Small Cells Placement Scheme in Metropolitan Area Environment

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***Abstract*— The low power radio access nodes, also known as small cells, are always applied to compensate the coverage of macro cells so as to increase the network capacity. The radio spectrum condition is greatly affected by the buildings and there will be many communication dead zones in the metropolitan area environment if only macro cells are deployed. Generally, the communication dead zone is always small and in irregular shape, therefore, the deployment of small cells is one of the most convincible ways to deal with it. However, the interference, necessary overlapping for handoff, coverage improvement, and cost are correlated to one another. And it is hard to determine the number and locations of small cells to be deployed. In this paper, we propose the Particle Swarm Optimization (PSO) based small cell placement algorithm to effectively deploy the small cells in the communication dead zone of metropolitan area. The fitness value in the PSO process of the proposed scheme is tuned by the adaption function to compromise the coverage maximization and necessary overlapping of small cells. A practical area of Taipei City was adopted as an experimental example to investigate the performance of the proposed scheme. The experimental results illustrate that the proposed scheme places small cells in proper locations so that the coverage can be effectively improved.**

***Index Terms*— LTE, Transmission coverage, Small cell deployment, Particle Swarm Optimization**

I. Introduction

Wireless mobile communication has created a convenient environment in which people can ubiquitously access networks and share information, and has enabled the deployment of several attractive services through handheld devices. The long term evolution (LTE) technology has been proposed to support current broadband services in mobile environment. LTE is an evolution of GSM /UMTS network technologies, which adopts new radio interface and modulation to offer high bandwidth for the mobile devices [1, 2]. However, in metropolitan environment, the dense high buildings and constructions greatly affect the propagation of radio spectrum and, therefore, introduce several communication dead zones in metropolitan area. In the communication dead zone, the radio channel quality is poor and the poor channel condition always introduces low spectrum efficiency. The low spectrum efficiency downgrades the effective data throughput and affects the deployments of mobile services. Although the operator can increase the transmission power of the base station, i.e. eNodeB (eNB), to increase the signal to noise ratio (SNR) to improve channel quality, it introduces interference problem among eNBs. Furthermore, the channel bandwidth of eNB is limited and it constrains the capacity that eNB can provide. Consequently, small cells are recognized as one of the suitable candidate solutions to overcome this problem. From the spectrum utilization point of view, the low transmission power of the small cell can effectively compensate the transmission signal in the dead zone, which macro base station is hard to reach, so as to increase the radio coverage and improve the radio channel quality without affecting the devices outside the dead zone. Furthermore, by cooperating with macro cells, the small/pico cells can reuse the spectrum of the macro cell under the permission of the macro base station, i.e. (eNB), so as to increase the network throughput. Thus, the small cell can effectively compensate the macro cell in practical deployment. These issues are quite important for the mobile network deployment to improve network services in the metropolitan area. In addition to increasing the radio coverage and network capacity, the capital expenditure (CAPEX) and the operation expenditure (OPEX) can also be reduced when comparing to the macro cell only approach as shown in Figure 1 [3].

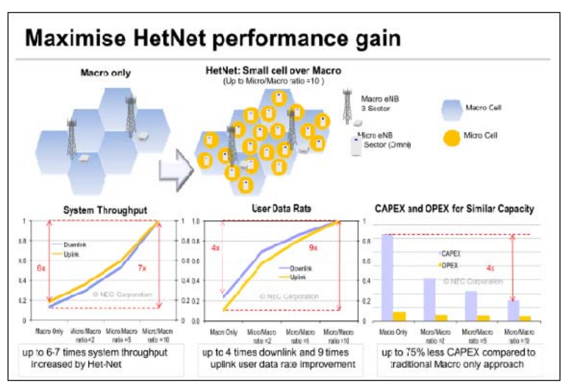

Figure 1 Comparisons of mixed macro/micro HetNet [3]

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As the small cell is applied to not only improve the radio coverage but also provide better spectrum utilization, therefore, the proper placement of small cells over the irregular area of communication dead zone is critical but not an easy job. Mostly, the placement of small cells relies on the knowledge of experts. And, therefore, there is no explicit evaluation metric to compare the effectiveness of the placement before practical deployment. In this paper, we propose the Particle Swarm Optimization (PSO) based approach to deal with this issue systematically. By properly designing the adaption function, the proposed PSO based scheme can effectively improve the radio coverage and consider the necessary overlaps among cells.

