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Transferring in control plane for 5G heterogeneous networks①

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Abstract

The heterogeneous network with the separation of the control plane and user plane (C/U) is an evolutionary approach to the fifth generation (5G) to achieve high system coverage and capacity. To minimize signaling load of the core network when there is a macro base station (BS) failure in the control plane, a scheme of transferring the control of small cells under the coverage of the failure macro BS to the neighbor macro BSs is proposed. The average handover rates between small cells related to user mobilities, the extended coverage of the neighboring macro BSs under the constraint of transmitting power and the load balance index of the system are analyzed, based on which the formula of maximizing the handovers processed by macro BSs is constructed and further solved by the convex optimization methods. Simulation results indicate that the proposed scheme can effectively increase the total handovers processed by the macro BSs and thus reduce the signaling load of the core network.

Key words: C/U separation, 5G, control plane optimization, signaling load

0 Introduction

The architecture of separated control and user planes is applied in 5G[1], where the macro base stations (BSs) in the control plane manage the mobility and connectivity, while the small BS within each small cell in user plane provides high data rates transmission[2].

In these heterogeneous networks, some existing work has been done on the management optimization and failure fixing. In Ref. [3], a new session restoration procedure is introduced for serving gateway (SGW) failure based on the next generation Evolve Packet Core (EPC) architecture to significantly reduce the signaling overheads in the core network. In Ref. [4], based on the heterogeneous networks and small BSs deployment characteristics, an algorithm was proposed to switch on or off the small BSs automatically to achieve higher efficiency and lower power consumption in 5G networks. In Ref. [5], an energy efficient, low-complexity technique for load-based sleep mode optimization is introduced in dense small cell networks. It defined an analytic model to characterize the distribution of the traffic load of a small cell and achieved the highest throughput. In Ref. [6], a C/U communication network paradigm was considered that a large number of small base stations were deployed within the coverage area of a macro cell. However, it did not analyze it from the practical aspect of user movement. In Ref. [7], a small cell controller (SCC) scheme was proposed to solve the macro BS failure in control plane, where the backup BS around the macro BS was set up to take over the controls automatically. However, this involved facility increasing and energy consumption as well as the coverage limitation of backup BSs.

In this paper, a scheme of optimally selecting neighbor macro BSs is proposed, where the control plane of users interrupted under the coverage of failure macro BS will be transferred to the selected neighboring macro BSs for the communication recovery. To give the optimal selection, the average handover rates between these small cells are analyzed based on the user mobilities as well as the extended coverage of the neighbor macro BSs under the constraint of transmitting power. According to the analysis, the maximization of handovers processed by macro BSs is formulated under the constraint of load balance index, which is solved by slacking the variables and the convex optimization

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methods. The simulation results show that the proposed scheme can effectively reduce the signaling load of the core network.

The rest of this paper is organized as follows. Section 1 introduces the system model of macro BS failure in the 5G heterogeneous networks. Section 2 presents two approaches to handover and the corresponding number of signaling processed in the core network. In Section 3, a scheme of selecting the neighboring macro BSs is proposed to take over the handovers, where the model of maximizing handovers processed by macro BSs is constructed. The simulation results are given in Section 4 and in Section 5 the paper is concluded.

1 System model

An issue of a macro BS failure in the heterogeneous cellular 5G networks is considered and the system structure is shown in Fig. 1. In normal state, there are $M+1$ macro BSs operating in the control plane, denoted as $\{B_0, B_1, \cdots, B_M\}$, each of which covers N small cells with the small BSs managing the user plane. Here, macro BS B_0 is assumed to fail, and thus users associated with small BSs $\{b_1, b_2, \cdots, b_N\}$ within the range of macro BS B_0 need to select neighbor macro BSs $\{B_1, \cdots, B_M\}$ for their control, otherwise their small BS connected directly to the core network will increase the signaling load of the core network. A binary decision variable b_{im} is used to describe this process, expressed as follows:

$$b_{im} = \begin{cases} 1 & \text{if small } BS\ b_i \text{ select macro } B_m \\ 0 & \text{otherwise} \end{cases} \quad (1)$$

