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Research Article

Centralized Management Mechanism for Cell Outage Compensation in LTE Networks

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To mitigate the performance degradation induced by the cell outage, in this paper, a centralized cell outage compensation management mechanism and the corresponding workflow are proposed. Then a concrete algorithm named autonomic particle swarm compensation algorithm (APSCA) is proposed to generate the compensation scheme. The simulation results show that the proposed APSCA is effective to resolve the coverage problems induced by the outage. In the simulation scenario, almost 98.3% users that would otherwise be dropped will be served by the surrounding cells, and the block probabilities of the compensating cells are still kept on the accepted levels.

1. Introduction

Self-healing is one of the functionalities of self-organizing network (SON). The purpose of self-healing is to solve or mitigate the faults which could be solved automatically by triggering appropriate recovery actions [1]. Cell outage Management (COM) is the main task of self-healing. COM includes several phases, such as cell outage detection (COD) and cell outage compensation (COC) [2, 3]. Cell outage is the total loss of radio services in the coverage area of a cell. There are diverse reasons for the cell outage, including

(1) system hardware or software failures (e.g., circuit pack failure, channel processing error, or configuration error, etc.),

(2) transmission problems (e.g., connectivity failure, optical cable failure, etc.),

(3) external failures (e.g., power supply outage, lightning strike, etc.).

In practical network, some outage causes can be detected by the network itself. In such cases, alarms will be sent to the operation, administration, and maintenance (OAM) system or operators. Some causes can be detected by OAM through analyzing performance counters or other measurement data. Also some causes cannot be detected by network or OAM directly in real time. In such cases, automatic cell outage detection is needed to derive the probability of an outage [4]. The aim of COD is to automatically detect the occurrence, type, and scope of an outage.

When a cell is in the outage, the coverage gap is induced, and almost all the users cannot establish or maintain the radio bearers via that particular cell. The aim of COC is to mitigate the performance degradation induced by the outage to the utmost extent by automatically adjusting the related radio parameters of the neighboring cells. Adjusting such parameters may influence the users served by those cells, and the performance may be degraded in those cells, such as throughput decrease and interference increase. The trade-off between the coverage/capacity gain of outage cell and the performance degradation of the surrounding cells should be considered and achieved. The design of COC mechanism and algorithm is extremely necessary to meet the coverage, capacity, and quality requirements based on the operator's compensation policy.

In this paper, we mainly focus on the COC under the precondition that cell outage has already been detected. Firstly, a centralized COC management mechanism and the corresponding workflow are proposed. Then a concrete algorithm named autonomic particle swarm compensation algorithm (APSCA) is proposed to generate the parameter adjustment scheme. APSCA is used to compensate the coverage gap induced by the outage while considering the balance between coverage/capacity and quality. At last, the achieved performance effects are evaluated.

The rest of this paper is organized as follows. Section 2 introduces the related works about COC. Section 3 proposes the centralized COC management mechanism and corresponding workflow. In Section 4, the COC algorithm APSCA is described and the complexity is analyzed, followed by the simulation results and discussion in Section 5. The paper is concluded in Section 6, where we conclude the current work and present a prospect of the future work.

2. Related Works

In 3GPP TS 32.541 [1], the general steps of automatic cell outage recovery and cell outage compensation are presented, but no any concrete COC algorithm is presented. The network parameters that can be adjusted by COC include cell reference signal transmission power P_{RS}, antenna tilt or azimuth, uplink target received power level P_0, and mobility parameters. In paper [5], a quantitative analysis of the compensation potential of different control parameters in mitigating outage-induced performance degradations in LTE networks is presented. In paper [6], a framework for automatic cell outage management and the key components necessary to detect and compensate the outages are presented. But no concrete compensation algorithms are proposed in [5, 6] yet.

In paper [7], an automated coverage optimization algorithm is proposed to optimize wireless downlink coverage in the RAN. However, the algorithm is based on the long-term measurements and analysis which is suitable for the normal network optimization scenario, but not suitable for the real-time cell outage compensation scenario. In papers [8–11], the algorithms, respectively, adjusting pilot power, target received power density, or antenna tilt of the surrounding cells to compensate the coverage gap are proposed. But these algorithms are all based on the stepwise adjustment methods in which the control parameters are consecutively adjusted step by step. After each step the system performance should be evaluated and then go to the next adjustment step until the compensation objective is reached. The convergence speed of those stepwise adjustment algorithms is comparatively fast, but the interim parameters may not be suitable and will usually bring instability to the system.

