Inter-tier Handover in Macrocell/Relay/Femtocell Heterogeneous Networks

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***Abstract*— Handover decision is one of the technical challenges in the heterogeneous network (HetNet). Current researches on this topic concentrate mainly on the two-tier networks. In this paper, we investigates the handover decision scheme for a more complex network: three-tier macrocell/relay/femtocell network. The unique characteristics of the inter-tier handover in three-tier networks are analyzed in this paper and an effective handover algorithm is proposed to reduce the frequent and unnecessary handovers based on the ideas of dwell probability and handover priority. Simulation results show that the proposed algorithm significantly reduces the number of handovers while maintaining the call dropping rate at the same level.**

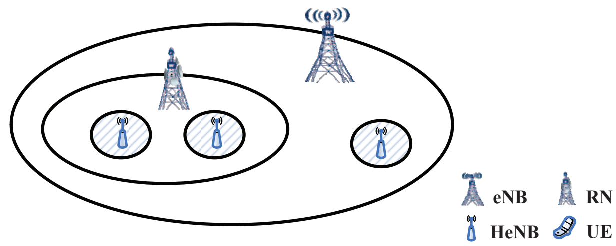

Figure 1: Three-tier heterogeneous network

I. Introduction

Heterogeneous network (HetNet) deployment is investigated by 3GPP LTE-A recently as a promising paradigm for further enhancing network performance [1]. The main idea of HetNet is to overlay low-power low-cost stations on the coverage holes and hotspot areas to complement the conventional macrocell for coverage extension and capacity enhancement [2]. There are various types of low-power stations, including micro eNB, pico eNB, home eNB (HeNB), relay node (RN), distributed antenna system (DAS) and so on. HetNet brings into a number of technical challenges such as backhaul network design, access control, handover decision, and intercell interference coordination [3]. This paper investigates the topic of handover decision in HetNet.

Many works have been done to design handover algorithms for different types of two-tier HetNets: macrocell/microcell network [4], microcell/picocell network [5], macrocell/relay network [6], [7]. Recently, femtocell is emerging as an efficient technology to provide better coverage and service for indoor users, and the macrocell/femtocell network architecture strongly appeals to both academia and industry. Thus, recent researches on handover decision in HetNet concentrate mainly on macrocell/femtocell network, and the considerations in the literature include signal strength, user velocity [8], user state [9], user position [10], asymmetry of cell power [11], etc.

In this paper, we study the handover decision algorithm for a more complex network: three-tier macrocell/relay/femtocell HetNet. The macrocell/relay/femtocell network is also referred to as eNB/RN/HeNB network, which consists of three tiers, including macro-tier, relay-tier and femto-tier. The network topology of the three-tier HetNet is illustrated in Fig.1. There are two types of handovers in the three-tier HetNet, namely intra-tier handover and inter-tier handover. Intra-tier handover, which refers to the handover of user equipment (UE) from one station to another station within the same tier, is an ancient topic in the cellular network and a large number of literature work on it. In this paper, we focus on the inter-tier handover, which refers to the handover of UE from one tier to another tier, including three cases: (i) the serving tier is macro-tier, and the target tiers are relay/femto-tier; (ii) the serving tier is relay-tier, and the target tiers are macro/femto-tier; (iii) the serving tier is femto-tier, and the target tiers are macro/relay-tier. Handover decision is based on the reference signal received power (RSRP) of the candidate stations. In the network, UE detects the RSRP of the candidate stations of both the serving tier and the target tiers. If the station of the serving tier satisfies the handover conditions, intra-tier handover is executed. Contrarily, if the target tier satisfies the handover conditions, inter-tier handover is executed. Inter-tier handover in three-tier networks is quite different from that in two-tier networks, and the differences are analyzed in the next section. The goal of this paper is to design an effective handover decision algorithm suitable for the macrocell/relay/femtocell HetNet. To the authors' knowledge, this is the first paper to study the topic of handover decision in *three-tier* HetNet.