The rest parts of this paper are organized as follows. The background and related works are described in the following section. The proposed PSO based small cell placement scheme and the designed associated adaption functions are explained in the section 3. Experimental results of a practical metropolitan area by using the proposed scheme are provided in the section 4 with discussions. And we conclude our works in the last section.

II. Background

The deployment of macro cell in metropolitan environment always introduces communication dead zones due to dense and high buildings and constructions [4]. Furthermore, the demand of network bandwidth in metropolitan is much higher than that in the rural area. The small/pico cells can be utilized to compensate the dead zones as shown in Figure 2 [5]. The hybrid macro/pico deployment approach can effectively increase the radio coverage. Additionally the network throughput can be increased due to the spectrum reuse in small cells.

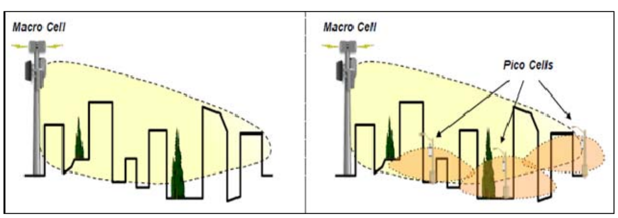


Figure 2 Communication dead zones and the use of pico cells [5]

The placement of small cells is a complex issue because the communication dead zone always irregular and different radio transmission condition spreads out the area. The small cells shall be placed to not only maximize the coverage but also minimize the overlap area. The placements of multiple small cells are mutually correlated to each other and any change of the location of a small cell may introduce coverage effect to the other small cells. It is not easy to achieve the optimum solutions, therefore, the fuzzy based approaches, such as neural network, gene algorithm [6, 7], PSO, etc., are more suitable to be applied for the design of the placement algorithm. In this paper, we proposed the PSO based scheme to place small cells in the proper locations of the dead zone.

The concept of PSO is originally proposed by Kennedy, Eberhart and Shi and was intended to simulate the social behavior for the representation of the movement of organisms in a bird flock or fish school [8, 9]. PSO describes the moving behavior of a group of particles. Each particle has its inertia of exploring speed and direction, however, the movement also considers the achievement of better fitness value from the group point of view. And the inertia weight ω is applied to determine the effect of the particle movement as shown in Figure 3. Thus the larger value of ω means the higher dependence of the particle original movement.

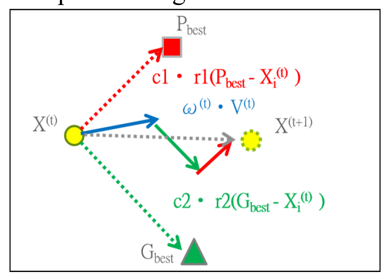


Figure 3 The concept of particle movement in PSO algorithm

In Figure 3, the values of P_{best} and G_{best} represent the optimal locations from the particle point of view and group point of view, respectively. V is the movement vector of the particle and $X^{(t)}$ and $X^{(t+1)}$ denote the locations at time t and $t+1$, respectively. Then the movement vector of particle i at time $t+1$, $V_i^{(t+1)}$, is calculated as

$$V_i^{(t+1)} = \omega \bullet V_i^{(t)} + c_1 r_1 \bullet (P_{best}^{(t)} - X_i^{(t)}) + c_2 r_2 \bullet (G_{best}^{(t)} - X_i^{(t)}) \quad (1)$$

and

$$X_i^{(t+1)} = X_i^{(t)} + V_i^{(t+1)} \quad (2)$$

where parameters c_1, r_1, and c_2, r_2 are factors and random variables of particle and group, respectively.

In the proposed scheme, the small cells to be placed are treated as particles and are assumed to be randomly placed over the dead zone area at beginning and the appropriate locations of the small cells are obtained through several movement iterations by referring to the designed fitness value.