In this paper, we present a framework for centralized COC management mechanism and propose a heuristic COC algorithm for LTE networks, which is named Autonomic Particle Swarm Compensation Algorithm (APSCA). By APSCA, the final optimal parameter adjustment scheme can be automatically generated by the centralized node. APSCA can overcome shortcomings of the previous work, and the convergence speed is rapid enough to meet the real-time requirements of COC.

3. Centralized COC Management Mechanism

When a cell is out of the service, the control parameters of the surrounding cells need be adjusted to implement the coverage compensation and guarantee the quality of network service. Several factors should be considered when adjusting the control parameters, such as traffic load, amount of users, interference, downlink reference signal transmission power, uplink target received power, and antenna patterns. If the distributed COC management framework is adopted, large numbers of data need be exchanged among different eNodeBs, which will greatly increase the complexity of the COC algorithm and the difficulty of the implementation. As such, a centralized COC management framework is proposed in the paper. In the framework, it is the responsibility of OAM to collect and process all kinds of data and generate the final adjustment scheme. The centralized framework is more suitable for COC features.

To realize the COC management, a closed control loop is designed, which is shown in Figure 1.

The COC closed control loop, including monitor, analysis, plan, enforcement, and evaluation functionalities, is located in the OAM node, and the managed elements (eNodeBs in LTE networks) communicate with OAM through the management interface. There are two kinds of data exchanged through the management interface for COC. On one hand, eNodeBs report necessary measurement data to the OAM, and on the other hand, OAM delivers the control parameter adjustment request to the specified eNodeBs.

The workflow of the centralized COC management is illustrated in Figure 2.

The steps of the workflow are described as follows.

(1) Monitor function continuously collects the necessary data from eNodeB, UE, and OAM to determine the cell outage and the conditions of COC. The necessary data can be alarms, event notifications, KPIs, counters, and other measurement data. In [2, 6], a list of major data is presented.

(2) For cell outage detection, measurement data mentioned above is considered to determine whether an outage has occurred. As cell outage detection is not a major concern of this paper, there is no detailed discussion about it. For more information, please refer to [4]. If the cell outage is detected, then go to step 3 else continue step (1).

(3) When the cell outage is detected, the COC specified measurements will be triggered. Monitor function gathers more necessary information from UEs and eNodeBs in LTE, such as configuration, performance, and measurement data. Compared with the data monitored in step (1), these data are more detailed and particular.

(4) Analysis function analyzes and diagnoses above information and makes a conclusion.

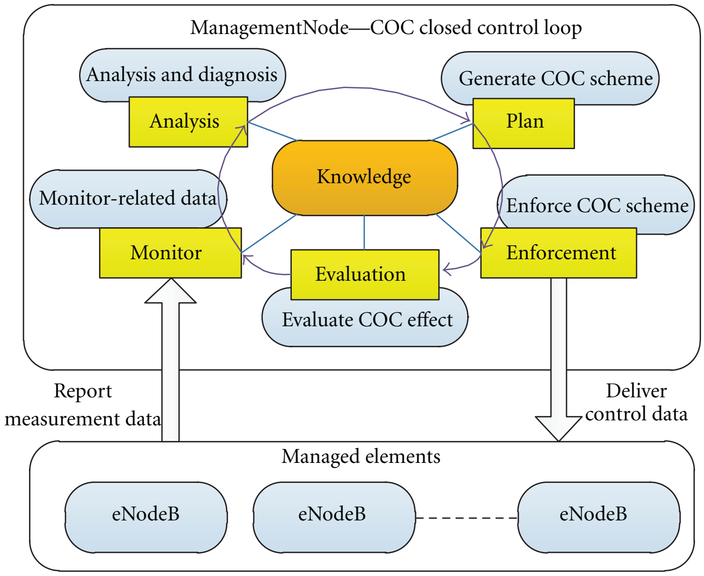


Figure 1: Centralized COC management framework.

