^{M}\left(\tilde{L}_J \times M\right)^m \times m / m!}{\sum_{m=0}^{M}\left(\tilde{L}_J \times M\right)^m / m!}\right\}\} + \eta = 0 \end{cases} \tag{11}$$

After solving the above equation group, we get the solution:

$$\begin{cases} \tilde{L}_h = \dfrac{\tilde{L}_h + \sum_{\breve{j}=1}^{J} \tilde{L}_{\breve{j}}}{1+J} \\ \tilde{L}_j = \dfrac{\tilde{L}_h + \sum_{\breve{j}=1}^{J} \tilde{L}_{\breve{j}}}{1+J} \qquad j \in \{1....J\} \\ \eta = \dfrac{\left(\dfrac{\tilde{L}_h + \sum_{\breve{j}=1}^{J} \tilde{L}_{\breve{j}}}{1+J} \times M \right)^M \Big/ M!}{\sum_{m=0}^{M} \left(\dfrac{\tilde{L}_h + \sum_{\breve{j}=1}^{J} \tilde{L}_{\breve{j}}}{1+J} \times M \right)^m \Big/ m!} \times \left[\dfrac{\sum_{m=0}^{M} \left(\dfrac{\tilde{L}_h + \sum_{\breve{j}=1}^{J} \tilde{L}_{\breve{j}}}{1+J} \times M \right)^m \times m / m!}{\sum_{m=0}^{M} \left(\dfrac{\tilde{L}_h + \sum_{\breve{j}=1}^{J} \tilde{L}_{\breve{j}}}{1+J} \times M \right)^m \Big/ m!} - M - 1 \right] \end{cases} \tag{12}$$

where $\dfrac{\tilde{L}_h + \sum_{\breve{j}=1}^{J} \tilde{L}_{\breve{j}}}{1+J}$ is the average load of $Cell_h$ and its assistant $Cell_j$ $\left(j \in \{1 \ldots J\}\right)$ after traffic offloading. From Equation (1b), the above average load after offloading equals the average load of $Cell_h$ and $Cell_j$ $\left(j \in \{1 \ldots J\}\right)$ before offloading $\dfrac{L_h + \sum_{\breve{j}=1}^{J} L_{\breve{j}}}{1+J}$.

Relay Cell to Relay Cell Optimal Offloaded Traffic

From the analysis above, this paper draws *Lemma1*:

1. **Formulation:** In heterogeneous relay cellular systems, a heavily loaded $Cell_h$ tries to offload edge users to the RSs of assistant $Cell_j$ $\left(j \in \{1 \ldots J\}\right)$;
2. **Demonstration:** The Equations (4)-(7) and Equation (12) state that the total blocking probability $\tilde{B}_{total}$ of the heavily loaded $Cell_h$ and its assistant $Cell_j$ $\left(j \in \{1 \ldots J\}\right)$ reach the minimal, when $Cell_h$'s load $\tilde{L}_h$ and each assistant $Cell_j$'s load $\tilde{L}_j$ $\left(j \in \{1 \ldots J\}\right)$ reach the same load.

According to *Lemma1*, we analyse the offloaded traffic to help $Cell_h$ and its assistant $Cell_j$ $\left(j \in \{1 \ldots J\}\right)$ reach the same load. The total traffic offloaded out from $Cell_h$ is expressed as $M_{off\ h}$, using Equation (13). This paper defines $M_{off\ j}$ as the offloaded traffic from $Cell_h$ to RSs in assistant $Cell_j$ $\left(j \in \{1 \ldots J\}\right)$. $M_{off\ j}$ can be calculated as Equation (14a). In addition, a cell's load ranges from 0% to 100%. When a cell's load exceeds the threshold of a hot-spot/heavily loaded cell, denoted as L_{hot}, this cell's performance may degrade dramatically, e.g., unsatisfied users, call dropping (SOCRATES, 2010). Telecom operators can set different L_{hot} values according to different application scenarios, typical L_{hot} value includes 70%, 80% (SOCRATES, 2010; Yang, 2012; Ramiro, 2012). Hence, we set the constraint in Equation (14b) to avoid $Cell_j$'s load exceeding the load threshold L_{hot}:

$$M_{off\ h} = M \times \left(L_h - \frac{L_h + \sum_{\breve{j}=1}^{J} L_{\breve{j}}}{1+J} \right) \tag{13}$$

$$M_{off\ j} = M \times \left(\frac{L_h + \sum_{\breve{j}=1}^{I} L_{\breve{j}}}{1+J} - L_j \right) \quad j \in \{1....J\} \tag{14a}$$

s.t. $M_{off\,j} \le M \times \left(L_{hot} - L_j\right)$ (14b)

Lemma1 can be widely used in LTE/LTE-Advanced cellular systems. Take the network planning and optimisation as an example (Han, 2012), telecom operators can redistribute cell's traffic to reach the same load among cells, thus minimising the total blocking probability in LTE/LTE-Advanced cellular systems.

In the proposed TBDUOS scheme, after calculating the optimal offloaded traffic $M_{off\,j}$, we employ the user-level offloading to decide the specific offloaded users from $Cell_h$ to RSs in assistant $Cell_j \left(j \in \left\{1 \ldots J\right\}\right)$.

USER-LEVEL OFFLOADING

Section IV introduces the user-level offloading stage of the proposed TBDUOS scheme. The TBDUOS scheme utilizes telecom big data to analyse the user portrait (Wang, 2015; Cheng, 2015) and further take the users clustering (Rekik, 2006; Zhang, 2015), thus selecting the offloaded users from the heavily loaded $Cell_h$ to assistant $Cell_j \left(j \in \left\{1 \ldots J\right\}\right)$.

User Portrait

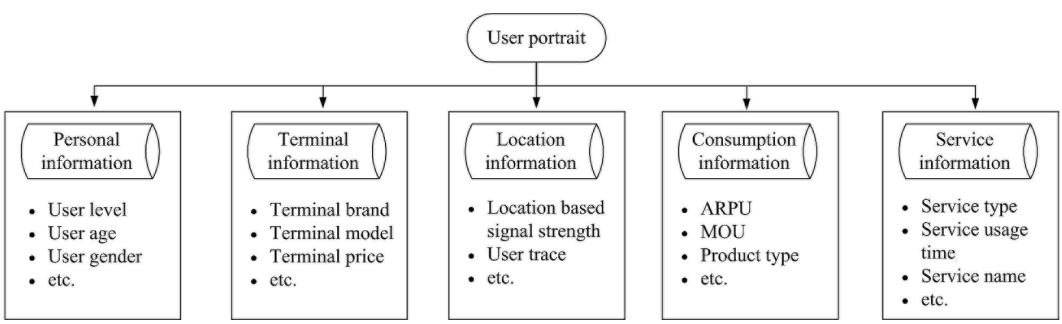
The TBDUOS scheme utilizes telecom big data to achieve each user's comprehensive portrait. User portrait contains its personal information, terminal information, location information, consumption information, service information. Figure 3 shows five categories of factors for the user portrait:

1. For the personal information, PI_1, PI_2, PI_3 represent the user level, the user age, the user gender, respectively. The personal information can be represent as Equation (15):

$$PI = \left(PI_1, PI_2, PI_3\right) \tag{15}$$

Telecom operators set the level of each user, namely PI_1. Take China Unicom as an example, user level includes the gold user and the silver user as well as the bronze user, according to user's social status, working information, years served by China Unicom, etc. (Han, 2012; Wang, 2015). In addition, both the user age PI_2 and the user gender PI_3 are basic information of a telecom customer, they are also the basic for the user portrait.

Figure 3. Five categories of factors for the user portrait



2. The terminal information includes the terminal brand, the terminal model and the terminal price, as shown in Equation (16):

$$TI = (TI_1, TI_2, TI_3) \tag{16}$$

where TI_1, TI_2, TI_3 represent the terminal brand, the terminal model, the terminal price, respectively.

3. The location information includes the location based signal strength received from the serving cell, and the user trace, which can be represent as Equation (17):

$$LI = (LI_1, LI_2) \tag{17}$$

where LI_1 is the signal strength received from the serving cell, and LI_2 is the user trace.

