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 (HOoff) 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, Cell1 is the hot-spot and tries to offload traffic to the lightly loaded Cell2. BS1 increases HOoff towards BS2, in order to trigger handover of Cell1 edge user. Fig.1 clearly shows that after MLB the shifted user receives the reduced RSRP2, which is lower than RSRP1 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, BS2 needs assign more subcarriers to meet the shifted user’s data rate requirement, which will reduce the spectrum utilisation.

To deal with link quality degradation, this paper employs a user relaying model: a non-active user is treated as a relay to forward data to the 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.

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 ∈ {1 ... 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 amplifies all received signals, including interference, noise and user signal, in Relay r.

\[ y_{ru}[n+1] = \lambda_r \cdot y_{br}[n] + Z_u[n+1] \]

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

\[ y_{ru}[n] = a_{ru} \cdot x_u[n] + Z_u[n] + I_u[n] \]

\[ y_{br}[n] = a_{br} \cdot x_r[n] + Z_r[n] + I_r[n] \]

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; \( a_{ru} \) 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 \( \lambda_r \), using (3):

\[ \lambda_r = \frac{P_r}{|a_{ru}|^2 P_b + \sigma^2 + |I_r[n]|^2} \]

where \( P_b \) and \( P_r \) are the transmission power of BS b and Relay r, respectively; \( \sigma^2 \) is the common variance of the Gaussian white noise; \( | | \) denotes the magnitude of the symbol.

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

\[ y_{ru}[n+1] = \lambda_r y_{br}[n] + Z_u[n+1] + I_u[n+1] \]

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 Link L_{ru} can be expressed as \( \text{SINR}_{u,n+1} \), using (5):

\[ \text{SINR}_{u,n+1} = \frac{P_r |a_{ru}|^2}{|a_{ru}|^2 \lambda_r^2 (|I_r[n]|^2 + \sigma^2) + |I_u[n+1]|^2 + \sigma^2} \]

\[ y_{br}[n+1] = a_{br} x_r[n+1] + Z_u[n+1] + I_u[n+1] \]

where \( a_{br} \) is the channel gain from BS b to Relay r. According to (6), SINR of User u in TS n+1 from Link L_{br} is denoted as \( \text{SINR}_{u,n+1} \), using (7):

\[ \text{SINR}_{u,n+1} = \frac{P_r |a_{br}|^2}{|I_u[n+1]|^2 + \sigma^2} \]
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 $\text{SINR}_{u,n}^{(L_{bu})}$, using (8):

$$\text{SINR}_{u,n}^{(L_{bu})} = \frac{P_b |a_{bu}|^2}{|I_b[n]|^2 + \sigma^2}$$

(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 $\text{SINR}_{u}^{AF}$, using (9):

$$\text{SINR}_{u}^{AF} = \text{SINR}_{u,n}^{(L_{bu})} + \text{SINR}_{u,n+1}^{(L_{bu})} + \text{SINR}_{u,n}^{(L_{bu})}$$

(9)

**B. Throughput of User with Relay $r$ assistance**

Based on $\text{SINR}_{u}^{AF}$, the throughput of User $u$ with Relay $r$ assistance is defined as $C_u^{AF}$, using (10):

$$C_u^{AF} = \frac{B}{2} \log_2 \left(1 + \text{SINR}_{u}^{AF} \right)$$

(10)

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 $|I_b[n]|^2$. 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 $C_u^{NO}$:

$$C_u^{NO} = \frac{B}{2} \log_2 \left\{1 + \frac{P_b |a_{bu}|^2}{|I_b[n]|^2 + \sigma^2} + \frac{P_b |a_{bu}|^2}{|I_b[n+1]|^2 + \sigma^2} \right\}$$

(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 $\text{SINR}_{r,n+1}$, using (13):

$$y_{br}[n+1] = a_{br}x_{b}[n+1] + Z_{r}[n+1] + I_r[n+1]$$

(12)

$$\text{SINR}_{r,n+1} = \frac{P_b |a_{br}|^2}{|I_r[n+1]|^2 + \sigma^2}$$

(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):

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

(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 SHIFTING 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 ($C_u^{AF}$, see (10)) to User $u$’s throughput without relay ($C_u^{NO}$, see (11)). Hence, $\Psi_{r,WTS}$ indicates the throughput gain of User $u$.