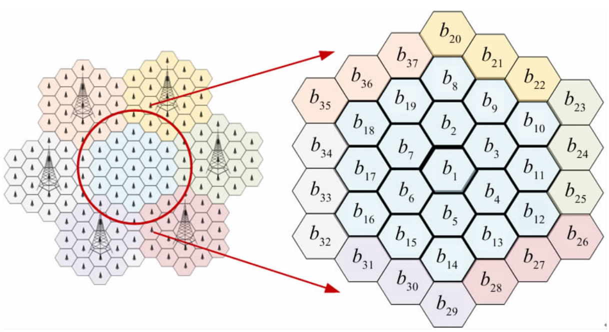

Fig. 1 The macro BS failure in the 5G systems

2 Handover and signaling

Due to the limited coverage and control resources of the neighbor macro BSs, it is impossible that all users will be served by a single neighboring macro BS. Therefore, different selections would lead to different handover statistics and different signaling load of the core network[8]. Here, two kinds of handovers are considered.

In the first one, two neighboring small cells select the same neighbor macro BS, where the handover signaling is forwarded to the macro BS instead of the core network when a user moves between these two small BSs. The handover in this case does not cause any signaling load of the core network.

In the second one, when two neighboring small cells select different macro BSs and there is a user moving through the macro cells, the handover signaling will be forwarded to the core network. In this situation, the mobility management entity (MME) of the core network needs to process $S = 4$ handover signaling, including path switching request, path switching request response, user plane update request and user plane update request response signaling[9]. Frequent handover in this case will lead to a heavy signaling load in the core network.

3 Neighbor macro BSs selection algorithm

3.1 The average handover rate

In the analysis of the handover rate, it is assumed that there are u_i users within the range of the small BS b_i, and their locations are simplified equal to the location of small BS b_i since the difference is relativly far small. User mobilities follow the fluid model[10], in which the average velocity of u_i users is denoted as v_i, and the moving direction of u_i users are uniformly distributed in $[0, 2\pi]$. Thus, the average mobile crossing rate R_i of users in small cell b_i is given as

$$R_i = \frac{u_i C v_i}{\pi^2 r^2} \quad (2)$$

where C is the perimeter of small BS b_i, and r is the radius.

Since there are six cells around small cell b_i and user moving directions are uniform, thus the handover time between small BSs b_i and b_j is in unit time, in other words, the average handover rate R_{ij} is

$$R_{ij} = \frac{1}{6} P_{CON}(R_i + R_j),\ i \in 1, \cdots, N,$$
$$j \in 1, \cdots, N',\ i \neq j \quad (3)$$

where P_{CON} is the probability of users in the connection state, and N' represents the number of neighbor small BSs taken into account when calculating the average handover rate.

3.2 Transmit power control

To support the users in the failure area, the neighbor macro BS must extend its coverage, which is discussed here based on the coverage compensation technology[11]. Two schemes are considered that provide M macro BSs and $M/2$ macro BSs respectively to be selected. Note the $M/2$ macro BSs are nonadjacent to each other and have less load of control resource compared with the remaining macro BSs.

The maximum compensation radius of macro BS B_m, which is also the maximum distance $d_{\max}$ between macro BS B_m and small BS b_i, depends on the maximum transmit power of the macro BSs. Based on the path loss model and the uplink and downlink of the system, $d_{\max}$ is given as follows[12]:

$$(P_{\max} - P_{\mathrm{m}}) \geqslant 37.6\lg(d_{\max}) - 37.6\lg(R) \quad (4)$$

where $P_{\max} = 46$ dBm is the maximum transmit power of the macro BSs while $P_{\mathrm{m}} = 34$ dBm is the power in the normal working state. R is the radius of macro BS. Besides, to ensure that no cover holes exist, the compensation radius of macro BS needs to meet $d_{\max} \geqslant 2R$. Therefore, the distance between macro BS B_m and small BS b_i within the maximum distance $d_{\max}$ is written as

$$\begin{aligned} & b_{im} d_{im} \leqslant d_{\max} \\ & 2R \leqslant d_{\max} \leqslant 2.085R \end{aligned} \quad (5)$$