4. The consumption information includes the average revenue per user (ARPU), the minutes of usage (MOU) for the user, user's product type, which can be represent as Equation (18):

$$CI = (CI_1, CI_2, CI_3) \tag{18}$$

where CI_1, CI_2, CI_3 are the product type, the ARPU, the MOU, the product type, respectively. ARPU indicates the user's revenue contribution towards telecom operators (Cheng, 2015). A user with high ARPU indicates this user has large revenue contribution, and hence telecom operators should provide good QoS for this high ARPU user. MOU indicates the telecom user's total voice connection time, and hence MOU reflects this user's voice service consumption level (Cheng, 2015).

5. The service information includes the service type, the service usage time, the service name etc., which can be represent as Equation (19):

$$SI = \left(SI_1, SI_2, SI_3\right) \tag{19}$$

where SI_1, SI_2, SI_3 represent the service type, the service usage time, the service name, respectively.

The overall user portrait consists of above five categories of factors, representing as Equation (20):

$$U = \left(PI, TI, LI, CI, SI\right) \tag{20}$$

Users Clustering

In this sub-section, the TBDUOS scheme considers above five categories of factors and then divides users into different clusters. For different scenarios, the factors of $U = \left(PI, TI, LI, CI, SI\right)$ are different. For the user offloading scenario, we consider the following key factors:

1. The personal information considers the user level, namely PI_1. It is because a high-level customer should take preference to be well served without suffering performance degradation in the offloading scenario;
2. The terminal information considers the terminal brand, namely TI_1. It is because a famous brand (e.g., Apple and Samsung) indicates high capability of terminal;

3. The location information considers the signal strength received from the serving cell, namely LI_1. It is because a user, which receives low signal strength from the serving cell, are easily to trigger handover;
4. The consumption information considers ARPU, namely CI_1. It is because ARPU reflects this user's contribution towards the telecom operator's revenue. The telecom operator should take preference to provide high QoS to the customer with high ARPU;
5. The service information considers the service type, namely SI_1. It is because the service type indicates the service tolerance of delay and link quality. For example, the voice service has lower tolerance than the interactive service.

In this paper, we assume the heavily loaded $Cell_h$ serves N users in $\{U\}$, including U_1, U_2, …, U_N. Therefore, the user portrait for the offloading scenario can be expressed as Equation (21):

$$U_n = (PI_{1,n}, TI_{1,n}, LI_{1,n}, CI_{1,n}, SI_{1,n}) \; n \in \{1...N\} \tag{21}$$

It is generally known that K-MEANS (Rekik, 2006) is a typical algorithm for users clustering. This paper employs K-MEANS algorithm to segment the N users $\{\boldsymbol{U}\}$ into K clusters (namely, K sets) $\mathbf{S} = \{S_1, S_2 \dots S_K\}$, thus to minimize the inter-cluster sum of squares. The process of K-MEANS algorithm includes four stages. In the first stage, K users in $\{\boldsymbol{U}\}$ are selected as the centers of each cluster, namely c_1, c_2…c_K $\left(k \in \{1 \dots K\}\right)$. In the second stage, the TBDUOS scheme assigns each user in $\{\boldsymbol{U}\}$ to the cluster to achieve the least within-cluster sum of squares. In the third stage, the TBDUOS scheme assumes N_i is the number of users in the i^{th} cluster $\boldsymbol{S}_i$, the TBDUOS scheme calculates the mean value of each cluster as the new center of each cluster, namely $c_i^{new} = \frac{1}{N_i} \sum_{U_n \in S_i} U_n$.
In the fourth stage, the TBDUOS scheme goes back to the second stage when $c_i^{new} \neq c_i \quad (i = 1,2...K)$, otherwise, the TBDUOS scheme outputs the cluster result.

After K-MEANS algorithm based clustering, the heavily loaded $Cell_h$ selects users in S_k as the offloaded users in sequence, the user-level offloading stage is finished until the released subcarriers of offloaded users reach the cell-level required offloaded traffic calculated in Equations (13) and (14) of Section III D. Finally, $Cell_h$ sends the offloading command to the selected users and triggers offload based handover to finish the process.

