

A Cell Outage Compensation Scheme based on Immune Algorithm in LTE Networks

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Abstract—Cell outage is the total loss of radio services in the coverage area of a cell. Aiming at mitigating the coverage problems caused by a sudden outage, this paper proposed a concrete cell outage compensation scheme based on immune algorithm. Taking into account the two objectives, coverage and quality, the scheme constructs a mathematical model which adjusts the uplink target received power in surrounding cells, and generates a specific solution by adopting immune algorithm. The reported simulation results show that the proposed algorithm is able to recover a large proportion of unserved users and mitigate the performance degradation.

Keywords—cell outage compensation; uplink target received power; immune algorithm; LTE

I. INTRODUCTION

Self Organizing Networks (SON) is an automation technology used to simplify network planning, configuration, optimization and healing. The objective of SON is to enable a set of functionalities for automated Self-Organization of LTE (Long Term Evolution) networks, so that human intervention is minimized in the planning, deployment, optimization and maintenance activities of these new networks [1]. SON consists of three functions: self-configuration (e.g., automatic neighbour relations), self-optimisation (e.g., mobility load balancing) and self-healing (e.g., coverage and capacity optimization). Cell outage management (COM) is a use case of self-healing, including cell outage detecting (COD) and cell outage compensation (COC). This paper will concentrate on the implement of COC.

The goal of COC is to mitigate the degradation of coverage, capacity and service quality caused by a cell or site level outage [2]. When an outage occurred, a variety of measurements such as handover failure rate, Key Performance Indicators (KPIs), Radio Link Failure (RLF) counter, and other measurement data are collected from users, base stations (called eNodeB in LTE networks), or Operations Administration Maintenance (OAM) center, and fed to the COC algorithm. Relevant parameters (pilot power, uplink target received power, etc.) in surrounding cells will be adjusted automatically to satisfy the operator's performance requirements based on coverage objectives and other quality indicators.

In this paper we present a cell outage compensation scheme based on immune algorithm and put forward a concrete COC algorithm in LTE networks. Taking into account the trade-off between coverage and quality, we

design a specific algorithm for COC. The simulation results prove that this COC algorithm is effective in enlarging coverage and ensure the link quality.

II. RELATED WORKS

Among the standardization organizations and research programs related to the characteristics of LTE SON, 3rd Generation Partnership Project (3GPP) is the most influential. Many research groups under 3GPP have been involved in many areas of the discussion and standardization of SON, including RAN2/ RAN3/ RAN4/ SA5, and mostly focus on RAN3 and SA5 so far. In 2009, SA5 started the requirement investigation of self-healing use cases, and defined the use case of cell outage compensation [3]. Beside 3GPP, the Self-Optimization and Self-Configuration in Wireless Networks (SOCRATES) projects from EU is also the main research organization related to LTE SON, and it mainly outputs the use cases, requirements, framework of SON. Meanwhile, the specific schemes of the SON use cases, algorithms and simulations are developed rapidly [4]. Furthermore, the Next Generation Mobile Networks (NGMN) under the telecom operators also pays close attention on SON, and it outputs the requirements related to SON and OAM as well as the research reports [5].

The proposals and reports mentioned above are instructive to the research of COC; however, little research has been conducted on the specific mechanisms and algorithms for COC. Reference [6] and [7] analyzed the simulations on COC of different scenarios and compared the effects of different parameters in simulation results. It turns out that preferable compensation results can be achieved by adjustment of uplink target received power (P_0). However, the stepwise iteration algorithms used in above references are inefficient, thus system cannot recover from outage in short time. Reference [8] proposed a COC method implemented in TD-SCDMA. Simulation results show that up to 78% of the user can be recovered in compensating cells. But the method is not Sufficient enough, and the compensation result is not satisfactory.

To improve above problems, this paper proposes a cell outage compensation scheme based on immune algorithm to fix the shortcomings (e.g., low speed and lack of mathematical model) of previous works, and solve the coverage problems due to a sudden outage quickly and effectively.