The remaining part of this paper is organized as follows: section II analyzes the characteristics of the handover in three-tier HetNet. Section III proposes a handover decision algorithm. Section IV evaluates the performance of the proposed

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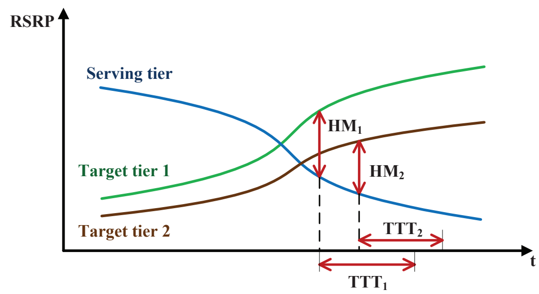


Figure 2: Handover event and parameters

algorithm and section V concludes the paper.

II. Analysis of Handover in Three-tier Network

The unique characteristics of the inter-tier handover in the macrocell/relay/femtocell HetNet are analyzed in this section.

A. Target tiers

In handover decision, the relevant parameters include reference signal received power (RSRP), hysteresis margin (HM) and time-to-trigger (TTT). A typical handover event A3 (see [12], section 5.5.4.4) in two-tier networks is as follows: UE makes periodic measurements of RSRP of both the serving and the target tiers. Once the following conditions are fulfilled, handover from the serving tier to the target tier is triggered:

- H-condition: $RSRP_t - RSRP_s > HM$;
- T-condition: H-condition is still satisfied after time TTT.

In the formula of H-condition, the subscripts t, s denote the target tier and the serving tier respectively.

Comparing with that in the two-tier HetNet, the inter-tier handover in the three-tier HetNet has one characteristic: two target tiers should be taken into consideration. Thus, two pairs of handover parameters, (HM_1, TTT_1) and (HM_2, TTT_2), need to be determined, as shown in Fig.2. A reference algorithm for determining the parameter values is that the two pairs of parameters are set identically. This reference algorithm is ineffective since it leads to frequent and unnecessary handovers, as analyzed in section II-B. Thus, novel algorithms for determining the values of the handover parameters should be designed to reduce these redundant handovers.

B. Dwell probability

Femtocell has two characteristics: (i) its coverage range is quite small (typically less than 30 m, while macrocell 2-5 km and relay 200-500 m); (ii) it is possible for the femtocell to be UE's destination (e.g. SOHO). Due to these characteristics, there exist several special scenarios of the inter-tier handover in macrocell/relay/femtocell networks, as shown in Fig.3.

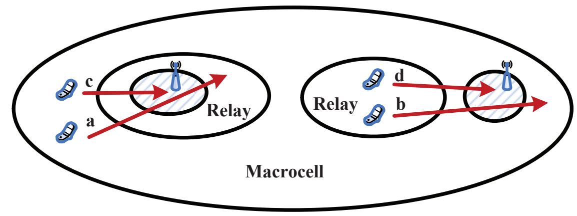


Figure 3: Handover scenarios

In scenario (a) and (b), femtocell is not the destination of UE and UE just passes through it. In these two scenarios, the reference algorithm runs the risk of generating frequent handovers, i.e. handover into and out of the femtocell within a short time interval. Therefore, the optimal strategy in these scenarios is to avoid the handover into the femtocell : in scenario (a), the handover flow of the reference algorithm is eNB→RN→HeNB→RN→eNB, while the flow of the optimal algorithm is eNB→RN→eNB; in scenario (b), the reference algorithm is RN→eNB→HeNB→eNB, while the optimal algorithm is RN→eNB. In scenario (c) and (d), femtocell is the destination of UE and UE will dwell in the femtocell for a long time. In these two scenarios, if higher priority is assigned to the handover to femtocell, unnecessary handovers can be reduced: in scenario (c), the handover flow of the reference algorithm is eNB→RN→HeNB, while the flow of the optimal algorithm is eNB→HeNB; in scenario (d), the reference algorithm is RN→eNB→HeNB, while the optimal algorithm is RN→HeNB.

C. Handover Priority

According to the above analysis, the pre-knowledge of whether UE dwelling in the femtocell is of great importance for making handover decisions. Though the precise knowledge is not available at UE, the probability of UE dwelling in the femtocell, P_{dwell}, can be predicted based on the history record. And to reduce the redundant handovers, the priorities (PRI) of the two target tiers should be determined as follows:

- When the serving tier is eNB:
  - if $P_{dwell} = 50\%$, then $PRI_{br} = PRI_{bh}$;
  - if $P_{dwell} > 50\%$, then $PRI_{br} < PRI_{bh}$;
  - if $P_{dwell} < 50\%$, then $PRI_{br} > PRI_{bh}$.
- When the serving tier is RN:
  - if $P_{dwell} = 50\%$, then $PRI_{rb} = PRI_{rh}$;
  - if $P_{dwell} > 50\%$, then $PRI_{rb} < PRI_{rh}$;
  - if $P_{dwell} < 50\%$, then $PRI_{rb} > PRI_{rh}$.
- When the serving tier is HeNB:
  - $PRI_{hb} = PRI_{hr}$.