SIMULATION ANALYSIS

A system-level simulator of relay cellular systems is designed via MATLAB R2009 (MATLAB, 2009; MATLAB, 1996). Most of parameters refer the 3GPP LTE-Advanced standard, and key modules also refer the open-source LTE-Advanced system-level simulator designed by Vienna University of Technology (3GPP, 2010; SOCRATES, 2010; Dahlman, 2011; Zheng, 2011; Ramiro, 2012). Table 2 depicts the key parameters of our simulator. Figure 4 shows the layout of relay cellular systems as well as users distribution. From Figure 4, this simulator generates six heavily loaded cells.

Based on the simulator, we simulate and evaluate the performance of the proposed TBDUOS scheme. The cell-level offloaded traffic analysis follows Section III and the user-level offloading stage strictly follows Section IV. The user information, including user level, service type, terminal brand, ARPU, are set according to customers' data of China Unicom.

In order to compare the performance of the TBDUOS scheme and the performance of conventional schemes, we also simulate both the cell-cluster based traffic offloading (CCTO) scheme of (Wang, 2010) and the utility function based traffic offloading (UFTO) scheme of (Yang, 2012; Yang, 2014).

Table 2. Simulator parameters

Parameter	Value
Cell layout	19 cells; Inter-site distance: 1.5Km
Subcarrier and Total bandwidth	Subcarrier: 15KHz; Total: 20MHz
Resource blocks (RB)	Total 100 (12 subcarriers per RB)
Frequency	2GHz
Distance between BS and RS	2/3 of cell radius
Relay mode	Decode-and-forward
BS-Inner user path-loss model	$37.6\times\log_{10}(d_{BS-Inner\ user})+128.1$
BS-RS path-loss model	$23.5\times\log_{10}(d_{BS\text{-}RS})+100.7$
RS-Edge user path-loss model	$38.1\times\log_{10}(d_{RS\text{-}Edge\,user})+129.9$
Log-normal shadow fading	Standard deviation: 8dB
Frequency planning	Full frequency reuse
Total BS transmit power	46dBm
Total RS transmit power	37dBm
BS height and RS height	BS: 15m; RS: 12m
User level	Gold level, silver level, bronze level
Service type	Four types: voice, interactive, background, stream
Terminal brand	Apple, Samsung, Xiaomi, Huawei, ZTE, OPPO, Lenovo, NOKIA
ARPU	Between 10RMB and 1000RMB
Maximum handover offset	9dB
L_{hot}	80%

In order to eliminate the performance difference induced by different simulation parameters, this simulator sets the same configuration (e.g., the same users distribution, the same user information, etc.) for the simulation of the TBDUOS scheme and the CCTO scheme as well as the UFTO scheme.

Figure 5 and Figure 6 illustrate the TBDUOS scheme performance for different types of services. Figure 5 compares the handover failure probability. The voice service and the stream service are easily to suffer handover failure, compared with the interactive service and the background service. It is because the voice and the stream services have higher link quality requirements than the interactive and background services. From Figure 5, since the CCTO scheme and the UFTO scheme do not consider the service type during traffic offloading, the handover failure probabilities of users with voice and stream services are much higher than the interactive and background services. In the proposed TBDUOS scheme, the service type is a key factor to decide the offloaded users, the TBDUOS

Figure 4. Relay cellular systems layout and users' distribution (unit: meter)