3.3 Load balance index

The load balance index measures the performance of loading of macro BSs, which is defined as Jane's fairness coefficient[13]:

$$L = \frac{(\sum_{m \in M} \rho_m)^2}{M \sum_{m \in M} (\rho_m)^2} \quad (6)$$

where ρ_m is the load level of the macro BS B_m. Assuming the resources in the control panel exhausted by connected users are almost equal, the load level ρ_m can be denoted by the number of users served by macro BS B_m:

$$\begin{aligned} \rho_m &= P_{CON}(U_m + \sum_{i \in N} b_{im} u_i) \\ U_0 &= \sum_{i \in N} u_i \end{aligned} \quad (7)$$

where U_m is the original number of users before coverage extending, U_0 is the number of users in failure macro BS B_0. Subsequently, the load balance index can be written as

$$L = \frac{\frac{1}{M}(U_0 + \sum_{m \in M} U_m)^2}{\sum_{m \in M} (U_m + \sum_{i \in N} b_{im} u_i)^2} \quad (8)$$

The range of the Jane's fairness coefficient L is $[1/M, 1]$, where the higher value indicates the more balanced load. Here, the minimum load balance index is set as $L_{\min}$, $L_{\min} \in [1/M, 1]$ to manage the constraint condition $L \geqslant L_{\min}$, which can be rewritten as follows:

$$\sum_{m \in M} (U_m + \sum_{i \in N} b_{im} u_i)^2 \leqslant \frac{1}{ML_{\min}} (U_0 + \sum_{m \in M} U_m)^2 \quad (9)$$

where $U = U_0 + \sum_{m \in M} U_m$ is the total number of users in the system.

3.4 Selection of the neighbor macro BSs

As discussed previously, different selection would lead to different handover statistics and different signaling load of the core network. Here, our objective is to minimize the signaling load of the core network, which encourages the users in neighboring small cells with higher average handover rate to select the same macro BS. The more handovers the macro BSs process, the less the signaling load of the core network is. Therefore, the optimization problem is expressed as follows:

$$\begin{aligned} & \max \sum_{m \in M} \sum_{i \in N} \sum_{\substack{j \in N' \\ j > i}} R_{ij} b_i b_{jm} \\ & \text{s.t.} \quad C1: b_{im} d_{im} \leqslant d_{\max} \\ & \qquad C2: \sum_{m \in M} b_{im} = 1, \ \forall i \in N \\ & \qquad C3: b_{im} \in \{0, 1\}, \ \forall m \in M \\ & \qquad C4: L \geqslant L_{\min} \end{aligned} \quad (10)$$

- In the objective function, if $b_{im} = 1$ and $b_{jm} = 1$, users in small BS b_i and small BS b_j will select the same macro BS B_m, in which the handover is R_{ij}, as shown in Eq. (2), which also means there is no signaling added to the core network. Otherwise, this handovers will be across two macro BSs and submitted to the core network.
- In constraint condition $C1$, $b_{im} d_{im} \leqslant d_{\max}$ requires the user being allocated within the coverage of the selected macro BS.
- In constraint condition $C2$, for the binary variable b_{im} in the $\{b_{i1}, b_{i2}, \cdots, b_{iM}\}$, only one of them is set to 1 and others are set to 0.
- In constraint condition $C3$, the value of b_{im} can only be 1 or 0 to indicate the selection or not.
- In constraint condition $C4$, use the constraint condition $L \geqslant L_{\min}$ to describe the load balance requirement.

To solve this optimization, b_{im} is released to the real value variable $0 \leqslant b_{im} \leqslant 1$, which can be considered as the weights of small BS b_i selecting the macro BS B_m. Correspondingly, the constraint condition changes to

$$C3: 0 \leqslant b_{im} \leqslant 1, \ \forall i \in N, m \in M \quad (11)$$

At this moment the optimization in Eq. (10) with the refined constraint in Eq. (11) is a constrained nonlinear programming convex optimization problem, which can be solved by linear programming convex optimization methods[14]. Since, the value of decision variable has been relaxed, there must be several $b_{im} > 0$ for a single small cell i and also the $C1$ partially lose its constraint, therefore, suboptimally for the final decision the small cell i is allocated to macro BS m^*:

$$m^* = \arg\max_m (b_{im} + \delta)\Gamma(d_{max} - d_{im}, 0) \quad (12)$$

where arbitrary small value δ is added to define $\Gamma(d_{max} - d_{im}, 0) = 1$ when $d_{max} - d_{im} \geqslant 0$, otherwise $\Gamma(d_{max} - d_{im}, 0) = 0$.