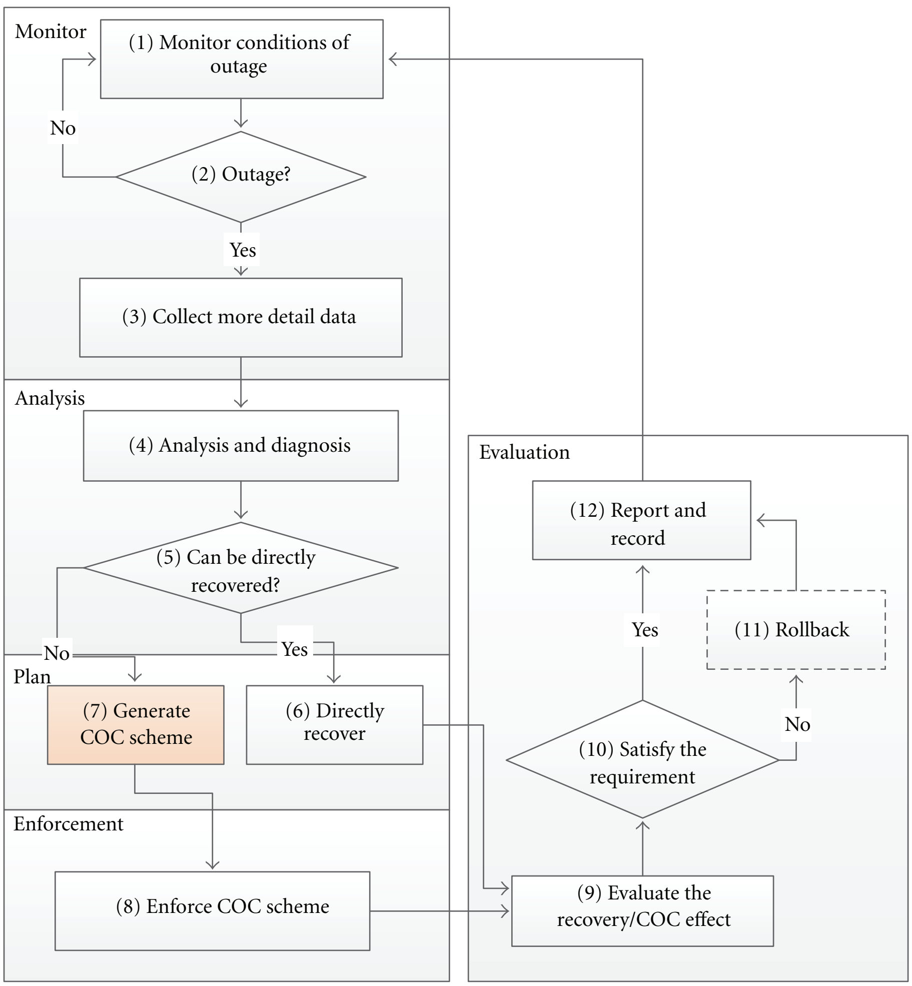


Figure 2: Workflow of centralized COC management.

(5) If the conclusion shows that the problem can be directly recovered, then go to step (6); else go to step (7).

(6) The network elements directly recover the problem which is not discussed in this paper. When the recovery action is finished, then go to step (9).

(7) To mitigate the influence of the cell outage and guarantee the QoS of users, COC will be triggered to take appropriate actions. A COC scheme generation algorithm named Autonomic Particle Swarm Compensation Algorithm (APSCA) is proposed, which will be discussed in detail in Section 4.

(8) After the COC scheme is generated, the enforcement function executes the COC scheme by delivering the parameter adjustment request to the specified eNodeBs. It should be noted that it is the eNodeBs that really adjust the control parameters according to the request.

(9) After recovery or COC, the evaluation function begins to assess the performance improvement brought by the recovery or COC. It is necessary to clarify the criteria to evaluate to what extent the compensation actions have reached in meeting the optimization goals. The COC evaluation criteria are given in Section 4.1.

(10) If the problems are recovered or the COC meets the requirements, then go to step (12), else go to step (11).

(11) If the problems are not recovered, then execute the rollback process when required.