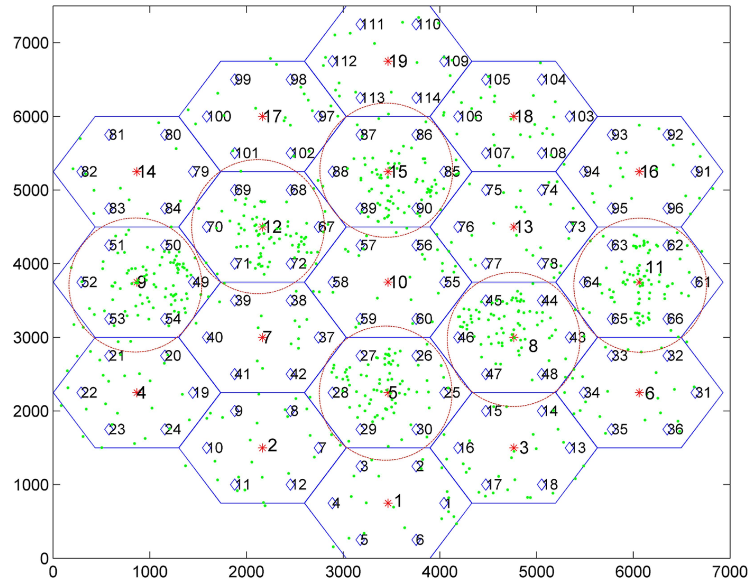
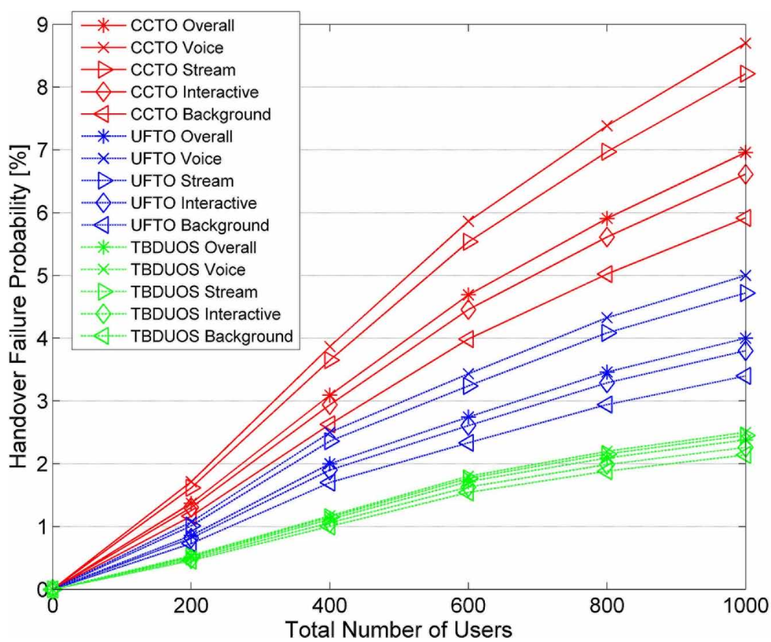


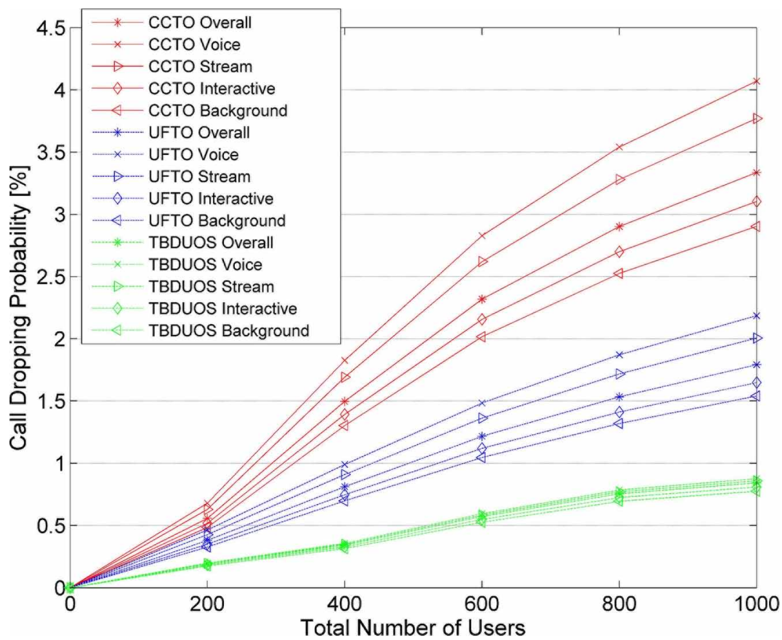
Figure 5. Handover failure probability comparison of four types of services



scheme takes preference to offload users with the interactive and the background services. Besides, the voice/stream users, which receive strong signal strength from assistant cells, will be more easily offloaded to assistant cells than voice/stream users received poor signal. Therefore, these offloaded voice/stream users have low handover failure probability under the TBDUOS scheme.

