User Relay assisted Traffic Shifting in LTE-Advanced Systems

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***Abstract*—In order to deal with uneven load distribution, mobility load balancing adjusts the handover region to shift edge users from a hot-spot cell to the less-loaded neighbouring cells. However, shifted users suffer the reduced signal power from neighbouring cells, which may result in link quality degradation. This paper employs a user relaying model and proposes a user relay assisted traffic shifting (URTS) scheme to deal with the above problem. In URTS, a shifted user selects a suitable non-active user as relay user to forward data, thus enhancing the link quality of the shifted user. Since the user relaying model consumes relay user's energy, a utility function is designed in relay selection to reach a trade-off between the shifted user's link quality improvement and the relay user's energy consumption. Simulation results show that URTS scheme could improve SINR and throughput of shifted users. Also, URTS scheme keeps the cost of relay user's energy consumption at an acceptable level.**

Keywords: mobility load balancing; link quality; relay selection

I. Introduction

Due to service development and user mobility, LTE/LTE-Advanced systems have the random, time-varying and often uneven traffic distribution [1][2]. Mobility load balancing (MLB) is an important resource management functionality that aims at balancing the traffic demand between the hot-spot cell and lightly loaded cells to avoid possible congestion and to increase the spectrum efficiency [3].

Generally, MLB schemes follow two stages: initially, a hot-spot cell chooses some less-loaded neighbouring cells as partners; then the hot-spot cell calculates the required offloading traffic and adjusts cell-specific handover offsets (HO_{off}) to shift edge users to selected partners. These two stages are designed in our previous work in [4] and [5].

MLB could achieve balanced load distribution. However, shifted users may receive low reference signal received power (RSRP) and suffer link quality degradation. As shown in Fig.1, $Cell_1$ is the hot-spot and tries to offload traffic to the lightly loaded $Cell_2$. BS_1 increases HO_{off} towards BS_2, in order to trigger handover of $Cell_1$ edge user. Fig.1 clearly shows that after MLB the shifted user receives the reduced $RSRP_2$, which is lower than $RSRP_1$ before MLB. Furthermore, the reduced RSRP may result in low SINR. In this paper, the phenomenon of the reduced RSRP and even reduced SINR of shifted users is called *link quality degradation*. This problem impacts networks performance. The shifted user may experience handover failure due to poor link quality. Furthermore, after successful handover, BS_2 needs assign more subcarriers to meet the shifted user's data rate requirement, which will reduce the spectrum utilisation.

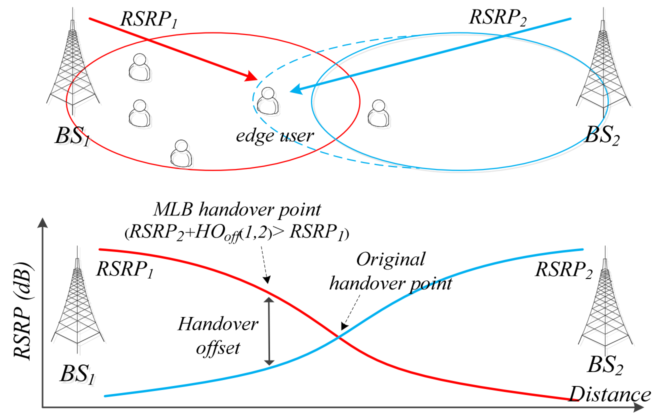

Fig.1. RSRP comparison of shifted user

To deal with *link quality degradation*, this paper employs a user relaying model: a non-active user is treated as a relay to forward information to a shifted user. The spatially independent transmission paths (relay link, BS direct link) can achieve spatial diversity, enhancing the shifted user's link quality.

The user relaying model enhances the shifted user's link quality at the expense of relay user's energy consumption. Hence, this paper further proposes a user relay assisted traffic shifting (URTS) scheme. It this scheme, a utility function considering above two factors is designed, which selects an appropriate relay user, enhancing the shifted user's link quality under low cost of relay user's energy consumption.

This paper is organized as follows: Section II presents the user relaying model. Section III analyses this model. Section IV describes the URTS scheme. Simulation results and conclusions are presented in Section V and VI, respectively.

II. User Relaying Model

This work follows our previous research on MLB [4][5]. After MLB implementation, the hot-spot cell offloads its edge users to lightly loaded neighbouring cells. These shifted users may suffer their link quality degradation (see Fig.1).

Meanwhile, there are many non-active users (e.g., sleep mode) in each neighbouring cell [1]. In the downlink of each *non-active user*, the control channel is partially used while the data channel is idle. Hence, the *idle data channel* can be utilised to forward transmission data to the shifted user.