Besides, to evaluate the performance, the total handovers R_{total}, $R_{total} = \sum_{m \in M} \sum_{i \in N} \sum_{j \in N', j > i} R_{ij}$ and the optimized value of the objective function Eq. (10) denoted as R_{op} are got. Thus, the number of handover signaling processed in the core network is $4(R_{total} - R_{op})$, and the ratio of the handover processed in macro BSs to the total handovers is R_{op}/R_{total}.

4 Simulation results

There are 7 macro BSs ($M = 6$) and $N = 19$ small BSs in the coverage of each macro BS, as shown in Fig. 1. And the users have four types of services: voice, streaming media, social network and background traffic. According to the parameters of the service model[15], the probability in connected state is set as $P_{CON} = 0.464$.

The radius of the small BS is $r = 125$ m and the radius of macro BS is $R = 4r = 500$ m. Therefore, the constraint $2R \leqslant d_{max} \leqslant 2.085R$ can be rewritten as $\sqrt{57}r \leqslant d_{max} \leqslant 1.04\sqrt{57}r$. To reduce the power consumption of the system, the maximum distance is set as $d_{max} = \sqrt{57}r$. The average velocities of users are between 0 - 108 km/h, which are further divided into three types: low velocity 0 - 36 km/h, medium velocity 36 - 72 km/h and high velocity 72 - 108 km/h. The total number U of users in the system is between $2 \times 10^3 - 50 \times 10^3$. The minimum load balance index L_{min} is set to 0.6 for the system performance evaluation.

It shows in Section 3.4 that the total handovers R_{op} of macro BSs proposed is affected by the total number U of users, the average velocity v_i, the minimum load balance index L_{min} and the number of selected macro BSs (M or $M/2$). The existing scheme of the small BS automatically taking over their control planes in the standard of next generation mobile network (NGMN) brings $4R_{total}$ signaling to the core network, and the existing SCC scheme does not increase the signaling but cost backups. Thus, in order to prove the effectiveness of the proposed algorithm under the same conditions, the proposed scheme and the static uniform scheme, (the small BSs are uniformly divided to the macro BSs based on the distance, as seen in Fig. 2) are presented, respectively with M macro neighbor BSs and $M/2$ neighbor macro BSs, which are referred to proposed scheme 1, proposed scheme 2, traditional scheme1 and traditional scheme 2.

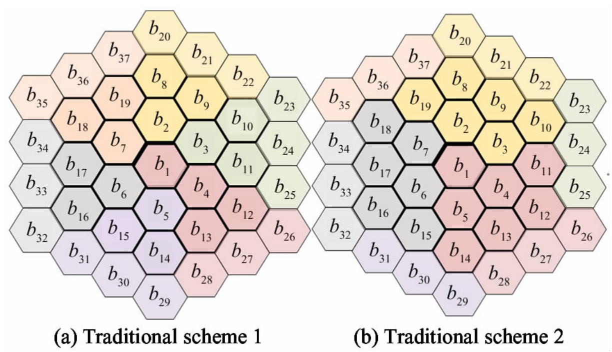

Fig. 2 The deployments of the traditional schemes

The deployments of traditional scheme 1 and scheme 2 are given in Fig. 2, where the small BSs originally covered by the failure macro BS are transferred to different neighbor macro BS (in different colors). It shows that small cells $\{b_2, b_8, b_9\}$, $\{b_3, b_{10}, b_{11}\}$, $\{b_1, b_4, b_{12}, b_{13}\}$, $\{b_5, b_{14}, b_{15}\}$, $\{b_6, b_{16}, b_{17}\}$ and $\{b_7, b_{18}, b_{19}\}$ select B_1, B_2, B_3, B_4, B_5 and B_6 in traditional scheme 1 respectively. And the small cells $\{b_2, b_3, b_8, b_9, b_{10}, b_{19}\}$, $\{b_1, b_4, b_5, b_{11}, b_{12}, b_{13}, b_{14}\}$ and $\{b_6, b_7, b_{15}, b_{16}, b_{17}, b_{18}\}$ select B_1, B_3 and B_5 in traditional scheme 2 respectively.