Figure 6 compares the call dropping probability of four types of services. Similarly, for both the CCTO scheme and the UFTO scheme, voice/stream users are more easily to suffer call dropping

Figure 6. Call dropping probability comparison of four types of services



than interactive/background users. Employing the proposed TBDUOS scheme, voice/stream users have similar call dropping probability with interactive/background users. From Figure 6, employing the TBDUOS scheme, the call dropping probability of each type of service is lower than the CCTO scheme and the UFTO scheme. Overall, Figure 5 and Figure 6 show that the TBDUOS scheme can keep good performance for voice/stream services. In addition, each service has better performance, in terms of handover failure and call dropping, than that under the CCTO scheme and the UFTO scheme.

ARPU reflects the user's revenue contribution towards telecom operators. Telecom operators should take preference to guarantee the QoS of high ARPU users. Figure 7 compares the handover failure probability of different ARPU users, namely ARPU less than 100RMB (ARPU<100) and ARPU larger than 100RBM (ARPU≥100). Both the CCTO scheme and the UFTO scheme only consider the user's signal strength without considering the user consumption information. Hence, employing the CCTO scheme, the handover failure probability of users with ARPU<100 and that of users with ARPU≥100 are similar. Under the UFTO scheme, the handover failure probability of users with ARPU<100 and that of users with ARPU≥100 are also similar.

From Figure 7, employing the proposed TBDUOS scheme, the handover failure probability is lower than that under the CCTO scheme and the UFTO scheme. In addition, the TBDUOS scheme considers user's consumption information to decide the offloaded users. Hence, the handover failure probability of users with ARPU≥100 is further reduced.

Telecom operators sets the level of each user (e.g., gold user, silver user, bronze user for China Unicom). Telecom operators should take preference to guarantee QoS of high level users (gold users and silver users). Figure 8 compares the call dropping probability of different user levels. Both the CCTO scheme and the UFTO scheme only consider the user's signal strength without considering the user level during offloading. Hence, employing the CCTO scheme, the call dropping probabilities are similar among gold users and silver users as well as bronze users. Under the UFTO scheme, the call dropping probabilities of three levels of are also similar.

Employing the TBDUOS scheme, the call dropping probability is lower than that under the CCTO scheme and the UFTO scheme. In addition, the TBDUOS scheme considers user level to