Hence, this paper employs a user relaying model. As shown in Fig.2, the shifted user selects a non-active user located in the lightly loaded cell (which is the handover target cell of the shifted user) as the relay user. When BS transmits data to the shifted user, the relay user receives these data in the first time slot and then forwards to the shifted user in the second time slot.

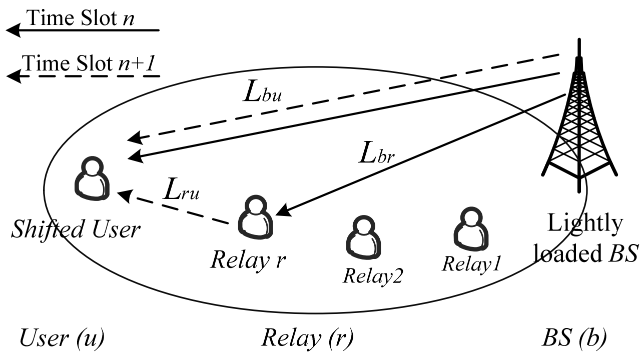

Fig.2. User relaying model

In order to simplify the description, this paper describes the user relaying model as: a destination shifted user, defined as *User u*; several non-active users, defined as *Relay r* $r\epsilon\{1 \dots R\}$; and a lightly loaded BS, defined as *BS b*. Therefore, for a specific user relaying model, it consists of one *Relay r*, one shifted *user u* and one source *BS b*.

The downlink transmission mode is shown in Fig.2, including two consecutive time slots [2] [6]. In time slot (TS) *n*, both *User u* and *Relay r* listen to the transmission of *BS b*; in TS *n+1*, both BS *b* and Relay *r* transmit to *User u* simultaneously [6]. Note that we assume *BS b* transmits the same data at two time slots [2] [6].

In this paper, *Relay r* is operating in the amplified-and-forward (AF) mode [7]. In the AF mode, the relay user amplifies all received signals, including interference, noise and user signal. Then it forwards these signals to the shifted user. The AF mode suits the user device, as the AF mode requires lower data processing capability than the decode-and-forward (DF) mode does. The parameters that will be used in subsequent sections are listed in Table I:

Table I Parameters of user relaying model

y_{br}: *Relay r's* received signal from *BS b*.
y_{bu}: *User u's* received signal, in *BS b to User u* link.
y_{ru}: *User u's* received signal, in *Relay r to User u* link.
a_{br} : Channel gain from *BS b* to *Relay r*.
a_{bu} : Channel gain from *BS b* to *User u*.
a_{ru} : Channel gain from *Relay r* to *User u*.
λ_r: Amplified factor of *Relay r*.
P_b: Transmission power of *BS b*.
P_r: Transmission power of *Relay r*.
$I_r[n]$: Inter-cell interference at *Relay r* in TS *n*.
$I_u[n]$: Inter-cell interference at *User u* in TS *n*.
$C_u^{AF\,r}$: Throughput of *User u* with *Relay r* assistance.
$C_u^{NO\,AF}$: Throughput of *User u* without relay assistance.
C_r^{BS}: *Relay r*'s throughput, with the same number of subcarriers being allocated to *Relay r*. C_r^{BS} reflects *Relay r*'s throughput loss.
x_b : User signal from *BS b*.
σ^2 : Common variance of the Gaussian white noise.
B: Bandwidth in the user relaying model.

III. Analysis of User Relaying Model

Based on the user relaying model, Section III analyses the throughput of shifted *User u*, as well as the impact of energy consumption of *Relay r*.

From the user relaying model, the received signals at *User u* and *Relay r* in TS *n* are given by (1) and (2), respectively.

$$y_{bu}[n] = a_{bu}x_b[n] + Z_u[n] + I_u[n] \tag{1}$$

$$y_{br}[n] = a_{br}x_b[n] + Z_r[n] + I_r[n] \tag{2}$$

where $Z_u[n]$ and $Z_r[n]$ are the noise at *User u* and *Relay r*, respectively; $I_u[n]$ and $I_r[n]$ are the inter-cell interference at *User u* and *Relay r*, respectively; a_{bu} is the channel gain from *BS b* to the *User u*; a_{br} is the channel gain from *BS b* to *Relay r*.

A. SINR of User u in User Relaying Model

In AF mode [7], *Relay r* amplifies all received signals and forwards to the shifted *User u* in TS *n+1*. According to (2), the amplified factor of *Relay r* can be expressed as λ_r, using (3):

$$\lambda_r^2(|a_{br}|^2 P_b + \sigma^2 + |I_r[n]|^2) = P_r \quad \Rightarrow \quad \lambda_r^2 = \frac{P_r}{|a_{br}|^2 P_b + \sigma^2 + |I_r[n]|^2} \tag{3}$$

where P_b and P_r are the transmission power of *BS b* and *Relay r*, respectively; σ^2 is the common variance of the Gaussian white noise; | | denotes the magnitude of the symbol. For example, $|I_r[n]|^2$ is the interference power at *Relay r*.