III. MODEL OF COC SCHEME

Generally speaking, the coverage area of wireless access network is usually limited by the uplink transmits power. Uplink transmits power is determined by two parameters (i.e., the uplink target received power P_0 and the path loss compensation factor α) that are broadcast by eNodeB. P_0 is standard power value based on the cell size. The value of P_0 varies from -132 to -96dBm with a default setting of -114dBm. The decrease of P_0 can increase coverage range effectively. Meanwhile, more user equipments (UE) access to neighbor cells; this leads to a decrease of user throughput capacity and service quality of edge users. We believe that when designing a COC algorithm, multiple optimization objectives (like some combination of coverage and quality) need to be considered. We choose P_0 as optimize parameter in COC and this algorithm make a trade-off between two optimization targets: coverage ratio and user service quality.

A. Uplink Power Control

According to the QoS constraints, cellular load and UE transmit power capability, LTE uplink power control is responsible to meet the minimum requirements of the signal-to-interference-plus-noise ratio (SINR) and limit inter-cellular interference. In open loop power control mode, the UE transmit power is defined as [9]:

$$P_{PUSCH} = \min\{P_{\max}, 10\log[M] + P_0 + \alpha \cdot PL\} \quad (1)$$

Where, P_{\max} is the maximum allowed transmit power, it depends on the UE power class. M is the number of physical resource blocks (PRB). PL is the downlink path loss estimate, calculated in UE based on the reference symbol received power (RSRP). P_0 is the uplink target received power. α is the path loss compensation factor, in the range [0,1]. P_0 and α are specific control parameters, broadcast in the cell.

Typically, the uplink power control parameters have a great influence on the value of SINR. Open loop power control has the advantages with low overhead and fast speed of control, so this paper use the open loop power control to adjust the parameter uplink target received power (P_0) in physical uplink shared channel. In the case of coverage is limited by uplink, reducing P_0 can achieve effective coverage gain for the outage area. The COC mechanism can be realized in OAM.

When an outage is occurred, the COC scheme first determines whether compensation is needed based on the data collected from UE and eNB. If the outage problem should be solved immediately, COC scheme will generate a specific compensation solution depending on the coverage objectives. This solution is obtained from a COC algorithm, with the goal of finding out the optimal parameters adjustment strategy of surrounding cells.

B. Mathematical Model of COC

Suppose the eNodeB corresponding to outage cell is eNB_0 , and the surrounding eNodeBs are denoted as $\mathbf{M} = \{eNB_1, eNB_2, \dots, eNB_m\}$, of which the total number is m . the P_0 corresponding to \mathbf{M} are denoted as $\mathbf{P}_0 = \{p_{eNB_1}, p_{eNB_2}, \dots, p_{eNB_m}\}$. The coverage area of all eNodeBs is S_{target} .

The link quality can be reflected from the received signal-to-interference-plus-noise ratio (SINR). $SINR_i$ is the SINR received from i -th UE and given by [10]:

$$SINR_i = \frac{P_i \cdot g_{ij}}{\sum_{k \in N, k \neq i}^m P_k \cdot g_{kj} + \sigma^2} \quad (2)$$

Where p_{ij} denotes the transmission power of user i , g_{ij} denotes the total channel gain from the user i to eNB_j , including pass loss, shadowing, and other factors if any. $\sum_{k \in N, k \neq i}^m P_k \cdot g_{kj}$ is the total interference and σ^2 denotes noise power.

In LTE networks, the minimum SINR is the basic performance parameter needed for the receiver to receive signal, determines the maximum allowed path loss. Suppose the minimum SINR allowed by uplink is δ , in order to guarantee the UL SINR, P_0 should satisfy:

$$p_{eNB_j} = \delta \cdot \left(\sum_{k=1, k \neq j}^m P_{ik} \cdot g_{ik} + \sigma^2 \right) \quad (3)$$

Therefore, a low P_0 will lead to the degradation of SINR, and cannot ensure the demand of SINR.