III. The Proposed PSO Based Placement Algorithm

Although the small cells shall be placed to cover the dead zone area as complete as possible while minimizing the operlapping area between macro/small cells, some overlapping between macro cell and small cell is helpful for the seamless handover (HO) of UE. However, the overlapping area shall be in proper size to just meet the requirement of the handover procedure. We performed a practical experiment to investigate the required handover time. And the overlapping area can be obtained from the required handover time and the movement speed of UE. The measurement result of the UE traveling from the small cell to the macro cell is shown in Figure 4. Generally, the handover procedure is triggered according to the strength of the reference signal received power (RSRP). The duration from the trigger of HO to the HO complete was measured to be around 2 second when the moving speed was 3m/sec. according to the measurement result.

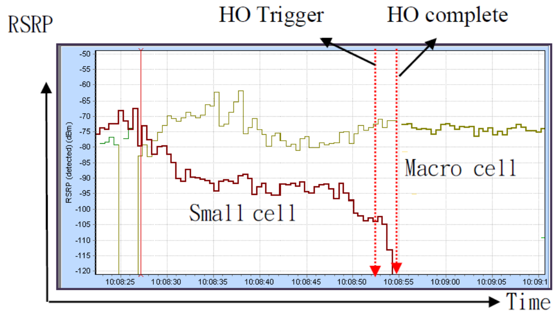


Figure 4 The measurement for UE handover between small cell and macro cell

The proposed algorithm follows the PSO concept, however, the fitness function is designed to meet the above objectives of small cell placements. The fitness function of the proposed scheme applies the points can be obtained over the coverage of the small cell in a specific placement location. The dead zone area can be divided into different parts according to RSSI signal strengths. The coverage of small cell can be categorized into six types according to the signal strengths and overlapping conditions as shown in Figure 5. The purple, green, and yellow areas mean the strong (RSSI>=-70), medium (-80=<RSSI<-70), and weak (RSSI<-80) signals covered by the macro cell. Each small rectangle, which is covered by the small cell, represents different points according to the rules in Table 1 with the constraints of the adaption functions shown in Figure 6.

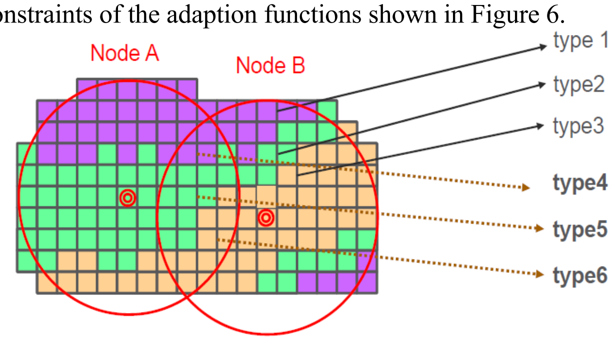


Figure 5 Coverage types of small cells

Table 1 RSSI strength and overlapping condition v.s. basic obtained point

Type	Overlap with other small cell(s)	RSSI strengths of macro cell	Obtained basic points
1	No	Strong	1
2	No	Medium	2
3	No	Weak	3
4	Yes	Strong	1
5	Yes	Medium	2
6	Yes	Weak	3

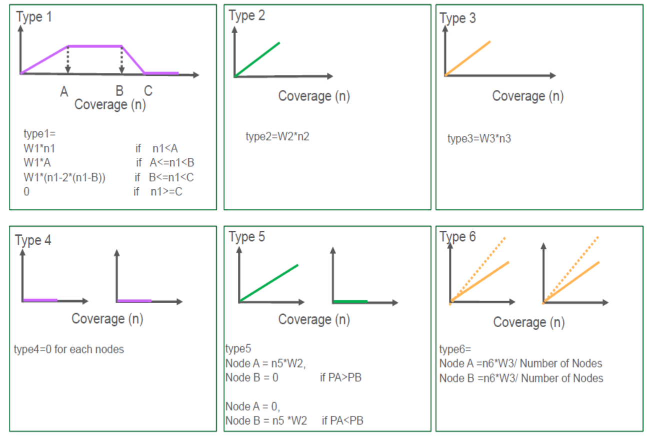


Figure 6 Adaption functions for points obtained in Table 1

In addition to the RSSI signal strength, the adaption functions are designed to consider the the effect of overlapping. For example, in type 1, the overlapping of small cell and macro cell is encouraged to support seamless handover described before by increasing its points to coverage size A and the point will decrease if the overlapping area exceeds B (i.e. unnecessary overlapping); in type 4, the operlapping of two small cells with the macro cell in its strong signal area is not necessary and, therefore, its point is equal to zero; type 5 considers the overlapping area of multiple small cells and the RSSI signal of macro cell is not strong, then the point belongs to the small cell, which has higher RSSI signal, obtains the points and the other small cell is set to be zero.