In TS *n+1*, *User u* received signals from *Relay r* and *BS b* are discussed in *i)* and *ii)*.

i) User u received signal from *Relay r* (*Link L_{ru}* in Fig.2) in TS *n+1* is denoted as $y_{ru}[n+1]$, using (4):

$$\begin{aligned} y_{ru}[n+1] &= \lambda_r y_{br}[n] a_{ru} + Z_u[n+1] + I_u[n+1] \\ &= (\lambda_r a_{ru} a_{br} x_b[n]) + (\lambda_r a_{ru} Z_r[n] + Z_u[n+1]) + \lambda_r a_{ru} I_r[n] + I_u[n+1] \end{aligned} \tag{4}$$

where $y_{br}[n]$ refers to (2); a_{ru} is the channel gain from *Relay r* to *User u*. According to (4), SINR of *User u* in TS *n+1* from L_{ru} can be expressed as $SINR_{u,n+1}^{(L_{ru})}$, using (5):

$$SINR_{u,n+1}^{(L_{ru})} = \frac{P_b\,|a_{ru}|^2 |a_{br}|^2\,\lambda_r^2}{|a_{ru}|^2\,\lambda_r^2(|I_r[n]|^2 + \sigma^2) + |I_u[n+1]|^2 + \sigma^2} \tag{5}$$

ii) User u received signal from *BS b* (*Link L_{bu}* in Fig.2) in TS *n+1* is denoted as $y_{bu}[n+1]$, using (6). From (6), SINR of *User u* in TS *n+1* from L_{bu} is denoted as $SINR_{u,n+1}^{(L_{bu})}$, using (7):

$$y_{bu}[n+1] = a_{bu}x_b[n+1] + Z_u[n+1] + I_u[n+1] \tag{6}$$

$$SINR_{u,n+1}^{(L_{bu})} = \frac{P_b\,|a_{bu}|^2}{|I_u[n+1]|^2 + \sigma^2} \tag{7}$$

iii) Besides, in TS n, *User u* received signal from *BS b* (*Link L_{bu}* in Fig.2) is shown in (1). Hence, SINR of *User u* in TS n from L_{bu} can be expressed as $SINR_{u,n}^{(L_{bu})}$, using (8):

$$SINR_{u,n}^{(L_{bu})} = \frac{P_b |a_{bu}|^2}{\|I_u[n]\|^2 + \sigma^2} \tag{8}$$

In (1) (4) (6), $x_b[n]$ and $x_b[n+1]$ are the same user signal from three separate links. *User u* combines them to enhance the signal quality. According to [6], the SINR achieved after signal processing at *User u* is defined as $SINR_u^{AF\,r}$, using (9):

$$SINR_u^{AF\,r} = SINR_{u,n}^{(L_{bu})} + SINR_{u,n+1}^{(L_{ru})} + SINR_{u,n+1}^{(L_{bu})} \tag{9}$$
$$= \frac{P_b |a_{bu}|^2}{\|I_u[n]\|^2 + \sigma^2} + \frac{P_b |a_{ru}|^2 |a_{br}|^2 \lambda_r^2}{|a_{ru}|^2 \lambda_r^2 (\|I_r[n]\|^2 + \sigma^2) + \|I_u[n+1]\|^2 + \sigma^2} + \frac{P_b |a_{bu}|^2}{\|I_u[n+1]\|^2 + \sigma^2}$$

B. Throughput of User u with Relay r assistance

Based on $SINR_u^{AF\,r}$, the **throughput of *User u with Relay r assistance*** is defines as $C_u^{AF\,r}$, using (10):

$$C_u^{AF\,r} = \frac{B}{2}\log_2(1 + SINR_u^{AF\,r}) \tag{10}$$
$$= \frac{B}{2}\log_2(1 + \frac{P_b |a_{bu}|^2}{\|I_u[n]\|^2 + \sigma^2} + \frac{P_b |a_{ru}|^2 |a_{br}|^2 \lambda_r^2}{|a_{ru}|^2 \lambda_r^2 (\|I_r[n]\|^2 + \sigma^2) + \|I_u[n+1]\|^2 + \sigma^2} + \frac{P_b |a_{bu}|^2}{\|I_u[n+1]\|^2 + \sigma^2})$$

where B is the bandwidth; $\frac{1}{2}$ denotes that *User u* receives the same transmission data in two time slots [2] [6].