(12) Report the COC enforcement result. OAM can record the necessary information according to the requirements. Then go to step (1) to continue monitoring the related data.

4. COC Algorithm

4.1. Coverage Evaluation Criteria. In LTE networks, the coverage effect can be evaluated by reference signal received power (RSRP) and reference signal received quality (RSRQ) measured by mobile users. The objective reference values of effective coverage of TD-LTE macrocell are as follows: firstly, the probability that the RSRP received by mobile users from the serving cell is stronger than $\text{RSRP}_{\text{minTh}}$ should exceed $\text{RSRP}_{\text{minRate}}$; secondly, the probability that the RSRQ received by mobile users from the serving cell is stronger than $\text{RSRQ}_{\text{minTh}}$ should exceed $\text{RSRQ}_{\text{minRate}}$.

Coverage problems can be represented as coverage gap and pilot pollution. In TD-LTE network, the coverage gap is defined as the area where RSRP < $\text{RSRP}_{\text{gapTh}}$, and the pilot pollution is defined by two criteria:

(a) number of cells whose RSRP > $\text{RSRP}_{\text{polTh}}$ exceeds K, and,

(b) the strongest RSRP−the Kth strongest RSRP ≤ R.

According to the practical network, the typical values of the above criteria are chosen as in Table 1.

Table 1: Coverage evaluation criteria.

Parameters	Value
$\text{RSRP}_{\text{minTh}}$	−105 dBm
$\text{RSRP}_{\text{minRate}}$	95%
$\text{RSRQ}_{\text{minTh}}$	−13.8 dB
$\text{RSRQ}_{\text{minRate}}$	95%
$\text{RSRP}_{\text{gapTh}}$	−119 dBm
$\text{RSRP}_{\text{polTh}}$	−90 dBm
K	3
R	6 dB

4.2. Model of COC Problem. In this paper, the cell reference signal transmission power P_{RS} is selected as COC adjustment parameter. The objective of COC is to serve the users, who would otherwise be dropped, by the surrounding cells as much as possible. The COC algorithm is to find out the optimal power adjustment scheme of the surrounding cells. P_{RS} can be calculated from RSRP according to link budget. For simplicity, in this paper, the P_{RS} adjustment objective is converted into RSRP adjustment objective, namely, a vector $P = [p_1, p_2, \ldots, p_m]$, where p_{i} represents the adjusted RSRP of each surrounding cell. Actual RSRP reported by the mobile user is denoted as $\mathbf{P}_i = [p_1^i, p_2^i, \ldots, p_m^i]$, where p_j^i is the reported RSRP by the ith mobile user from the jth neighboring cell and the unit is dBm.

Assume that outage cell is C_0, the amount of users in C_0 is n, and the number of neighboring cells is m. In this paper, two optimization objectives are considered.

(1) *Minimize the Coverage Gap.* The optimization objective can be described by the following expression:

$$\min P_{\text{gap}} = \frac{\sum_{i=1}^{n} \varepsilon\left(-1 \times \sum_{j=1}^{m} \varepsilon\left(p_j^i + p_j - P_{\text{th}}\right)\right)}{n}, \quad (1)$$

where p_j^i is the RSRP received by the ith mobile user from the jth surrounding cell. P_j represents the adjusted RSRP of the jth surrounding cell, P_{th} represents the threshold of the RSRP (see Table 1), and the unit of all these parameters is dBm. $\varepsilon(x)$ is step function. If $x \geq 0$, then $\varepsilon(x) = 1$; else $\varepsilon(x) = 0$. $(p_j^i + p_j - p_{\text{th}}) < 0$ denotes that user i cannot be served by cell j. When the user i cannot be served by all the m surrounding cells, then $\sum_{j=1}^{m} \varepsilon(p_j^i + p_j - p_{\text{th}}) = 0$, that is, $\varepsilon\{-1 \times \sum_{j=1}^{m} \varepsilon(p_j^i + p_j - p_{\text{th}})\} = 1$. The expression (1) is the percentage of uncovered users in n users, which can be represented as the probability of coverage gap.