For the example in Figure 7, the points obtained by small cell A and B are illustrated as follows:

Small cell A:

Type1+Type 2+Type 3+Type 4+Type 5+Type 6

=(15-5)*1+24*2+28*3+4*1*0+8*2+18*3/2

=185

Small cell B:

(16-6)*1+27*2+24*3+4*1*0+0+18*3/2

=163

And the total fitness value is 185+163=348

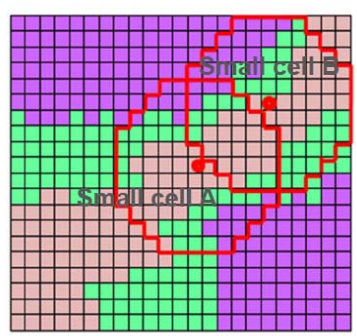


Figure 7 An example with two small cells

IV. EXPERIMENTAL RESULTS OF A PRACTICAL CASE

In order to investigate the effectiveness of the proposed scheme, a practical communication dead zone in Taipei city, shown in Figure 8, was adopted for small cells placement. The area was partitioned into several 5m*5m rectangles as shown in Figure 9. The values of A, B, and C, in the type 1 adaption function, were assumed to be 10, 15, and 20, respectively. The parameters c_1 and c_2 of equation (1) was set to be 1 and 2, respectively. The maximum number of PSO iterations was set to be 25. However, the PSO procedure will be terminated if the fitness value does not increase for the latest 5 iterations.

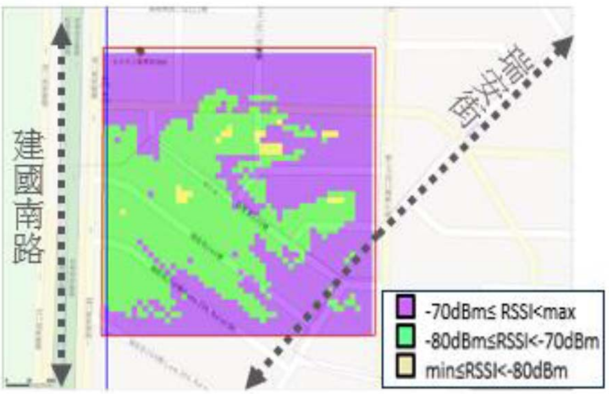


Figure 8 Experiment of the practical communication dead zone in Taipei City

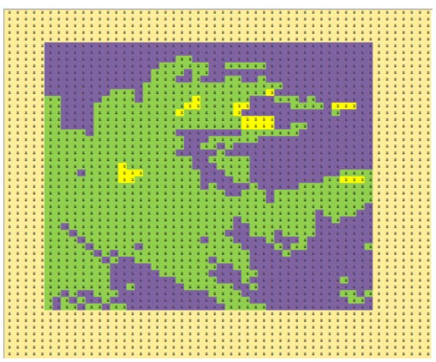
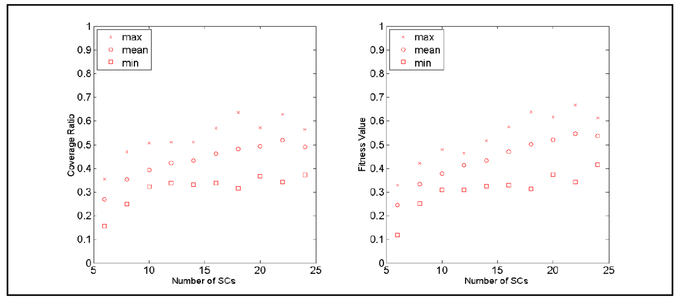


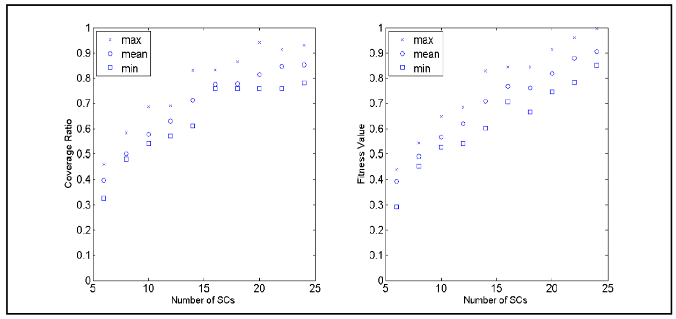
Figure 9 The partitioned experimental area

Initially, the small cells are randomly spread out over the area with medium and weak RSSI signal strength. Then the small cells start to move according to the equation (1) of the proposed scheme to seek for better fitness value. The simulation results were obtained through the statistics of 12 times.