Relay selection impacts the value of $|a_{ru}|^2$, $|a_{br}|^2$ and $\|I_r[n]\|^2$. From Equation (10), selecting a suitable relay user could improve the throughput of the shifted user.

C. Throughput of User u without relay

If there isn't a relay link, *User u* only receives a signal from *BS b* (*Link L_{bu}* in Fig.2) in TS n and TS $n+1$. From (7) (8), the **throughput of *User u* without relay** is defined as $C_u^{NO\,AF}$:

$$C_u^{NO\,AF} = \frac{B}{2}\log_2\{1 + \frac{P_b |a_{bu}|^2}{\|I_u[n]\|^2 + \sigma^2} + \frac{P_b |a_{bu}|^2}{\|I_u[n+1]\|^2 + \sigma^2}\} \tag{11}$$

D. Throughput Loss of Relay r

From the user relaying model, *Relay r* amplifies signal power and forwards to *User u* in TS $n+1$. This consumes the energy of *Relay r* and shortens *Relay r* battery working time, which will result in the throughput loss of *Relay r*. This paper uses throughput as the single metric, which allows us to compare the benefit to shifted users and the cost to relays directly. We define C_r^{BS} as ***Relay r*'s throughput**, with the same number of subcarriers (the same bandwidth) being allocated to *Relay r*. Hence, C_r^{BS} reflects ***Relay r*'s throughput loss**, and indicates the impact of energy consumption of *Relay r*.

If *Relay r* becomes active, the received signal at *Relay r* in TS $n+1$ is given by (12). Correspondingly, the achieved SINR of *Relay r* in TS $n+1$ is defined as $SINR_{r,n+1}$, using (13).

$$y_{br}[n+1] = a_{br}x_b[n+1] + Z_r[n+1] + I_r[n+1] \tag{12}$$

$$SINR_{r,n+1} = \frac{P_b |a_{br}|^2}{\|I_r[n+1]\|^2 + \sigma^2} \tag{13}$$

where P_b is the transmission power of *BS b*; $\|I_r[n+1]\|^2$ is the interference power at *Relay r* in TS $n+1$. a_{br} is the channel gain from *BS b* to *Relay r*. According to (13), C_r^{BS} can be expressed as (14):

$$C_r^{BS} = \frac{B}{2}\log_2\{1 + \frac{P_b |a_{br}|^2}{\|I_r[n+1]\|^2 + \sigma^2}\} \tag{14}$$

Relay selection impacts the value of $|a_{br}|^2$ and $\|I_r[n+1]\|^2$. Equation (14) indicates that selecting an appropriate relay could keep the throughput loss of the relay user at a low level.

IV. USER RELAY ASSISTED TRAFFIC SHIFGING SCHEME

From the analysis above, the user relaying model provides a complementary link to improve the throughput of the shifted user. However, this model also consumes the battery power of the relay user and shortens its working time, which will reduce the relay user's total throughput. Both the factor of the shifted user's throughput and the factor of the relay user's throughput loss should be considered jointly in relay selection.

Therefore, based on the user relaying model, this paper proposes a user relay assisted traffic shifting (URTS) scheme. The key of URTS scheme lies in designing a utility function to select an appropriate relay for the two factors' trade-off.

A. Weight of Traffic Shifting

In order to select a proper *Relay r* to increase the throughput of the shifted *User u*, this paper designs the weight of traffic shifting (WTS) as $\Psi_{r,WTS}$. As shown in (15), $\Psi_{r,WTS}$ equals the ratio of *User u's* throughput with *Relay r* assistance ($C_u^{AF\,r}$, see (10)) to *User u's* throughput without relay ($C_u^{NO\,AF}$, see (11)). Hence, $\Psi_{r,WTS}$ indicates the throughput gain of *User u*.

$$\Psi_{r,WTS} = \frac{C_u^{AF\,r}}{C_u^{NO\,AF}} \qquad r \in \{1,2...R\} \tag{15}$$

B. Weight of Throughput Loss

The energy consumption of *Relay r* will shorten its battery working time and reduce its total throughput. Under the similar energy consumption of the non-active *Relay r*, this paper designs the weight of throughput loss (WTL) to compare the throughput loss of *Relay r*, and the throughput improvement for *User u*. $\Psi_{r,WTL}$ is calculated as (16):

$$\Psi_{r,WTL} = \frac{C_r^{BS}}{C_u^{AF\,r} - C_u^{NO\,AF}} \qquad r \in \{1,2...R\} \tag{16}$$

* $C_u^{AF\,r} - C_u^{NO\,AF}$ reflects the throughput improvement of *User u*, with *Relay r* assistance.

*C_r^{BS} reflects *Relay r*'s throughput loss itself (see (14)).