Let $P_{\max} = 10\log[M] + P_0 + \alpha \cdot PL$, the maximum pass loss in the eNB service area:

$$PL_{\max} = \frac{P_{\max} - 10\log[M] - P_0}{\alpha} \quad (4)$$

According to the path loss model (e.g., Cost231-Hata model and the Okumura model), we can get uplink coverage radius d and coverage area S which are corresponding to the maximum path loss separately. Larger the coverage area is, more users will be covered. As a result, Per-user link quality will be decreased. One representation is that the value of some user SINR will be reduced. Therefore, when designing the COC algorithm, we should take both two facts into consideration.

When designing the model of COC, at first, we must ensure the normal communication of users in the outage region, which means the value of SINR should be greater than the minimum requirement. In order to fulfill the communication requirements in outage areas, that is, SINR must be greater than a given threshold δ :

$$SINR_i \geq \delta \quad \forall i \in N \quad (5)$$

The first optimization objective can be expressed as:

$$\max f_{SINR} = \sum_{i=1}^n \text{sgn}(SINR_i - \delta) \quad (6)$$

Where $\text{sgn}(\cdot)$ is a function returns an integer indicating the sign of a number. If number is greater than 0, $\text{sgn}(\cdot)$ returns 1; if equal to 0, it returns 0; if less than 0, returns -1. In this way, the value of f_{SINR} can be an indicator of performance.

The coverage ratio of whole area is another indicator that can estimate the performance of compensation result. To achieve effective compensation, the coverage ratio must be sufficiently large. The coverage area $S(p_{eNB_i})$

can be calculated from the maximum pass loss PL_{\max}^i . Define the second optimization objective by the following expression:

$$\max f_{\text{coverage}} = \frac{S(p_eNB_1) \cup S(p_eNB_2) \cup \dots \cup S(p_eNB_m)}{S_{\text{target}}} \quad (7)$$

Since P_0 gradually decreases in the entire optimization process, it cannot be less than the given threshold:

$$P_0 \geq P_{0\min} \quad (8)$$

IV. IA-BASED COC ALGORITHM

Immune algorithm (IA) is a new optimization algorithm imitating the immune system to solve the multimodal function optimization problem. Immune algorithm uses the characteristic information from problem to reduce the degradation in optimization process and maximum the optimization effect. The Immune algorithm perceives the problem as the antigens while the solution as the antibody [11]. To estimate the quality of solution, we use a global fitness function and Antibody density in our algorithm.

A. Global Fitness Function

To find the optimal solutions of P_0 by applying the immune algorithm, a global optimization scheme is considered. In this problem, the antibody is the set of P_0 . In order to satisfy the above two optimization objectives and achieve the trade-off between them, here we create a global fitness function:

$$F_{\text{fit}} = \lambda_1 f_{\text{SINR}} + \lambda_2 f_{\text{coverage}} \quad (9)$$

λ_1 and λ_2 denote the weight parameters. For different scenarios, the goal of compensation will be different; changing the values of these two parameters will achieve different compensation effects.

B. Antibody Density

For given two arbitrary m -dimensional vectors $P_0^{(p)}$ and $P_0^{(q)}$, the difference between them is due to different P_0 . This can be measured by *Euclidean* distance. The *Euclidean* distance between two vectors can be calculated by:

$$ED(P_0^{(p)}, P_0^{(q)}) = \sqrt{\sum_{i=1}^m (p_eNB_i^{(p)} - p_eNB_i^{(q)})^2} \quad (10)$$

If the *Euclidean* distance of two antibodies is less than the given threshold θ , the two antibodies are neighbors:

$$\text{antiNB}(P_0^{(p)}, P_0^{(q)}) = \begin{cases} 1, & ED(P_0^{(p)}, P_0^{(q)}) < \theta \\ 0, & \text{others} \end{cases} \quad (11)$$

The density of antibody is defined as the ratio of the number of neighbors with the whole population size:

$$\text{density}(P_0^{(p)}) = \frac{\sum_{q=1}^{\text{pop_size}} \text{antiNB}(P_0^{(p)}, P_0^{(q)})}{\text{pop_size}} \quad (12)$$

Based on the *Euclidean* distance, we can estimate the density of antibodies. This value is used in the operator *immune selection* to choose the individuals with low density in population.