Figure 10 illustrates the coverage percentages and fitness values versus the numbers of small cells (with transmission radius 25m) before and after the proposed PSO placement scheme. It shows that the proposed PSO based scheme significantly improves the coverage of the dead zone. For example, the coverage percentage of the proposed scheme becomes 80% when the number of small cells is 20, however, it is around 45% initially. The fitness value is getting higher as the coverage percentage increases.



(a) Coverage and fitness value before the proposed scheme



(b) Coverage and fitness value after the proposed scheme

Figure 10 The coverage percentages and fitness values v.s. number of deployed small cells

Figure 11 shows the coverage percentages and fitness values for number of cells with two different transmission powers. We assumed that the radiuses of small cells with power and higher transmission powers are 25m (5m*5) and 20m (5m*4), respectively. It illustrates that the coverage percentage approaches 100% when the number of small cells with radius 25m exceeds 30.

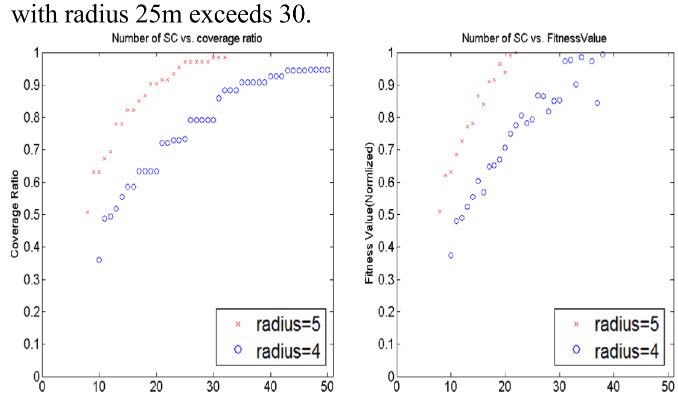


Figure 11 The coverage percentages v.s. numbers of small cells with different radius

Practically, the operator may need to achieve a target coverage percentage of a communication dead zone. Figure 12 shows the numbers of the required small cells to achieve the desired coverage percentages.

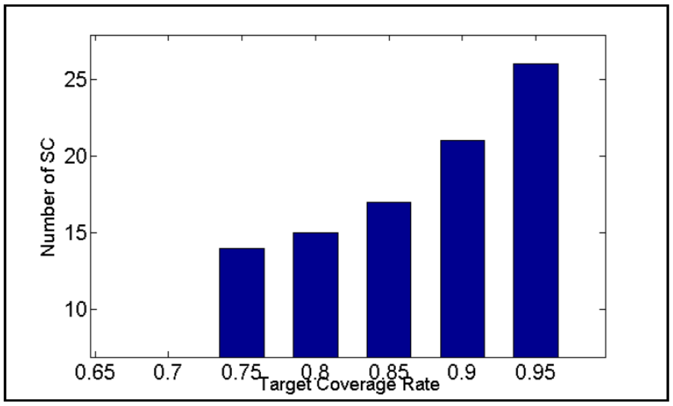


Figure 12 Numbers of required small cells v.s. target coverage raios

In metropolitan area, the deployment cost of small cell may vary from location to location, i.e. CAPEX, due to different construction, environment, engineering, negotiation, etc.. If the deployment cost is critical and needed to be taken into consideration, the proposed placement algorithm can be adapted by slightly modifying the calculation of fitness value to take the deployment cost into consideration.

For example, assuming the above communication dead zone is divided into 9 different areas with different deployment costs as shown in Figure 13. The deployment costs of the small cells in the yellow, the central light-green, and deep-green areas are assumed to be 1, 3, and 2, respectively. Thus, the above obtained fitness value shall plus the deployment cost depending the placement location of the small cell. We compare the results of the placements of small cells for the effect when the deployment cost is considered in the fitness value.