$\Psi_{r,WTL}$ indicates the impact of energy consumption. In (16), the higher throughput loss of *Relay r* leads to the higher $\Psi_{r,WTL}$.

C. Utility Function based Relay Selection

In order to select a suitable user to reach the trade-off between the ***weight of traffic shifting*** and the ***weight of throughput loss,*** this paper designs a utility function u_r as (17):

$$u_r = \frac{\psi_{r,WTS}}{\psi_{r,WTL}} = \frac{C_u^{AF\,r} \times (C_u^{AF\,r} - C_u^{NO\,AF})}{C_u^{NO\,AF} \times C_r^{BS}} \qquad r \in \{1...R\} \quad (17)$$

According to (17), the higher *User u*'s throughput with *Relay r* assistance could lead to higher u_r. Meanwhile, the lower throughput loss of *Relay r* could lead to higher u_r. Hence, URTS scheme tries select *Relay k* to maximize u_r :

$$Relay\ k = \underset{r\in\{1,2...R\}}{\arg\max}\ u_r = \underset{r\in\{1,2...R\}}{\arg\max} \frac{C_u^{AF\,r} \times (C_u^{AF\,r} - C_u^{NO\,AF})}{C_u^{NO\,AF} \times C_r^{BS}} \quad (18)$$

From (18), the utility function relates to $C_u^{AF\,r}$, C_r^{BS}, $C_u^{NO\,AF}$. *User u* has its correspondingly fixed $C_u^{NO\,AF}$, given by (11).

$C_u^{AF\,r}$ and C_r^{BS} are varying with different *Relay r*. From (10), $C_u^{AF\,r}$ is based on three varying parameters: $|a_{ru}|^2$, $|a_{br}|^2$, $|I_r[n]|^2$. From (14), C_r^{BS} is based on $|a_{br}|^2$ and $|I_r[n+1]|^2$.

D. URTS Scheme Process

Based on the analysis above, *User u* could calculate the utility function to select suitable relay, only under knowing the value of $|a_{br}|^2$, $|a_{ru}|^2$, $|I_r[n]|^2$, $|I_r[n+1]|^2$. To reduce the complexity and signalling load, the URTS scheme calculates them according to existing/measurable parameters in other resource management functionalities, e.g., cell selection, admission control. Specifically, they can be estimated as:

i) $|a_{br}|^2$ (a_{br} is the channel gain from *BS b* to *Relay r)*: Since *Relay r* knows its received RSRP from *BS b,* as well as *BS b*'s transmission power (which could be informed from *BS b* in control channel [1]), *Relay r* estimates $|a_{br}|^2$ as (19):

$$|a_{br}|^2 \approx \frac{Relay\ r\text{'s received RSRP from BS b}}{BS\ b\text{'s transmission power } P_b} \quad (19)$$

ii) $|a_{ru}|^2$ (a_{ru} is the channel gain from *Relay r* to *User u)*: After *Relay r* responding to *User u*, *User u* knows its received response signal power from *Relay r*. Besides, *Relay r* reports P_r (see Fig.3) to *User u*. *User u* calculates $|a_{ru}|^2$ as (20):

$$|a_{ru}|^2 \approx \frac{User\ u\text{'s received response power from Relay r}}{Relay\ r\text{'s transmission power } P_r} \quad (20)$$

iii) $|I_r[n]|^2$, $|I_r[n+1]|^2$ (interference power of *Relay r* in TS *n* and *n+1*): In the *full frequency reuse* LTE-Advanced cellular networks [1] [4], precise interference estimation is difficult. It is because *Relay r's* interference, which is imposed by other cells using the co-channel subcarriers, is varying due to the dynamic subcarriers allocation of neighbouring cells. To reduce the estimation complexity, *Relay r* considers the RSRP from all neighbouring BSs as the interference, and then calculates the theoretically heaviest interference $|I_r|^2$.

The flowchart of URTS scheme is shown in Fig.3, which involves the process of shifted *User u* and *Relay r*.