Figure 7. Handover failure probability comparison of different ARPU

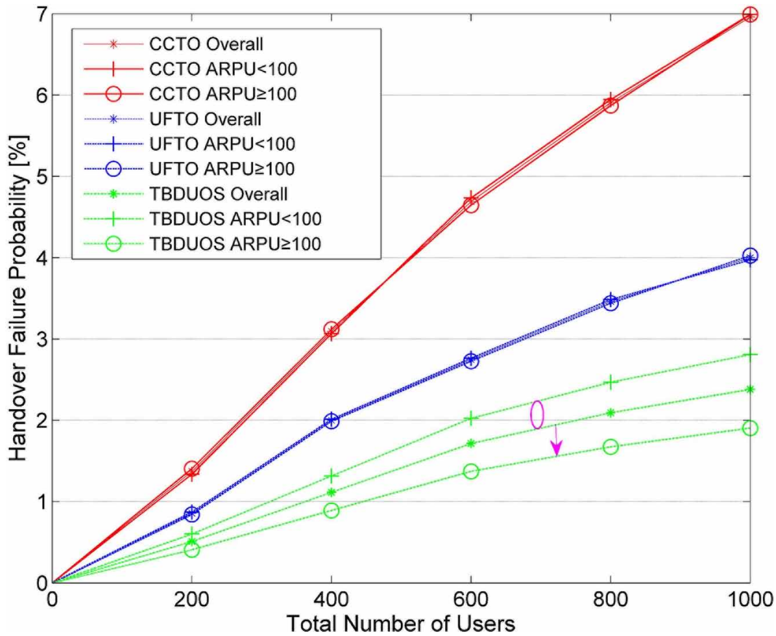
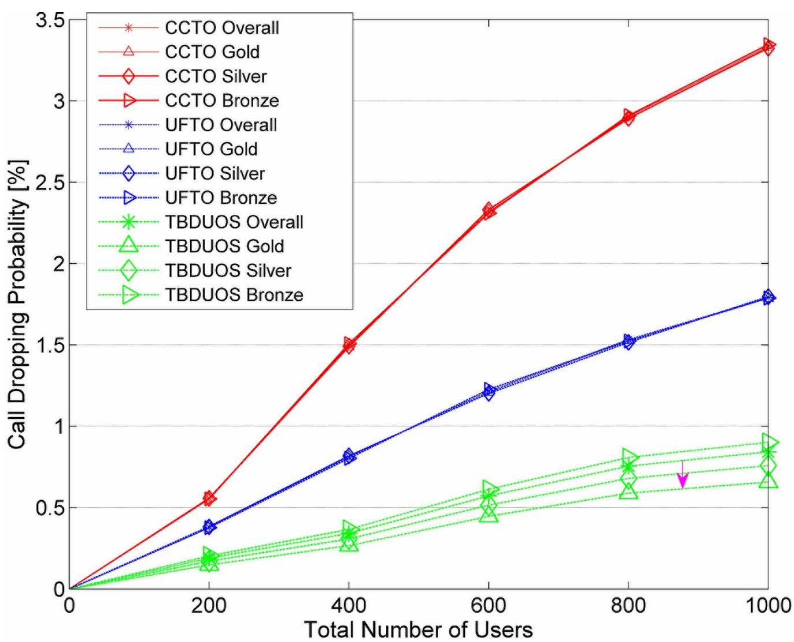


Figure 8. Call dropping probability comparison of three levels of users



during the offloading. Therefore, the call dropping probabilities of both the gold users and silver users can be further reduced.

Figure 9 shows the overall blocking probability of three schemes to compare their traffic offloading performance. It is because more users can get access cellular systems under more balanced load distribution. In the cell-level offloaded traffic analysis stage of TBDUOS scheme, the calculated offloaded traffic can minimise the total blocking probability of the heavily loaded cell and its assistant cells. According to Figure 9, the TBDUOS scheme has better performance than the CCTO scheme and the UTFO scheme.

In order to evaluate the TBDUOS scheme comprehensively, we also employ the TBDUOS scheme in single-hop cellular systems without relay stations. Specifically, we simplify the TBDUOS scheme and remove the relay stations consideration in the cell-level offloaded traffic analysis stage and the user-level offloading stage. For the simulator, there are still 19 cells with the inter-site distance of 1.5 kilometers, and the basic parameters of each cell and each user still follow Table 1. The difference is that relay stations are removed, and all served users are connected by BS via single-hop direct connection. Figure 10 shows the overall blocking probability of three schemes in single-hop cellular systems. From Figure 10, employing the proposed TBDUOS scheme, the overall blocking probability is lower that under the CCTO scheme and the UTFO scheme. Figure 9 and Figure 10 reflect that the proposed TBDUOS scheme has better traffic offloading performance, in terms of call blocking, than the conventional CCTO scheme and the UTFO scheme in both relay cellular systems and single-hop cellular systems.