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

(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):

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

(16)

$C_u^{AF} - C_u^{NO}$ 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):

$$U_r = \frac{C_{AF} - C_{NO}}{C_{AF} - C_{BS}} \quad r \in \{1...R\}$$

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 $U_r$:

$$Relay\ k = \arg \max_{r \in \{1...R\}} U_r = \arg \max_{r \in \{1...R\}} \frac{C_{AF} - C_{NO}}{C_{AF} - C_{BS}}$$

From (18), the utility function relates to $C_{AF}$, $C_{BS}$, $C_{NO AF}$. User $u$ has its correspondingly fixed $C_{NO AF}$, given by (11). $C_{AF}$ and $C_{BS}$ are varying with different Relay $r$. From (10), $C_{AF}$ is based on three varying parameters: $|\alpha_{br}|^2$, $|\alpha_{br}|^2$, $|I_r[n]|^2$, $|I_r[n + 1]|^2$. From (14), $C_{BS}$ is based on $|\alpha_{br}|^2$ and $|I_r[n + 1]|^2$.

D. URTS Scheme Process

Based on the analysis above, User $u$ can calculate the utility function to select the candidate relay, only under knowing the value of $|\alpha_{br}|^2$, $|\alpha_{br}|^2$, $|I_r[n]|^2$, $|I_r[n + 1]|^2$. 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 expressed as:

1. $|\alpha_{br}|^2$ (where $\alpha_{br}$ 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 ($\gamma$), it can be informed from BS $b$ in control channel [1]). Relay $r$ estimates $|\alpha_{br}|^2$ as (19):

$$|\alpha_{br}|^2 = \frac{\text{Relay } r \text{ 's received RSRP from BS } b}{\text{BS } b \text{ 's transmission power } P_b}$$

2. $|\alpha_{ru}|^2$ 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 $|\alpha_{ru}|^2$ as (20):

$$|\alpha_{ru}|^2 = \frac{\text{User } u \text{ 's received response power from Relay } r}{\text{Relay } r \text{ 's transmission power } P_r}$$

3. $|I_r[n]|^2$, $|I_r[n + 1]|^2$ (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 $r$.

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 $|\alpha_{br}|^2$ from (19). Besides, Relay $r$ estimates $|I_r|^2$ as the sum of RSRP from all neighbouring BSs. Then Relay $r$ responds and sends $|\alpha_{br}|^2$, $|I_r|^2$, and $P_r$ to User $u$.

After receiving the responses, User $u$ calculates $|\alpha_{ru}|^2$ from (20). User $u$ calculates the utility function $U_r$ of all responding non-active users, based on $|\alpha_{ru}|^2$, $|\alpha_{ru}|^2$, $C_{NO AF}$ (User $u$ calculates its correspondingly $C_{NO AF}$ 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>
<thead>
<tr>
<th>Parameter</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Subcarrier and Total bandwidth</td>
<td>Subcarrier: 15K Hz; Total: 5M Hz</td>
</tr>
<tr>
<td>Physical resource blocks(Prb)</td>
<td>Total 25 (12 subcarriers per Prb)</td>
</tr>
</tbody>
</table>
In the cell adjusts partners, then the hot-spot cell estimates its shifted users’ scheme [3] in LTE is simulated for comparison. In [3], the hot-spot cell will be shifted to relay user assists the transmission of the shifted user. In addition, the proposed utility function based relay selection. Finally, the traffic shifting [5]. After CLB, the shifted user triggers the of user-vote assisted partner selection [4] and cooperative load balancing (CLB) scheme, consisting whether it needs to be shifted out. This process refers to our scheme, each active user in the hot-spot cell needs to be aware of user relay assisted traffic shifting scheme. Fig.5 shows its simulation flow. Before URTS scheme, each active user in the hot-spot cell needs to be aware of 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.

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

![Fig.4. Cells layout and users distribution (unit: meter)](image)

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 of 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 \( H_{\text{off}} \) towards partner \( C_{u} \). Then User \( u \) in the hot-spot cell will be shifted to \( C_{u} \), 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 \( H_{\text{off}} \) 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.

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.

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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