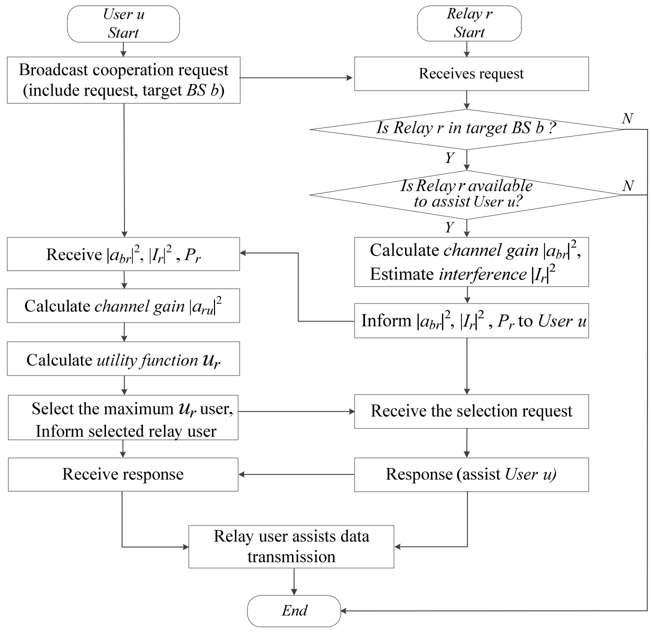

Fig.3. Flowchart of URTS scheme

As shown in Fig.3, if a user in the hot-spot BS needs to be shifted to the target *BS b*, the shifted *User u* broadcasts its cooperation request and its target *BS ID* (denotes *BS b*).

After receiving the broadcast, the non-active user judges whether it is in the coverage of *BS b* and whether it is available to assist *User u* (Since a non-active user can only assist a shifted user at a time). If it is, this non-active *Relay r* calculates $|a_{br}|^2$ from (19). Besides, *Relay r* estimates $|I_r|^2$ as the sum of RSRP from all neighbouring BSs. Then *Relay r* responds and sends $|a_{br}|^2$, $|I_r|^2$, and P_r to *User u*.

After receiving the responses, *User u* calculates $|a_{ru}|^2$ from (20). *User u* calculates the utility function u_r of all responding non-active users, based on $|a_{ru}|^2$, $|a_{ru}|^2$, $C_u^{NO\,AF}$ (*User u* calculates its correspondingly $C_u^{NO\,AF}$ from (11)). Then *User u* selects a non-active user with the largest u_r as relay.

After relay user selection, the selected non-active user starts to assist *User u* to forward the transmission data.

Note that: multiple shifted users may request one non-active user at the same time. Under this scenario, the non-active user chooses one shifted user, from which the non-active user receives the strongest broadcast power. It is because the high received power indicates good link quality between two users.

V. SIMULATION ANALYSIS

A. Simulation Scheme Introduction

This paper designs a downlink system-level LTE-Advanced simulation platform based on [1]. As shown in Fig.4, there are three hot-spot areas, which cover 70% active users and 70% non-active users. Other important parameters are shown in Table II. Besides, this paper simulates four schemes.

Table II Simulation Platform Parameters

Parameter	Value
Subcarrier and Total bandwidth	Subcarrier: 15K Hz; Total: 5M Hz
Physical resource blocks(PRB)	Total 25 (12 subcarriers per PRB)

Frequency	2G Hz
Inter-site distance	500m (3-sector antenna splits site)
Log-normal shadow fading	Standard Deviation: 8dB
BS-MS Path loss model	37.6 *lg* (*r*) + 128.1, *r-km*
MS-MS Path loss model	-27.6+20*lg* (2000)+20*lg* (d), *d-meter*[8]
Total BS transmission power	43 dBm
Total MS transmission power	21 dBm
User mobility	Speed: 3m/s; Direction: Random
Scheduler	Max C/I
Traffic model	Guaranteed 64kbps

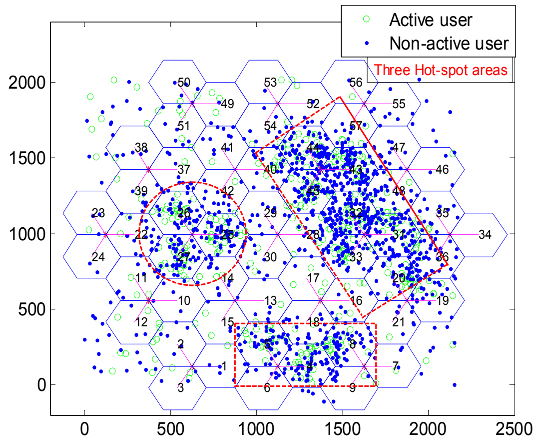

Fig.4. Cells layout and users distribution (unit: *meter*)

i) URTS (named *CLB with utility function user relay* in Fig.6-9)

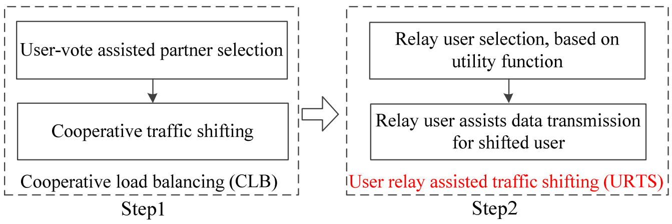

Fig.5. Overall simulation flow of URTS scheme

This work simulates the proposed (utility function based) URTS scheme. Fig.5 shows its simulation flow. Before URTS scheme, each active user in the hot-spot cell needs to be aware whether it needs to be shifted out. This process refers to our previous cooperative load balancing (CLB) scheme, consisting of user-vote assisted partner selection [4] and cooperative traffic shifting [5]. After CLB, the shifted user triggers the proposed utility function based relay selection. Finally, the relay user assists the transmission of the shifted user.