CONCLUSION

This paper designs a novel telecom big data based user offloading self-optimisation (TBDUOS) scheme. Its aim is to balance the load distribution and to achieve good service performance as well as benefit the customer management. In order to achieve these objectives, in the cell-level offloaded traffic analysis stage, the optimal offload traffic is calculated to minimise the total blocking probability

Figure 9. Call blocking probability comparison (relay cellular systems)

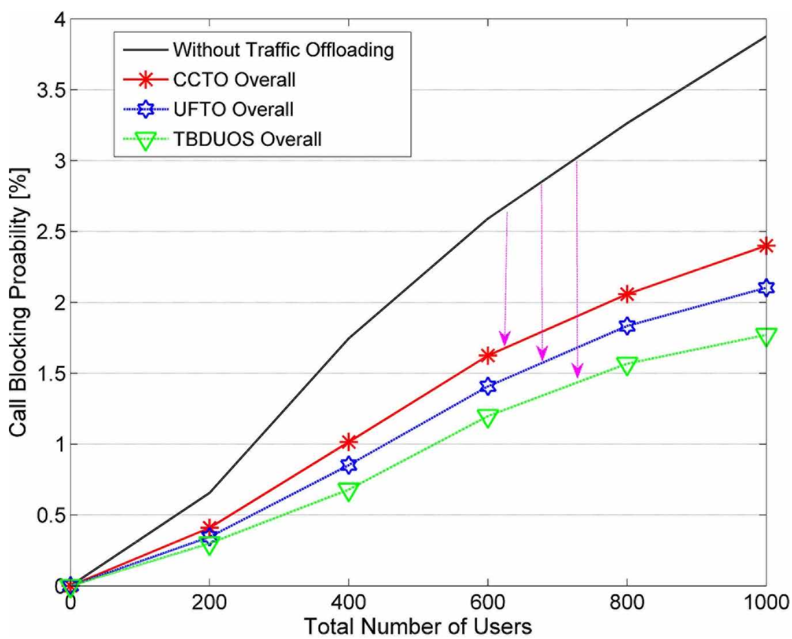
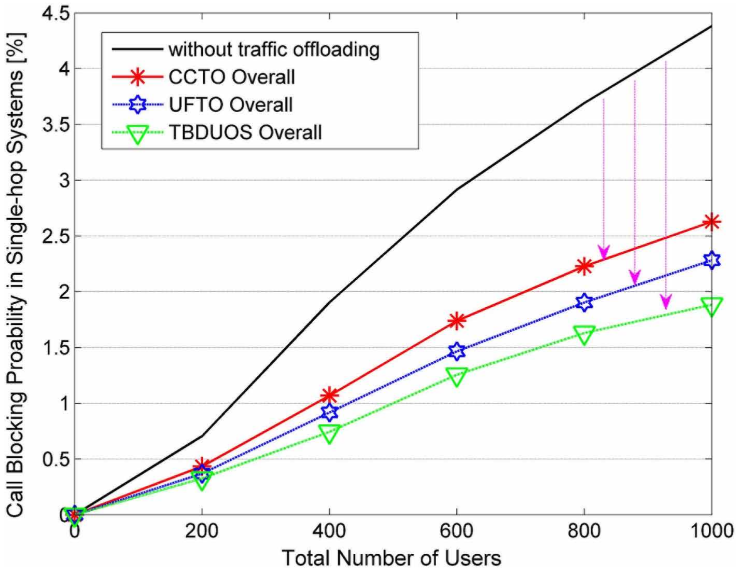


Figure 10. Call blocking probability comparison (single-hop cellular systems)



of the heavily loaded cell and its assistant cells. In the user-level offloading stage, the TBDUOS scheme draws the user portrait according to the personal information, terminal information, location information, consumption information and service information. Based on the user portrait, we employ the K-MEANS algorithm to manage users clustering and finally offload users to assistant cells. Simulation results show the proposed TBDUOS scheme can reduce the handover failure probability and the call dropping probability of voice/stream users. In addition, both high ARPU (average revenue per user) users and high level users (gold and silver users) can experience low handover failure probability and call dropping probability. The TBDUOS scheme can also keep the call blocking probability at a low level. This paper focuses on the technical introduction and the simulation results of the TBDUOS scheme. In the future, we plan to carry on the lab test and further apply the TBDUOS scheme into the physical cellular systems of China Unicom. In the physical cellular systems, more factors of the user portrait will be considered under different hot-spot scenarios (e.g., university campus, business area, stadium, etc.), thus improving the robustness and the universality of the TBDUOS scheme.

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