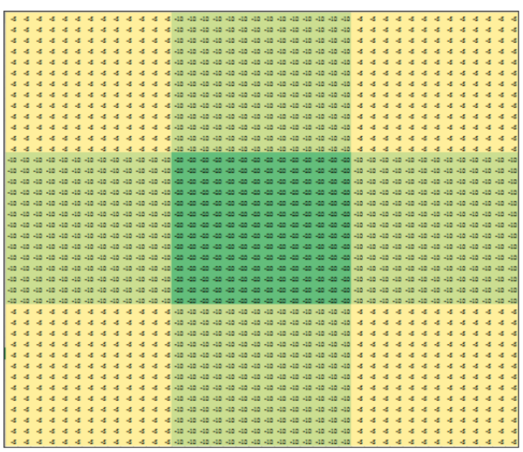


Figure 13 Communication dead zone with different deployment costs

Figure 14 compares the initial placement of small cells and the results of the proposed PSO based algorithm without and with the deployment cost consideration by deploying 6 small cells. Figure 14 (b) is the result of the original PSO algorithm and Figure 14 (c) provides the result when the deployment cost is considered. Thus the fitness value is applied in the proposed PSO scheme. The results indicate that, although one small cell is still placed in the central deep-green area, the proposed scheme can avoid placing the small cell in the high cost area when the deployment cost is considered. Table 2 compares the coverage percentage, cost, and the coverage gained for each unit of cost of the scheme with and without the deployment cost consideration in each iteration of the PSO procedure. It clearly shows that the coverage saturates from the third iteration when the proposed scheme does not consider the deployment cost. However, when the proposed scheme takes the deployment cost into consideration, it still tries to find the proper locations for small cells. And, at the fifth iteration, its placement achieves a lower cost while the coverage is over 40%. Although the coverage of the scheme, which considers the deployment cost, may be a little less than the original proposed scheme, the CAPEX may be critical in some practical situations.

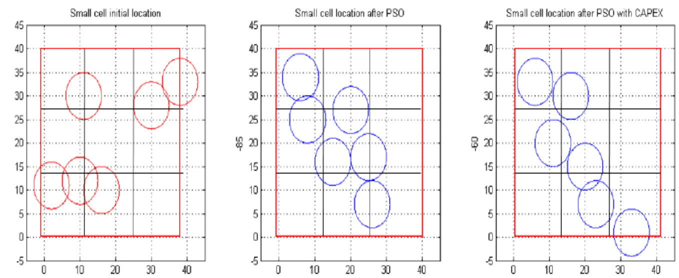


Figure 14 Small cell deployment in different deployment cost area

Table 2 Comparison for the proposed scheme with/without deployment cost consideration

Iteration	Without deployment cost			With deployment cost		
	Coverage	Cost	Cove../Cost	Coverage	Cost	Cove./Cost
1	45.89%	65	0.71	41.03%	75	0.55
2	43.34%	80	0.54	42.31%	65	0.65
3	45.49%	75	0.61	45.65%	85	0.54
4	45.65%	75	0.61	37.21	60	0.62
5	45.65%	85	0.54	41.91%	60	0.70

V. Conclusions

The deployment of small cells provides a appropriate way to enhance the coverage of communication dead zone and increase the network capacity. However, it is not easy to place the small cells properly expecially when the shape of the communication dead zone is irregular such as in metropolian area. In this paper, we propose a systematin approach to deal with the small cell placement issue based on the heuristic concept of PSO. By properly designing the adaption function to obtain the fitness value in each round of the PSO process, the proposed scheme shows that it tries to seek for the proper locations for small cells to minimize the cost while maintaining the high coverage. The proposed scheme is applied for a practical dead zone environment of Taipei City to examine its effectiveness. The experimental results show that the proposed scheme can properly allocate the small cell so as to enhance the coverage over the dead zone. Furthermore, from the CAPEX point of view, the deployment cost can be considered by adjusting the fitness function and the experimental result also shows the effectiveness in dealing with this tradeoff issue. During our study, the initial placement may affect the achieved coverage and current scheme does not properly consider the effective initial placement and it is our ongoing study issue.

ACKNOWLEDGMENT

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