The subscripts b, r, h denote eNB, RN, HeNB respectively and the combined subscripts denote the handover directions, e.g. br denotes the handover from eNB to RN. In the next section, we propose a handover algorithm based on these analysis.

III. Proposed Handover Algorithm

In this section, we propose a handover algorithm for inter-tier handover in three-tier macrocell/relay/femtocell HetNet. The algorithm consists of three schemes:

(1) *Probability predicting scheme*: predicting the probability of UE dwelling in the femtocell based on the history record.

(2) *Parameter mapping scheme*: mapping the predicted dwell probability onto the values of the handover parameters.

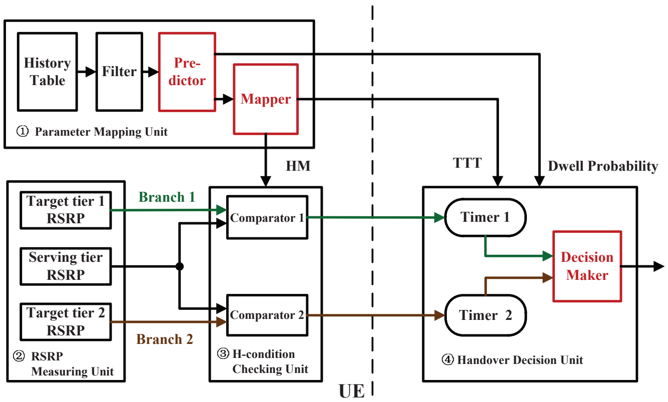


Figure 4: Logical diagram of the handover decision module

A high priority leads to small values of HM and TTT, while a low priority leads to large values.

(3) *Handover advancing scheme*: advancing the handover of the high-priority branch in some instances.

The handover decision module and the proposed handover algorithm are described below.

A. Handover Decision Module

The handover decision module consists of four units, as shown in Fig.4: parameter mapping unit (PMU), RSRP measuring unit (RMU), H-condition checking unit (HCU) and handover decision unit (HDU). PMU determines the values of the handover parameters; RMU and HCU trace the handover conditions; HDU makes the handover decision. PMU,RMU,HCU reside in UE, while HDU belongs to UE's serving station.

① Parameter mapping unit

This unit is to predict the dwell probability and map predicted probability onto the values of the handover parameters (HM, TTT). There are four parts in this unit: history table, filter, predictor and mapper. The history table records the numbers of UE *passing by*[1] and *dwelling in*[2] each femtocell. Denote by $N^i_{pass}[n]$ and $N^i_{dwell}[n]$ the numbers of UE passing by and dwelling in femtocell-i during time period n. The recorded numbers are then put into the filter with a constant forgetting factor. The outputs are:

$$F^i_{pass}[n] = (1-\alpha)\cdot F^i_{pass}[n-1] + \alpha \cdot N^i_{pass}[n] \tag{1}$$

$$F^i_{dwell}[n] = (1-\alpha)\cdot F^i_{dwell}[n-1] + \alpha \cdot N^i_{dwell}[n] \tag{2}$$

where $F^i_{\sim}[n-1], F^i_{\sim}[n]$ are respectively the old and updated filtered numbers, and α is the forgetting factor. The dwell probability for time period $n+1$ can be predicted based on the filtered numbers in time period n:

$$P^i_{dwell}[n+1] = F^i_{dwell}[n] / F^i_{pass}[n] \tag{3}$$

[1]When the RSRP of femtocell-*i* rises above a pre-set threshold, it counts as one *passing-by* event; and within a certain time interval (e.g. 20 min) after that, no new *passing-by* events are recorded.

[2]When UE keeps the connection with femtocell-*i* for more than a certain time interval (e.g. 5 min), it counts as one *dwelling-in* event.