C. Operator Description

Based on the optimization problem we discussed above, here we choose three operators to find the optimal solution: Immune Cloning, Clone Mutation and Immune Selection which are described as follows.

Immune Cloning: In immunology, Cloning means asexual propagation so that a group of identical cells can be descended from a single common ancestor, such as a bacterial colony whose members arise from a single original cell as the result of mitosis. At the beginning of IA, the antibodies will clone themselves to enlarge the solution space which will increase the opportunity to find the results.

A pre-cloning population Bp will be reproduced following a specified proportion. Cp is the resulting population from applying *Immune Cloning*.

Clone Mutation: For the operator *Clone Mutation*, the first step is to randomly select an element p_eNB_j from each antibody and mutate it according to (13). After mutation, the element becomes p_eNB_j' , and the mutated antibody denoted as P_0' . The entire set of mutated antibodies composites the mutation population Cp' .

$$p_eNB_j' = \begin{cases} p_eNB_j + \xi_j, & \text{rand}(1) \geq 0.5 \\ p_eNB_j - \xi_j, & \text{others} \end{cases} \quad (13)$$

Where, ξ_j is the unit change of j -th parameter in each antibody.

Immune Selection: This operator is designed to guarantee the diversity of population. The density must be controlled when a new generation of antibody is generated. Therefore, when making an immune selection, we select the antibody with lower density and higher fitness [12]:

$$F_{\text{select}}(P_0^{(p)}) = \frac{1}{\text{density}(P_0^{(p)})} \cdot \frac{F_{\text{fit}}^{(p)}}{\sum_{q=1}^{\text{pop_size}} F_{\text{fit}}^{(q)}} \quad (14)$$

D. Description of COC Algorithm Process

Suppose the antibody population is $Ap = \{P_0^1, P_0^2, \dots, P_0^{n_A}\}$ with the size of n_A , the pre-cloning population is $Bp = \{P_0^1, P_0^2, \dots, P_0^{n_B}\}$ with the size of n_B , the cloning population is $Cp = \{P_0^1, P_0^2, \dots, P_0^{n_C}\}$ with the size of n_C , the memory population is $Mp = \{P_0^1, P_0^2, \dots, P_0^{n_M}\}$ with the size of n_M . The frame work of IA-based COC algorithm can be seen in fig. 1, and the process is described as follows:

1) Generate a random initial antibody population Ap with the size n_A . Create the initial $Mp = \Phi$, $Bp = \Phi$ and $Cp = \Phi$ with the size n_M , n_B and n_C . Set the maximum iterative times T_{\max} , counter $t=0$.

2) Calculate the value of fitness function for each antibody, choose the highest n_B ones to constitute the pre-cloning population set $Bp(t)$.

3) Get the clone population $Cp(t)$ by applying the *Immune Cloning* on $Bp(t)$.

4) Perform *Clone Mutation* on $Cp(t)$ and generate the resulting population set $Cp(t)'$.