Fig. 3 plots handovers R_{op} processed by macro BSs with the increasing users having the lower average velocity in 0 - 36 km/h. It shows that when the number

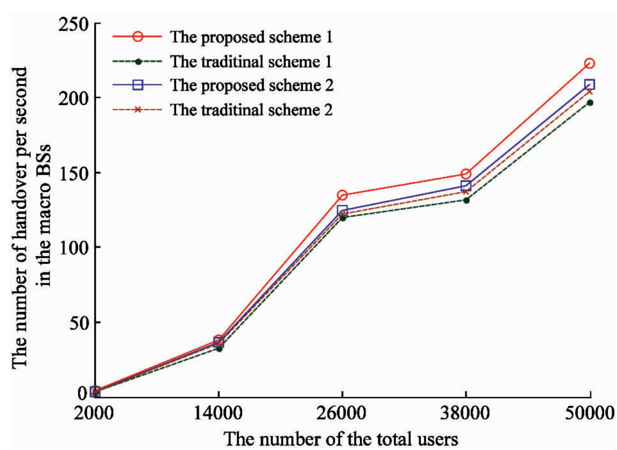

Fig. 3 The handovers processed by macro BSs versus the number of users

of users changes from 2×10^3 to 50×10^3, the handovers in the four schemes are getting higher. Moreover, the total handovers operated by macro BSs in the proposed scheme 1 is higher than all the other schemes. Hence the handovers of $R_{total} - R_{op}$ transferred to the core network in the proposed scheme 1 is the lowest. Besides, the value of R_{op} in proposed scheme 2 is also higher than traditional scheme 2, which means the proposed scheme brings lower signaling load $4(R_{total} - R_{op})$ in the core network. The more users in the system, the more improvement are provided by the proposed schemes than the traditional schemes.

Fig. 4 gives the ratio R_{op}/R_{total} versus the total number of users, with the same simulation parameters in Fig. 3. It shows that the ratio R_{op}/R_{total} in proposed scheme 1 is still the highest among the schemes, which means that about 70% percent of the signaling in the control panel is processed by the macro BSs, steadily even when there are more users. Due to the less neighbor macro BSs in proposed scheme 2, there is a lower ratio in the case of few users, and gradually outperforms traditional schemes along the user increasing.

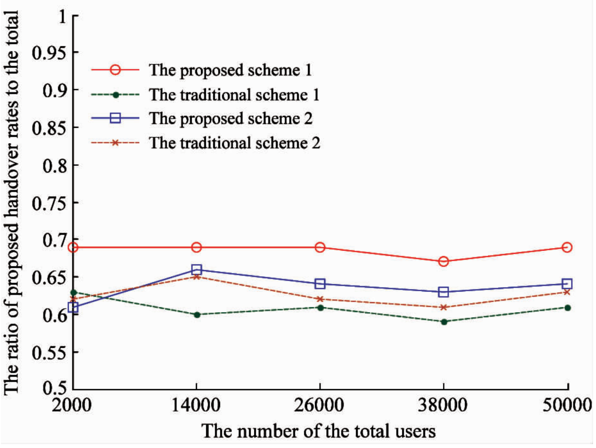

Fig. 4 The ratio R_{op}/R_{total} versus the number of users

Fig. 5 plots the total handovers R_{op} processed by macro BSs versus the increasing users with different velocities from low velocity 0 – 36 km/h, medium velocity 36 – 72 km/h to high velocity 72 – 108 km/h. It shows there are more handovers operated by macro BSs in the proposed scheme than that in the proposed scheme 2 when users are within the same level of velocity. For the performance in different velocities, the higher velocity triggers high value of R_{op} in the proposed schemes, meaning the lower signaling load $4(R_{total} - R_{op})$ in the core network.