The mapper then maps the predicted probability onto the handover parameters. The mapping scheme is depicted in III-B.

② RSRP measuring unit

This unit makes periodic measurements of the RSRP: serving tier $RSRP_s$, target tiers $RSRP_{t1}, RSRP_{t2}$.

③ H-condition checking unit

This unit checks whether the H-conditions are satisfied:

$$\text{H1:} \quad RSRP_{t1} - RSRP_s > HM_1$$
$$\text{H2:} \quad RSRP_{t2} - RSRP_s > HM_2$$

If condition H1 is satisfied, comparator-1 sends trigger signal Hsat_1 to timer-1. Similarly, if condition H2 is satisfied, trigger signal Hsat_2 is sent to timer-2.

④ Handover decision unit

This unit comprises two timers and a decision maker. Each timer can be initiated to track the corresponding T-condition by the trigger signals from the comparators:

T1: Condition H1 is still satisfied after time TTT_1

T2: Condition H2 is still satisfied after time TTT_2

Once condition T1 is satisfied, timer-1 sends signal Tsat_1 to the decision maker. Similarly, if condition T2 is satisfied, signal Tsat_2 is sent to the decision maker. Then, the decision maker determines which branch to execute the handover. The handover decision scheme is described in section III-C.

B. Parameter Mapping Scheme

This subsection depicts the parameter mapping scheme of PMU. There are three types of handovers in the macrocell/relay/femtocell networks, and each type corresponds to two pairs of parameters: (i) eNB-RN handover (handover between eNB and RN): (HM_{br}, TTT_{br}), (HM_{rb}, TTT_{rb}). (ii) Inbound handover (handover to HeNB): (HM_{bh}, TTT_{bh}), (HM_{rh}, TTT_{rh}). (iii) Outbound handover (handover out of HeNB): (HM_{hb}, TTT_{hb}), (HM_{hr}, TTT_{hr}). The parameter mapping scheme is to map the dwell probability onto the values of the above six pairs of handover parameters, based on the handover priorities described in II-C.

Note that the possible values for HM and TTT are specified in 3GPP technical documents (see [12], section 6.3.5):

- HM: between 0 and 15 with the step of 0.5 in [dB];
- TTT: (0, 40, 64, 80, 100, 128, 160, 256, 320, 480, 512, 640, 1024, 1280, 2560, 5120) in [ms].

The parameter mapping scheme for each type of handover is as follows:

(i) For the parameters of *eNB-RN handover*, their values are the baseline for determining the parameter values of HeNB-related handovers and thus should be constants independent of the dwell probability. The adopted scheme in this paper is:

$$HM_{br} = HM_{rb} = 7.5\,\text{dB}$$
$$TTT_{br} = TTT_{rb} = 320\,\text{ms}$$

Note that 7.5 and 320 are medians of specified possible values.

(ii) For the parameters of *inbound handover*, their values depend on the dwell probability P_{dwell}: if $P_{dwell} = 50\%$, the

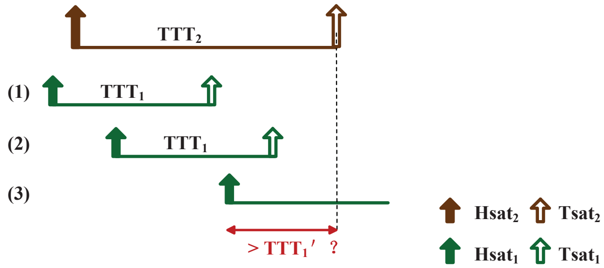


Figure 5: Trigger order of the two branches

values are set equal to the baseline values; if $P_{dwell} > 50\%$, the values are set smaller than the baseline values to raise the priority of the inbound handovers; if $P_{dwell} < 50\%$, larger values are adopted to reduce the inbound handovers. In the parameter mapping scheme, the dwell probability is (nearly) evenly divided into 31 and 16 levels for HM_{bh}/HM_{rh} and TTT_{bh}/TTT_{rh} respectively, and each level maps onto one specified possible value, as shown in Table I.