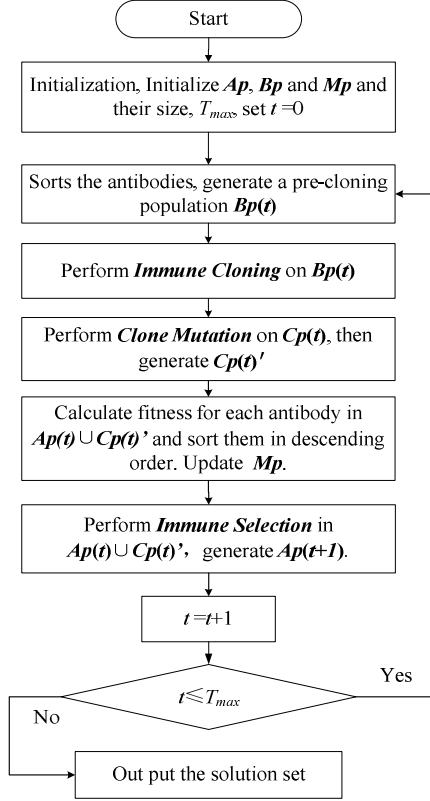


Fig. 1. Process of IA-based COC algorithm

5) Calculate F_{fit} for each antibody in $Ap(t) \cup Cp(t)'$ and sort them in descending order. Update the memory set Mp by choosing individuals with the highest F_{select} in $Ap(t) \cup Cp(t)'$.

6) Perform *Immune Selection* in $Ap(t) \cup Cp(t)'$, select the best w individuals to enroll in $Ap(t+1)$, other antibodies in $Ap(t+1)$ are randomly generated in solution space.

7) If $t > T_{max}$ is satisfied, the antibody in Mp with the highest fitness value will be exported as the output of the algorithm, Stop; Otherwise, $t = t + 1$ and return to 2).

V. SIMULATION AND DISCUSSION

In this section, we present performance results analysis for the COC algorithm in three parts: coverage gain analysis, performance impact analysis and comparison with other algorithms.

A. Simulation Environment

The simulation is based on LTE network, in an urban area with $4.5\text{km} \times 4.5\text{km}$. 7 eNodeBs are located in the area, ranging from 300m to 500m. 200 UEs are randomly distributed within the range. Under normal circumstances, the coverage of this area is limited by uplink. Suppose the performance degradation of downlink caused by outage is still in an acceptable scope, we just focus on the COC action for uplink in the simulation. The other key parameters concerned in simulation are shown in Table I. The parameters of IA are set to match the simulation scenarios, illustrated in Table II.

B. Simulation result and Discussion

TABLE I. SIMULATION PARAMETERS

Parameter	Values
System bandwidth	20 MHz
Channel mode	Typical urban
Carrier frequency	2600 MHz
Uplink transmit power	23 dBm
Downlink transmit power	46 dBm
Antenna mode	3GPP 3D Model
Antenna height	35m(eNB), 1.5m(UE)
Antenna downtilt	15°
Path loss model	Cost231-Hata
α	1
Shadowing	8 dB
Penetration loss	20dB
Cable loss	2dB
Gain of eNB antenna	18dBi

TABLE II. PARAMETERS OF IA

Parameter	Values
n_A	50
n_B	20
n_M	20
w	30
λ_1, λ_2	0.5
θ	2
ζ	1 dBm
P_{0min}	-132 dBm
T_{max}	200

1) Coverage gain analysis

eNB_0 is located in the middle and selected to be the outage cell. Due to the outage, parts of the area cannot satisfy the uplink coverage demand, which will trigger the COC action, and the surrounding cells of eNB_0 will adjust P_0 based on the compensation scheme. The coverage areas before and after COC are shown in fig. 2.

The red circles in fig. 2 denote the coverage area of surrounding cells under normal state, and the blue circles denote the adjusted coverage areas. There are 5 eNBs adjusting their P_0 to compensate the outage areas, both cell 2 and cell 6 have significant change. The adjustment results can be seen in Table III. Since the two optimization objectives have the same weight and the goal of our algorithm is to achieve maximum fitness value, the two functions: f_{SINR} and f_{cov} will have mutual restriction and neither of them can reach their highest value. Thus there still exist areas without compensation and users failing to reach the threshold of SINR. The final results of COC algorithm show that optimized coverage ratio can reach 92% and there are 86% recovered users that satisfy the SINR threshold requirement. Changes of each function can be seen in fig. 3. When the number of iterations reaches 40, each function has already converged to an optimal outcome. This fully proves that this algorithm has the characteristics of rapid convergence and can get compensation scheme in time.