(2) *Minimize the Pilot Pollution.* The optimization objective can be described by the following expression:

$$\min P_{\text{pollution}} = \frac{\sum_{i=1}^{n} \varepsilon\left(\left(\sum_{j=1}^{m} \varepsilon\left(p_j^i + p_j - P_{\text{th}}\right)\right) - K\right)}{n}. \quad (2)$$

When the dominant pilots received by the user exceed K (see Table 1), expressed as $\sum_{j=1}^{m} \varepsilon(p_j^i + p_j - p_{\text{th}}) \geq K$, that is,

$\varepsilon\{\{\sum_{j=1}^{m}\varepsilon(p_j^i+p_j-p_{\text{th}})\}-K\}=1$. The expression (2) is the percentage of pilot pollution users in n users, which can be represented as the probability of pilot pollution.

According to the expressions (1) and (2), the optimization problem is a multiobjective nonlinear optimization problem. In the paper, an Autonomic Particle Swarm Compensation Algorithm (APSCA) is proposed to solve it. APSCA is suitable for multiobjective optimization problems and especially suitable for COC scenario because of the high speed of convergence.

4.3. APSCA Description. In APSCA, the surrounding cells are regarded as particle swarm. To find the optimal reference signal transmission powers of surrounding cells is equivalent to finding the optimal positions of particle swarm. Suppose the particle swarm includes m particles. APSCA defines each particle in the D-dimensional space. The location and velocity of the particles are, respectively, denoted as vector $X_i=(x_{i1},x_{i2},\ldots,x_{id})$ and $V_i=(v_{i1},v_{i2},\ldots,v_{id})$ where $i=1,2,\ldots,m$. The previous best position of a single particle is denoted as $P_i=(p_{i1},p_{i2},\ldots,p_{id})$, and the previous global best position of the particle swarm is denoted as $P_g=(p_{g1},p_{g2},\ldots,p_{gd})$.

Before finding the best position, the particles update their velocity and position according to the following formulae:

$$v_{id}=v_{id}\cdot w+c_1\cdot r(p_{id}-x_{id})+c_2\cdot r\left(p_{gd}-x_{id}\right), \quad (3)$$

$$x_{id}=x_{id}+v_{id}, \quad (4)$$

where w is the constant inertia factor, c_1 and c_2 are acceleration coefficients, and r is a random number between (0, 1). We choose expressions (1) and (2) as fitness functions of particle i and choose the objective reference values of effective coverage listed in Table 1 as objective optimization criteria.

The process of APSCA is described in Algorithm 1.

4.4. Complexity Analysis of APSCA. According to the paper [12], the APSCA is convergent if the algorithm parameters ($c1, c2$, and w) are given appropriate values.

In APSCA, the number of particles in the swarm is m which denotes the number of surrounding cells, and the dimension of each particle is D. The time complexity of APSCA is calculated as follows.

(1) The time complexity of initialization is $O(mD)$.

(2) In each iteration, the time complexity to update the location and velocity for all particles is $O(mD)$.

(3) In each iteration, the time complexity to calculate the fitness function is $O(nmD)$, where n denotes the number of original users located in the outage area.

(4) In each iteration, the time complexity to update the optimal particle is $O(m)$.

(5) In each iteration, the time complexity to update the global optimal particle swarm is $O(m)$.

(6) Suppose the iteration times is N; then the total time complexity is represented as $O[mD+N*(nmD+mD+2m)]$ which can be approximately represented as $O(NnmD)$, where m is not more than 7 and D is not more than 2 in COC scenario.

Based on the previous analysis, the time efficiency of the algorithm is high. The APSCA is suitable for the centralized COC management scenario.

Table 2: Key simulation system parameters.

Parameters	Value
Carrier frequency	2.6 GHz
Inter-eNodeB distance	500 m
System bandwidth	20 MHz (100 RB)
Antenna mode	3 GPP 3D Model
Antenna downtilt	15°
Channel mode	Typical urban
Maximum eNodeB output power	46 dBm
Maximum UE output power	23 dBm
Path loss from Macro to UE	$L=128.1+37.6\log_{10}(R)$ (Unit of R is km)
Std deviation of shadow fading	−8 dB
Penetration loss	20 dB
UE density across macrocells	Uniform distribution
UE distribution within a macrocell	Uniform distribution
Service rate of edge users	128 kbps (UL), 512 kbps (DL)

5. Simulation and Discussion

The compensation effect of the APSCA is validated in the TD-LTE scenario using Qualnet and Matlab. The simulation shows APSCA can effectively solve the coverage problem induced by cell outage while the performance degradation of compensating cells can be kept on the accepted levels.