(iii) For the parameters of *outbound handover*, the values are set equal to the baseline values:

$$HM_{hb} = HM_{hr} = 7.5\,\mathrm{dB}$$
$$TTT_{hb} = TTT_{hr} = 320\,\mathrm{ms}$$

C. Handover Decision Scheme

There are two branches in the handover decision module, and each branch sends trigger signals Hsat, Tsat to the decision maker (DM) when the H-condition and T-condition of this branch are satisfied. DM makes handover decision based on these trigger signals. Assume that the priority of branch-1 is higher than that of branch-2 $(PRI_1 > PRI_2)$. Thus $TTT_1 < TTT_2$. The different scenarios of the trigger orders are shown in Fig.5, and the handover decision scheme is as follows:

(i) In scenario (1) and (2), branch-1 (the high-priority branch) satisfies the T-condition first. For these two scenarios, the handover request of branch-1 is confirmed.

(ii) In scenario (3), branch-2 (the low-priority branch) satisfies the T-condition first. For this scenario, a new parameter TTT_1' $(TTT_1' < TTT_1)$ is proposed to assist the handover decision: at the time instant of Tsat_2 triggering, branch-1 checks the following two conditions:

- The elapsed time after Hsat_1 triggers is more than TTT_1';
- The H-condition of branch-1 is satisfied.

If the above two conditions are both satisfied, branch-1 handovers; otherwise branch-2 handovers. By introducing TTT_1', the handover of the high-priority branch can be advanced. TTT_1' should be smaller than TTT_1, and meanwhile should not be too small to overcome the fast fading. In the proposed scheme, the value of TTT_1' is set to be one level lower than that of TTT_1 in the specified value set: (1) when $P_{dwell} < 50\%$, the high-priority branch is eNB→RN or RN→eNB. Recall that $TTT_{br} = TTT_{rb} = 320\,\mathrm{ms}$ and the value previous 320 in the specified TTT value set is 256 [ms]. Thus the values of TTT_{br}'/TTT_{rb}' are set to be 256 ms, i.e. $TTT_{br}' = TTT_{rb}' = 256\,\mathrm{ms}$. (2) When $P_{dwell} > 50\%$, the high-priority branch is eNB/RN→HeNB. The setting of the values of TTT_{bh}'/TTT_{rh}' is shown in Table II.

Table I: Parameter Mapping Table for Inbound Handover

P_{dwell} (%)	[0,3)	[3,6)	[6,9)	[9,12)	[12,15)	...	[39,42)	[42,45)	[45,55]
HM_{bh}/HM_{rh} (dB)	15	14.5	14	13.5	13	...	8.5	8	7.5
TTT_{bh}/TTT_{rh} (ms)	5120	5120		2560		...	480		320
P_{dwell} (%)		(55,58]	(58,61]	(61,64]	(64,67]	...	(91,94]	(94,97]	(97,100]
HM_{bh}/HM_{rh} (dB)		7	6.5	6	5.5	...	1	0.5	0
TTT_{bh}/TTT_{rh} (ms)		256		160		...	40		0

Table II: Value of TTT_{bh}'/TTT_{rh}'

P_{dwell} (%)	(50,55]	(55,61]	(61,67]	(67,73]	(73,79]	(79,85]	(85,91]	(91,97]	(97,100]
TTT_{bh}/TTT_{rh}	320	256	160	128	100	80	64	40	0
TTT_{bh}'/TTT_{rh}'	256	160	128	100	80	64	40	0	

The flowchart of the proposed handover decision algorithm is shown in Fig.6. Note that in the flowchart $PRI_1 > PRI_2$.