TABLE III. VALUE OF P_0

Cell No.	Initial/dBm	After COC/dBm
0	-117	Outage
1	-117	-116
2	-117	-132
3	-117	-121
4	-117	-119
5	-117	-117
6	-117	-131

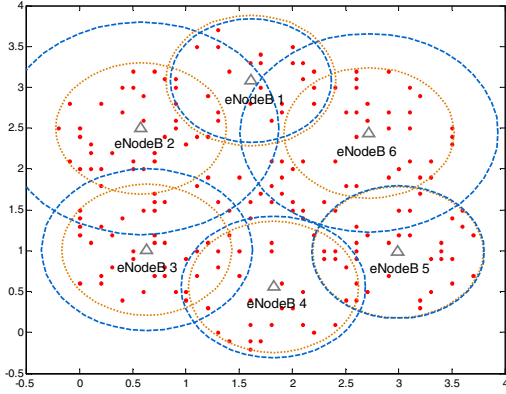


Fig. 2. Coverage comparison

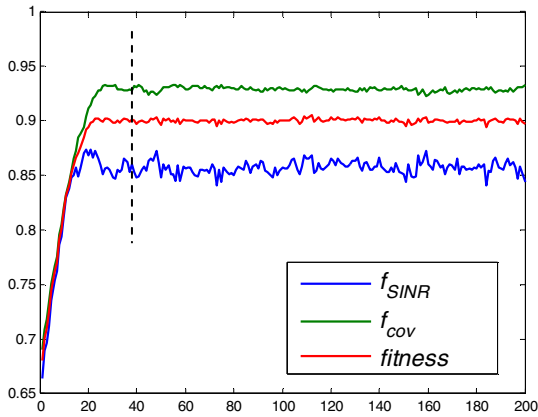


Fig. 3. Changes in iterations

2) Performance Impact Analysis

The cumulative probability of SINR can be seen in fig. 4. The outage will lower the SINR values of cell-edge users that fail to satisfy the normal communication requirement. When compensation is executed, the cell edge SINR would increase slightly, but the adjustment of P_0 would enlarge the coverage as well as inter-cell interference, so that the overall regional SINR would decrease, which is the cost for obtaining the coverage gain. Considering the uplink quality is also the optimal objective, the COC algorithm will take it as the optimization target, and make a reasonable trade-off with coverage goal, so the average SINR is still in the acceptable range.

3) Algorithm comparison

References [6] and [8] proposed two compensation methods based on the P_0 adjustment scheme. Compared with our algorithm, both two methods adjust P_0 by small step size and get the adjustment results after a large number of iterations. Our algorithm only needs about 40 iterations to converge an optimal result while the other two need more than 100 iterations to achieve the effective coverage compensation. Here we use four indicators (i.e., iteration times, link quality, relative compensation factor and coverage ratio) to estimate the performance of these three algorithms.

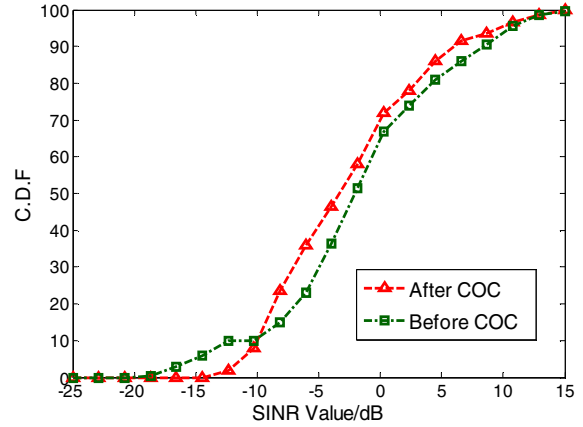


Fig. 4. Cumulative probability of SINR

The four indicators are concentrating on the coverage gains and the sacrificed quality in simulation area. The achieved coverage can be estimated by a relative compensation factor (RCF) [6]:

$$RCF = \frac{N_{save}}{N_{loss}}$$

Where, N_{loss} is the total number of users that loose coverage due to the outage, N_{save} is the total number of users that are recovered due to the COC actions. The RCF is estimate the coverage gain via users' view, and the coverage ratio can be estimated in terms of eNBs. The link quality can be evaluated by cell-edge user (i.e. the 5th percentile downlink channel quality) throughput.