5.1. Simulation Parameters Configuration. The simulation scenario is a TD-LTE urban macrocell region of 3.5 km × 3.5 km. Top view of simulation environment is shown in Figure 3 . In the simulation scenario, there are 7 eNodeBs with space about 500 m and about 300 users randomly scattered in the area which are not totally shown in the figure.

Refer to [13]; the key simulation system parameters are configured as Table 2.

5.2. Simulation Results and Discussion. Assume that eNodeB0 (and the corresponding cell C_0) which is located in the middle of the region is in the outage. Figure 4 shows the simulation results of cell outage compensation by APSCA.

By calculating the simulation data, we can learn that almost 98.3% of the coverage area of the cell C_0 is covered by the surrounding cells after compensation. Among the compensating cells, cells C_3 and C_6 are the most two cells to compensate the cell C_0, while other surrounding cells make the minor contribution to compensation.

–Initialization
Initialize number of particles, dimension of particle, maximum iterations, objective optimization criteria, $c1$, $c2$ and w, and so forth.
For each particle i
Initialize V_i and X_i;
Initialize P_i;
END
Initialize P_g;
–Search the Best Solution
Do
For each particle i
Update V_i according to Equation (3);
Update X_i according to Equation (4);
Evaluate the fitness of current X_i according to Equations (1) and (2);
If current X_i is better than P_i, **then**
$P_i = X_i$;
End
End
Update P_g using the best particle;
While max iterations or objective optimization criteria is reached.

Algorithm 1: Process of APSCA.

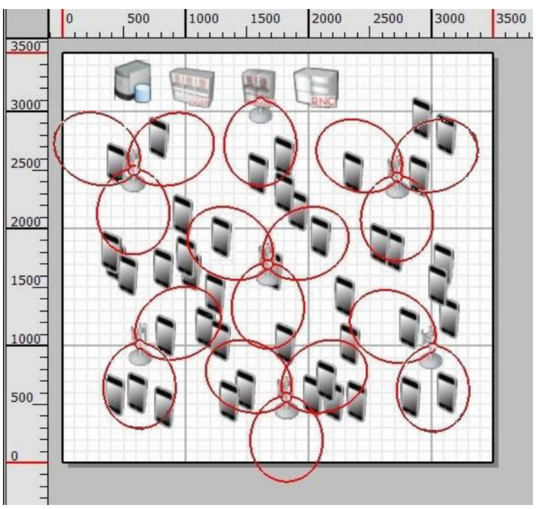


Figure 3: Simulation scenario.

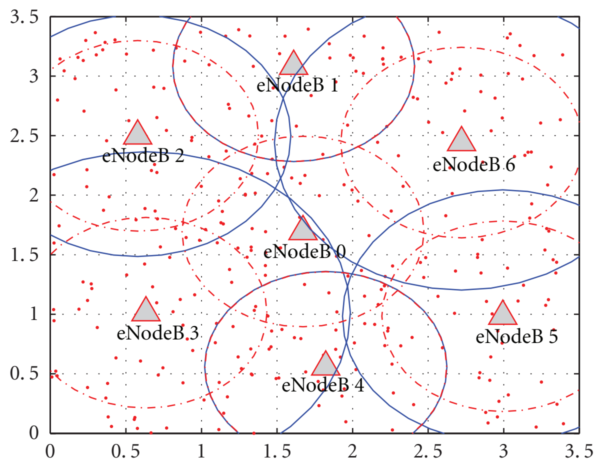


Figure 4: Compensation results.