ii) CLB scheme

This work also simulates the standalone *CLB* scheme *(without user relay)* [4][5]. In the *CLB* scheme, the hot-spot cell adjusts HO_{off} towards partner $Cell_b$. Then *User u* in the hot-spot cell will be shifted to $Cell_b$ without relay assistance.

iii) Typical MLB scheme

In addition, the *typical mobility load balancing (MLB)* scheme [3] in LTE is simulated for comparison. In [3], the hot-spot cell selects all less-loaded neighbouring cells as partners, then the hot-spot cell estimates its shifted users' required subcarriers in each partner cell. The hot-spot cell gradually adjusts cell-specific HO_{off} towards each partner to offload users until two cells reach a similar load.

iv) WTS based user relay assisted traffic shifting scheme (named *CLB with WTS user relay* in Fig.6-9)

Section V tries to evaluate whether the proposed *utility function* could improve the performance of shifted users under acceptable throughput loss of relay users. Therefore, the reference *CLB with WTS user relay* scheme is simulated. Its simulation flow is similar to Fig.5. The only difference is that a shifted user only considers the proposed *WTS (weight of traffic shifting)* $\Psi_{r,WTS}$ during the relay selection. As discussed in Section IV A, *CLB with WTS user relay* scheme aims at selecting the relay which can *best improve* the throughput of the shifted user, while it does not consider the throughput loss of relay users.

B. Simulation Results

Load balancing (LB) handover failure rate reflects the link quality of shifted users [1], because the better the link provided by a partner cell, the more shifted users can be handed over successfully. Fig.6 shows that the *CLB* scheme has lower LB handover rate than the *typical MLB* scheme. Compared with the *CLB* scheme, the proposed *CLB with utility function user relay* scheme can further reduce the LB handover failure rate. It is because the relay link could enhance the link quality of the shifted user. As a result, the improved link quality decreases the LB handover failure rate.

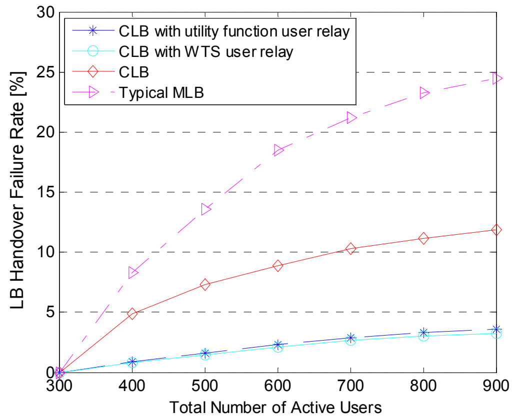

Fig.6. LB handover failure rate comparison

In order to evaluate the proposed *CLB with utility function user relay* scheme in helping shifted users of different link qualities, Fig.7 divides shifted users into five categories, according to their SINR after shifting (without user relay assistance): SINR lower than 1; between 1 and 2; between 2 and 6; between 6 and 12; between 12 and 18.

Among five categories, the poor link quality shifted users (SINR<1), experience the largest SINR improvement via the proposed *CLB with utility function user relay* scheme. For example, Fig.7 shows that the proposed scheme can increase up to 110% SINR for shifted users in SINR<1 category, as well as increase 75% for shifted users in 1<SINR<2 category.

The proposed scheme also effectively improves SINR for the medium link quality shifted users. For example, the shifted users' SINR can be improved up to 32% and 20% in 2<SINR<6 category and 6<SINR<12 category, respectively.

Fig.7 also shows that the proposed scheme could slightly increase the SINR of good link quality shifted users, e.g., 12<SINR<18 category. But their SINR enhancements are not as outstanding as the poor/medium link quality users.

From the analysis above, the proposed scheme is more useful for the shifted users who suffer poor link quality. Due to the improved SINR and the reduced handover failure rate, Fig.8 shows that the *CLB with utility function user relay* scheme can improve the overall throughput of all shifted users, compared to *CLB* scheme.

