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User-centric JT-CoMP for High Altitude Platforms

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***Abstract*—This paper investigates how user-centric joint transmission coordinated multipoint (JT-CoMP) can be implemented for High Altitude Platform (HAP) systems to best enhance the user experience at the edge of coverage of HAP cells, along with the overall performance of the system. In CoMP, there is a known trade-off between carrier to interference plus noise ratio (CINR) gain and loss of capacity delivered to users. It is shown that implementation of an appropriate bandwidth allocation scheme for a CoMP region can enhance bandwidth efficiency and contribute to determining the optimal Power Level Difference (PLD). Using the right PLD value will minimise the trade-off between CINR levels and the capacity delivered to users. Typically, a PLD of 9 dB will maximise the overall mean capacity.**

Keywords—CoMP; user-centric; interference; HAP; resource allocation

I. INTRODUCTION

High Altitude Platforms (HAPs) are an effective way to deliver wireless communication services, such as cellular and broadband services, as an alternative to conventional terrestrial infrastructure. HAPs are either airships or aircraft operating in the stratosphere (at an altitude of 17 – 22 km) [1, 2]. Their high altitude provides a higher probability of achieving Line of Sight (LoS) connectivity, with a single HAP capable of delivering potentially hundreds of spot beams [3]. Each of these spot beams can form a cell, and hence a HAP is capable of delivering many aspects of a wireless communication service, thereby serving a greater number of users with much less infrastructure compared to an equivalent terrestrial system. HAP technologies are currently maturing with the involvement of large businesses like Facebook and Airbus. Facebook's Aquila successfully completed its second flight test on May 22nd 2017 [4], but now Facebook has decided use third party aircraft. It will use Airbus' aircraft to undertake telecom trials towards end 2018. Airbus has also scheduled a first full scale flight for their Zephyr T in 2018 [5], while AeroVironment Inc., a global leader in unmanned aircraft systems (UAS) recently announced a joint venture to fund development and production of solar-powered high-altitude unmanned aircraft systems with a contract value of $65 million [6].

CoMP is an emerging approach that was introduced by the third generation partnership project (3GPP) in Release 11 [7] to mitigate cell-edge interference and as a result improve the capacity of cell-edge users. The benefit of CoMP is not only to eliminate interfering signals but also to convert the unwanted signals into useful signals. In this work, the focus is on joint transmission CoMP (JT-CoMP) where two or more cells cooperate to send the same data simultaneously to an intended user. Synchronization between the cooperating cells will be required to perform JT-CoMP.

The purpose of this paper is to extend the application of JT-CoMP to HAP based systems, and show how JT-CoMP can be used on a HAP system to improve the capacity of the users at the edge of coverage of HAP cells, which are formed using highly directive beams generated using a phased array antenna on the HAP. The paper will also find the best Power Level Difference (PLD) to determine suitable users who would benefit from using CoMP in the overlap regions. HAPs can deploy multiple beams at the same time with each beam reusing the same spectrum which causes interference between the cells as shown in [3]. The users at the cell edge are the furthest from the boresight of a beam (center of the cell) so that they have the lowest received signal level, and at the same time are the closest to the neighboring cell which is the source of interference. These factors make such users vulnerable in terms of poor Carrier to Interference plus Noise Ratio (CINR). Just as in terrestrial systems, applying CoMP will increase the CINR of those affected users, but due to the interconnected layout of HAP cells, there is a trade-off in that the users will be allocated less bandwidth compared to a traditional scheme where CoMP is not applied. To solve this issue, we present a bandwidth allocation scheme for CoMP that not only improves the CINR, but also increases the capacity of the cell-edge users.

This first time application of CoMP to a HAP system exploits a unique advantage of HAPs in that the designer can have much tighter control over the overlapping area compared with terrestrial systems, which is governed largely by the propagation environment, so this provides another way to enhance CoMP performance in addition to appropriate selection of the PLDs. HAP systems also benefit from easier methods of synchronization between cells, given that all the HAP beams are physically within the same system for both uplink and downlink transmission, while it is still possible to map the formed cells on to physical eNodeBs.

There is no previous work dealing with CoMP for HAPs, unlike with terrestrial wireless networks where methods that reduce cell-edge interference have been considered. Most of the reported research work on CoMP in the literature is focused on user-centric CoMP clustering where a user selects its own serving base station(s). In terrestrial CoMP networks, user-centric clustering and resource allocation are often tackled separately. For example, the authors in [8] propose a user-centric clustering approach in order to reduce cell-edge interference for single-tier networks. The proposed user-centric approach is compared against the traditional static clustering approach and the results show that the user-centric approach provides better cell-edge throughput as well as improved average user throughput. Another approach that utilises CoMP to address cell-edge interference in a dense network is proposed in [9]. This work proposes a user centric clustering approach where users can determine their potential serving base stations based on the average path loss. Then, based on an objective function, users select their cooperative base stations so that the normalized goodput is maximised. The obtained results demonstrate that CoMP can significantly enhance network coverage and the throughput of cell-edge users. In [10], a user-centric approach has been proposed to reduce cross-tier interference in heterogeneous networks that consist of macro and pico base stations. In the proposed approach, a user can operate either under CoMP or non-CoMP modes. A user chooses to operate under the non-CoMP mode if the second strongest received signal is not sufficiently strong compared with the received power from the best serving base station. On the other hand, a user chooses to operate under CoMP mode if the powers received from the strongest and second strongest base stations are comparable.