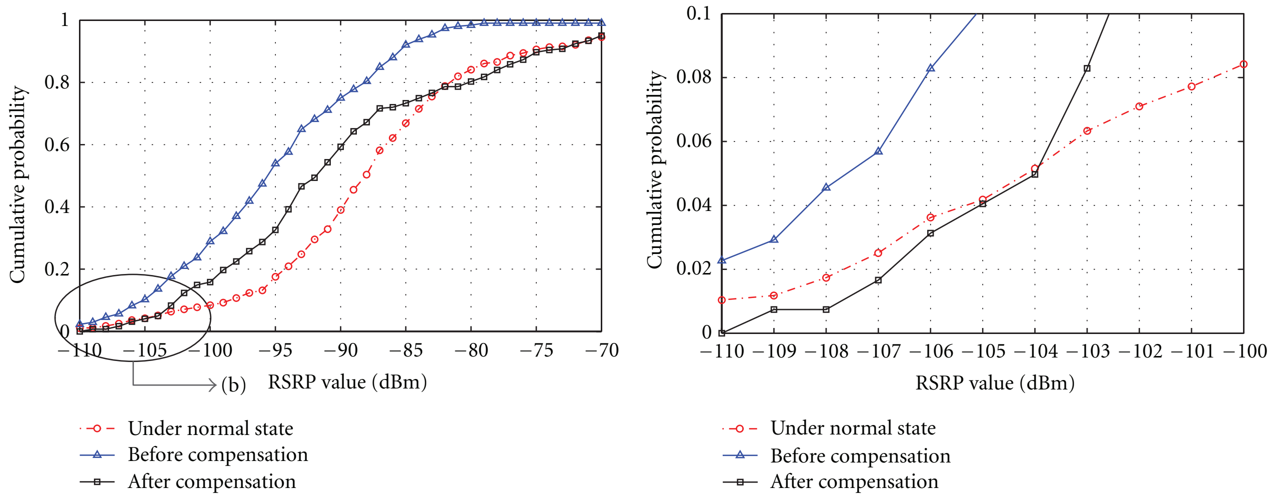
The coverage gains of the outage cell and the performance degradation of the surrounding cells induced by compensation will be discussed in detail.

(1) *Coverage Gains Analysis.* On one hand, from the viewpoint of the users in the outage cell, the received RSRP/RSRQ and their cumulative probabilities are shown in Figures 5 and 6,respectively.

As illustrated in Figure 5(a), compensation brings obvious coverage gains, especially for the weak coverage. As illustrated in Figure 5(b), before compensation, the cumulative probability that RSRP is lower than $\text{RSRP}_{\text{minTh}}$ (-105 dBm) exceeds 10% which is far worse than the objective reference value of effective coverage. After compensation, the cumulative probability that RSRP is lower than $\text{RSRP}_{\text{minTh}}$ (-105 dBm) equals to 3.9% which is within the scope of effective coverage.

Furthermore, according to Figure 5(b), when the RSRP is below -105 dBm, the cumulative probability after compensation is lower than that of normal state, which means compensation is effective in decreasing the probability of weak coverage.

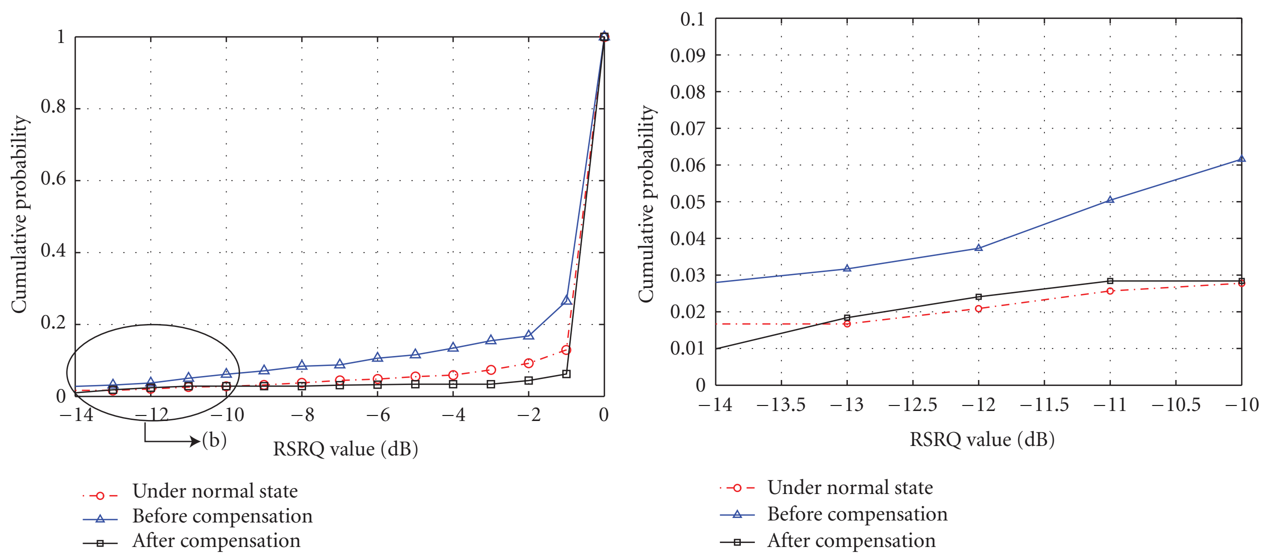
As illustrated in Figures 6(a) and 6(b), after compensation, the cumulative probability that RSRQ is stronger than -13.8 dB is 98.2%, which is within the scope of