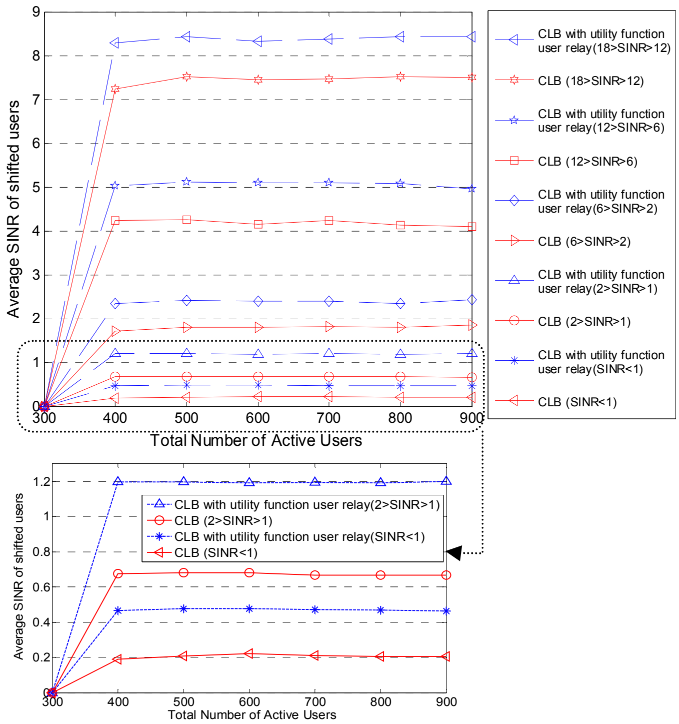

Fig.7 SINR comparison of shifted users in different SINR categories

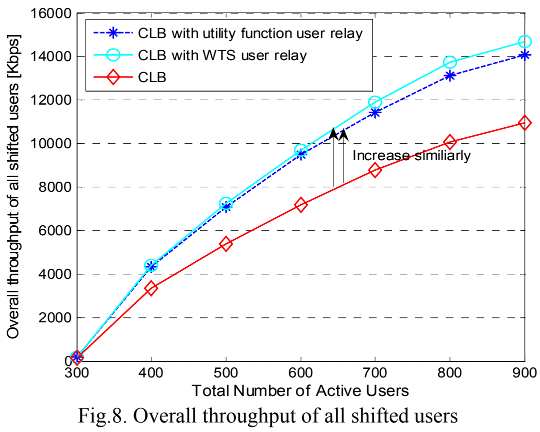

Fig.8. Overall throughput of all shifted users

Fig.6, 8, 9 further evaluate the *utility function* in the trade-off between shifted users performance and relay users performance.

In Fig.8, both the *CLB with utility function user relay* scheme and *CLB with WTS user relay* scheme can improve the overall throughput of shifted users. For example, under 700 users scenario, the *CLB with utility function user relay* scheme can increase the throughput by 31% and the *CLB with WTS user relay* scheme can increase the throughput by 35%, compared to the *CLB* scheme. The reason for the slight difference is that the *WTS* scheme only aims at selecting the relay user to most improve the throughput of the shifted user, while the *utility function* also considers the throughput loss of the relay user. Besides, Fig.6 clearly shows that *CLB with utility function user relay* scheme has a similar LB handover failure rate as the *CLB with WTS user relay* scheme.

Fig.9 shows the overall throughput loss of relay users. The throughput loss in the *CLB with utility function user relay* scheme is 23%~30% less than that in the *CLB with WTS user relay* scheme.

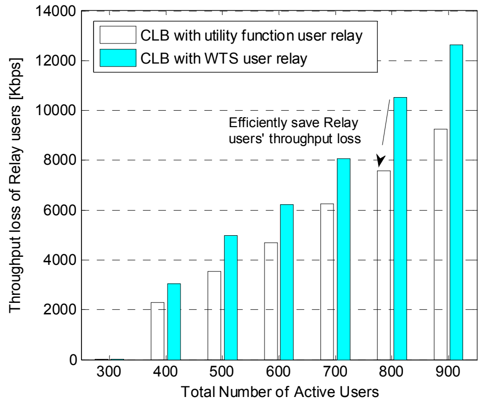

Fig.9 Overall throughput loss of all relay users

In summary, Fig.6, 8, 9 verifies that shifted users have similar performance in *CLB with utility function user relay* scheme and *CLB with WTS user relay* scheme. Meanwhile, *CLB with utility function user relay* scheme can significantly reduce the throughput loss of relay users. Therefore, the proposed *utility function* can reach the trade-off between shifted users' performance and relay users' throughput loss.

VI. Conclusion

This paper employs a user relaying model to enhance the link quality of shifted users in load balancing. Furthermore, based on this model, a user relay assisted traffic shifting (URTS) scheme is proposed. URTS scheme could effectively increase the link quality of shifted users under accepted cost of relay users' energy consumption.

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