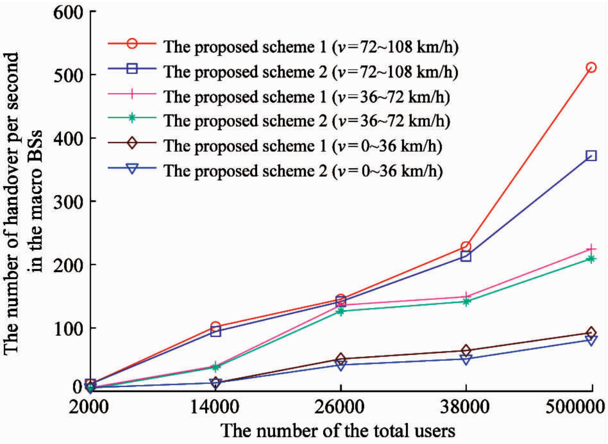

Fig. 5 The handovers processed by macro BSsversus the total number of users with different velocity

Fig. 6 shows the value of load balance index L versus the number U of users with different velocities. It can be seen that when users increase from 2×10^3 to 50×10^3, the value of L in the proposed scheme 1 is always higher than the proposed scheme 2. This is because that proposed scheme 2 has limited selection to the $M/2$ macro BSs, whereas the proposed scheme has more selection to balance the load. The values of L in the four schemes are relatively stable when the users are changed.

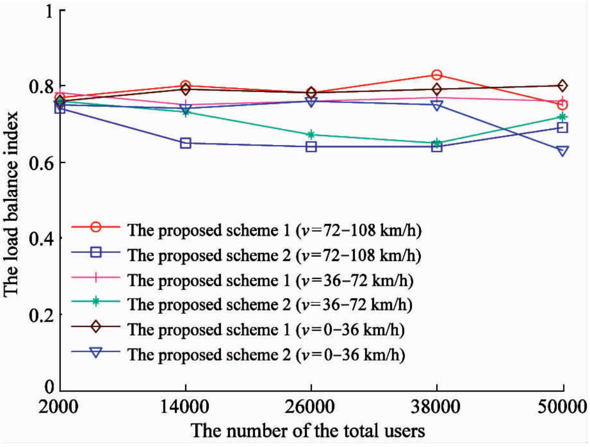

Fig. 6 Load balance index versus the number of users with different velocity

Fig. 7 gives the deployments of the proposed scheme 1 and 2, with U = 26 000 users running in the low velocity 0 – 36 km/h. It shows that small cells $\{b_1, b_2, b_3, b_5, b_8, b_{10}, b_{11}\}$ in proposed scheme 1 have different macro BSs selection from the equally distribution in traditional scheme 1, since the neighboring small BSs with higher R_{ij} prefer to select the same macro BS in proposed scheme 1 and the value of R_{op} is increased by about 13%. Besides, the small BS of b_{15} in proposed scheme 2 has a different macro BSs selection from the traditional scheme, which brings about 2% of R_{op} increased.

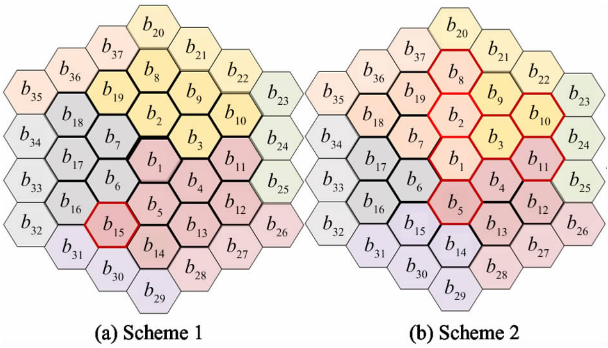

Fig. 7 The deployments of the proposed schemes

5 Conclusions

The scheme of selecting neighbor macro BSs in the case of the own host failure is proposed in this paper. To minimize the signaling load of the core network, an optimization objective is design to maximize the handovers processed by macro BSs, where the average handover rate between small cells is derived based on the user mobility, the extend of the coverage of the neighbor macro BSs was given under the constraint of transmitting power as well as the load balance index considered. The simulation results indicate that, compared with the traditional schemes, the proposed schemes can effectively increase the handovers processed by the macro BSs, hence reducing the signaling load of the core network.

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