(a) Integrated graph

(b) Enlarged partial graph

FIGURE 5: RSRP and cumulative probability of outage cell.



(a) Integrated graph

(b) Enlarged partial graph

FIGURE 6: RSRQ and cumulative probability of outage cell.

effective coverage, and is 11.33% higher than that of before compensation.

Figures 5 and 6 show that APSCA can effectively solve the coverage problems induced by cell outage.

(2) *Performance Impact Analysis.* On the other hand, from the viewpoint of users in the compensating cells, the service block probability can reflect the performance impact induced by compensation in some degrees. So we choose the cell C_3 to simulate the service block probability and take the HTTP service as an example. The simulation result is shown in Figure 7.

As shown in Figure 7, the cell C_3 begins to compensate the cell C_0 at 11:00 am; after that time, the block probability is a little higher than that of normal state. According to statistics, the service peak hours are during 13:00~17:00. After 13:00, the block probability rises obviously, and the peak block probability is 63% higher than that of normal state (no compensation). The reason is that many additional users from the cell C_0 are now served by C_3, which degrades the performance of C_3 in some ways. But the block probability is still below the threshold of 1% [14] which means the block probabilities after the compensation are still kept on the accepted levels.

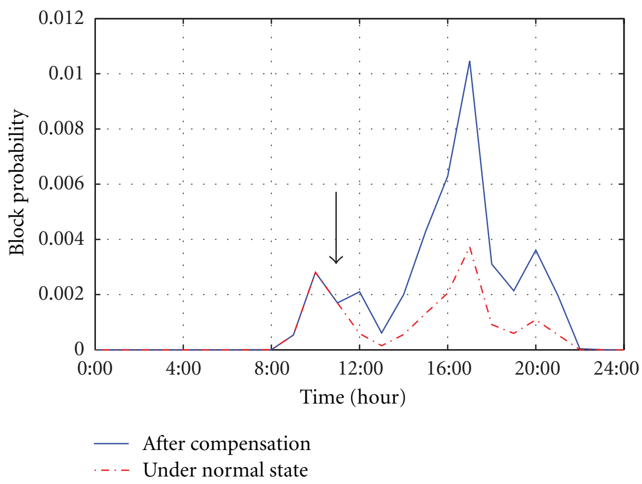


Figure 7: Service block probability of compensation cell.

6. Conclusion

To mitigate the performance degradation induced by the cell outage, a centralized cell outage compensation management mechanism and a concrete compensation scheme generation algorithm named APSCA are proposed in the paper. Simulation results show that the APSCA is effective in compensating the coverage problem induced by cell outage while the performance degradation of the compensating cells can be kept on the accepted levels.

Our future work will focus on the following three steps. First, we will investigate how to adjust other control parameters, such as antenna parameter and uplink target received power, to compensate the outage, and analyze which kind of parameters are more suitable for effective compensation in different scenarios. Second, the relations among these control parameters will be studied, and cooperative adjustment scheme generation algorithm will be designed. Lastly, more factors, such as load, interference and services, will be taken into consideration when designing the COC mechanism and algorithm.

Acknowledgments

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