Fig. 5 shows the algorithm performance comparison results. Fig. 5(a) is the comparison of convergence speed, fig. 5(b) shows the difference of cell-edge users link quality using these three algorithms, fig. 5(c) is the comparison of RCF and fig. 5(d) indicates the difference of uplink coverage ratio. These four indicators measure the compensation results from two different aspects (coverage, quality). From the results, our COC algorithm

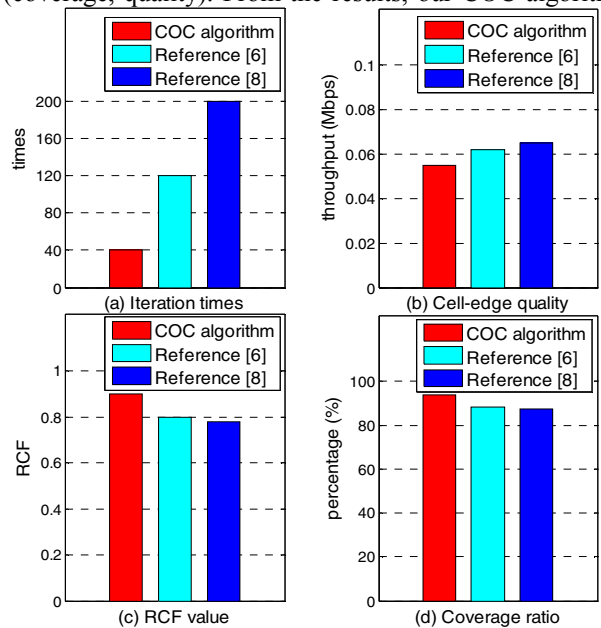


Fig. 5. Comparison results

has a better performance in restore coverage that 91% users have been recovered; while there are only about 80% users could be recovered for the other two algorithms. Besides, we have an acceptable cell-edge quality sacrifice as a trade off.

This proposed algorithm mainly has two advantages:

Large application scope. In our algorithm, we can use two weight parameters: λ_1, λ_2 to adjust the proportions of coverage and quality according to different scenarios. For example, we can set λ_1 larger than λ_2 in a coverage-driven scenario to have a better coverage performance. For the other two algorithms, they have a rigid and fixed optimal strategy and cannot give a targeted optimal solution.

Rapid convergence procedure. The proposed algorithm can come to a stable optimal result after about 40 times iterations; meanwhile, the other two algorithms need about 200 times iteration to give a stable result.

Through the analysis above, the COC algorithm can give a specific and quick optimal solution for different scenarios with different performance requirements and keep the performance degradation at an acceptable level.

VI. CONCLUSION

In this paper we presented an implementation of cell outage compensation algorithm. A major goal of this paper is to mitigate the degradation of coverage and service quality due to a sudden cell outage by using the COC algorithm as soon as possible. We have discussed the reason of selecting P_0 as the adjustment parameter, and the procedure of implementing an IA-based COC algorithm which can give a better and flexible balance between coverage and quality for different scenarios. In the section of algorithm comparison, we have made a performance analysis among three different algorithms; two main advantages of the COC algorithm have been introduced.

In the presented simulations, we only considered a single scenario. In our further research, the analysis of algorithm will be argued in different scenarios. More control parameters will be combined into adjustment, e.g., if channel quality is more valued, change the value of α may get a better compensation result.

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