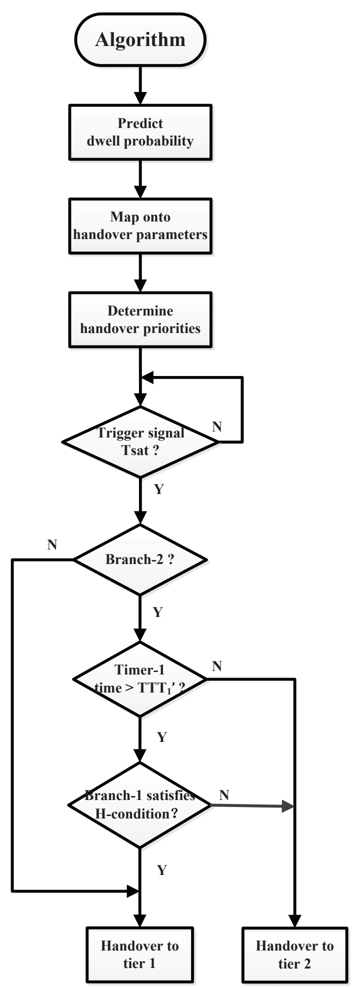
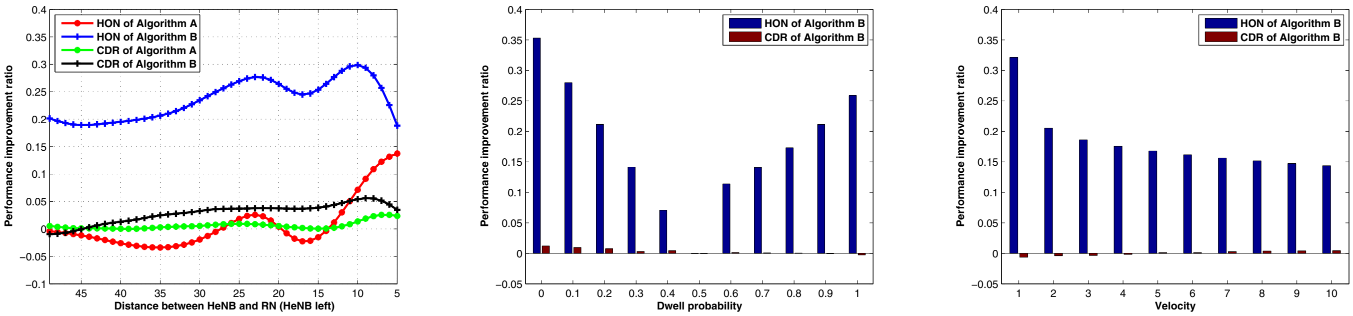


Figure 6: Proposed handover decision algorithm



(a) (b) (c)

Figure 7: Performance evaluation

IV. Simulation Results

The simulation scenario is as follows : eNB,RN,HeNB lie in a line and the distance between eNB and RN is 225 m. HeNB locates between eNB and RN, and in the simulation its distance from RN varies from 5 to 50 m. The reference signal (pilot signal) power of eNB,RN, HeNB are $46, 30, 24$ dBm respectively. Path loss (loss exponent 3.0) and shadow fading (lognormal fading with standard deviation 4 dB) are considered in the channel model. UE moves from the midpoint of eNB and RN toward RN. The dwell probability is randomly generated. Three algorithms are evaluated in the simulation: reference algorithm, algorithm A (only parameter mapping scheme), algorithm B (parameter mapping scheme and handover advancing scheme). The concerned metrics are handover number (HON) and call drop rate (CDR). In the simulation, we use the *improvement ratios* of the metrics to evaluate the performance of the proposed algorithm. The *improvement ratio* of HON is defined as:

$$\frac{HON\,(\text{reference algorithm}) - HON\,(\text{proposed algorithm})}{HON\,(\text{reference algorithm})}$$

and the definition formula of the *improvement ratio* of CDR has the same form as that of HON.

The simulation results are shown in Fig.7. Fig.7(a) shows the performances of the algorithms when HeNB locates in different places, the abscissa denoting the distance between HeNB and RN. It can be seen that algorithm B has a smaller HON and a lower CDR than both the reference algorithm and algorithm A. In addition, the performance improvement of algorithm B becomes more prominent when HeNB locates closer to RN. Fig.7(b) shows the performances of algorithm B with different dwell probabilities. It can be seen that when the probability is 50%, algorithm B has the same performance as the reference algorithm. This is because when $P_{dwell} = 50\%$, the handover parameters and priorities of algorithm B are identical to those of the reference algorithm. However, when the probability deviates from 50%, algorithm B outperforms the reference algorithm. Fig.7(c) shows the performances of algorithm B with different UE velocities. It can be seen that algorithm B reduces HON while maintaining CDR at the same level. Furthermore, algorithm B is more effective in the scenario of low-velocity motions.

V. Conclusion

In this paper, we focus on the topic of handover decision in macrocell/relay/femtocell networks and an effective handover algorithm is proposed to reduce the redundant handovers. The proposed algorithm comprises three schemes: probability predicting scheme, parameter mapping scheme and handover advancing scheme. Simulation results show that the proposed algorithm significantly reduces the number of handovers while maintaining the call drop rate at the same level.

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