Recently, the authors in [11] propose a user-centric clustering CoMP algorithm to balance the load in dense multi-tier networks. Based on the proposed approach, a user forms its own set of cooperative base stations by selecting the best m base stations that provide the strongest received power, provided that the value of m is not larger than the maximum cluster size. In [12], a user-centric CoMP clustering algorithm is proposed with the objective of optimising energy efficiency in heterogeneous networks. In the proposed clustering algorithm, a user cluster is formed by selecting the set of base stations that provide sufficiently strong Received Signal Strength (RSS). There is some research that has considered joint user-centric and resource allocation in terrestrial CoMP networks [13]. They investigated the performance of JT-CoMP considering both user-centric clustering as well as resource allocation in multi-tier networks with the objective of balancing the load among different tiers. Here in this paper, the focus is on JT-CoMP which considers joint user-centric clustering and radio resource allocation in HAPs.

This paper is organized as follows: in section II, the system model is described in detail. The performance of CoMP implemented on a HAP is presented in section III, and lastly, the conclusion in section IV.

II. System Model

In this section the system model, performance metrics, and the proposed scheme are explained in detail.

A. System Layout

The system layout shown in fig. 1 consists of a HAP that is located at an altitude of 20 km above ground and the center of a 30 km radius service area, with overlapping HAP cell footprints, Non-CoMP user equipment (N-UE), and CoMP user equipment (C-UE). Users are randomly distributed across the service area according to a uniform distribution. The type of user will be determined by the PLD. The HAP is considered to be equipped with a 25x25 element phased array antenna with half wavelength spacing between the elements, to perform beamforming, which can form a 22 cell footprint based on the pointing scheme from [3] which is determined using a K-means Clustering scheme. Clusters are formed by selecting groups of users based on the carrier to noise ratio (CNR) level of each user. The CNR levels of users need to be at least equal or higher than the CNR threshold. Then the newly formed clusters need to obey a restriction (CINR threshold based on [3]) so that there will be boundaries between one cluster and another. This process makes sure that the cluster forming cells will not overlap and cause high interference. These are then mapped on to the serving cells. The system is modelled with a full-buffer traffic model, thus the performance of snapshots is acquired.

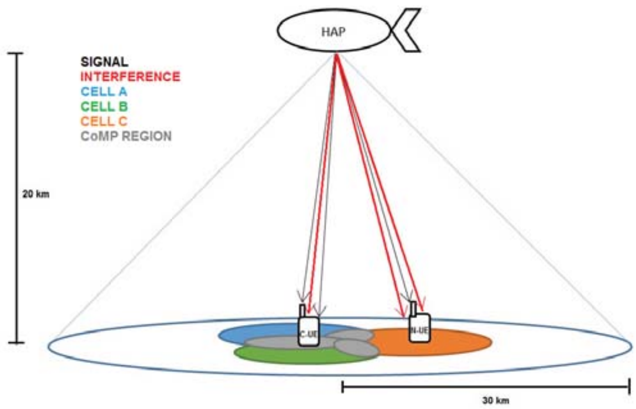

Fig.1. HAP cell footprints and the overlapping region as a CoMP region

B. Power Level Difference (PLD)

Received power level, P_R at the user equipment (UE) can be measured as follows:

$$P_R = \frac{(P_T.G_T.G_R)}{P_L} \quad (1)$$

Where P_T is the transmit power emitted by the HAP, G_T is the HAP antenna gain, G_R is the receiver antenna gain, while P_L is path loss which will be explained later in (5).

In this work, the set of cooperative cells (Cs) that serves a general user is defined as follows:

$$Cs = \begin{cases} \{x_1\} & if\ \frac{P_{R_2}}{P_{R_1}} > \gamma \quad (non-CoMP) \\ \{x_1, x_2\} & if\ \frac{P_{R_2}}{P_{R_1}} < \gamma \quad (CoMP\ two\ ways) \\ \{x_1, x_2, x_3\} & if\ \frac{P_{R_2}}{P_{R_1}}\ and\ \frac{P_{R_3}}{P_{R_1}} < \gamma \quad (CoMP\ three\ ways) \end{cases} \quad (2)$$

Where x_1, x_2, x_3 are the cells that provide the strongest, second strongest, and third strongest received power to a typical user, respectively, while $P_{R_1}, P_{R_2}, P_{R_3}$ are the received signal levels from the strongest, second strongest, and third strongest cells to a user respectively, and γ is the power level difference (PLD) threshold that determines how strong or how weak the second strongest received power is as compared with the strongest received power. Based on (2), a user operates in the CoMP mode if the received power from the second strongest base station is up to γ times less than the received power from the strongest cell; otherwise a user operates under the non-CoMP mode. The CoMP user will again being tested if the third strongest receive power is up to γ times less than the strongest cell; the user will belong to three ways CoMP region, otherwise, it stays in a two way CoMP region.

C. Performance Metrics

To measure the signal and interference levels experienced by the users in the system for the downlink transmissions, we consider established and widely used metrics. We simulate the system based on the scenario in fig. 1, and we use Carrier to Interference plus Noise Ratio (CINR), and Channel Capacity per User (C). CINR is divided into two categories which are the CINR Non-CoMP, and CINR CoMP. These metrics can be described based on (1) and (2) as follows:

$$CINR = \frac{\sum_{j \in Cs} P_{R_j}}{P_N + \sum_{k=no.of\ cells;\ k \notin Cs} P_{I_k}} [11] \quad (3)$$

Where, P_N represents the noise power, and P_I represents the interference powers which will be added up based on how many interference sources we have in the system. For (3), the number of wanted signals (P_R) added depends on (2) which determines whether users will operate as Non-CoMP, two way CoMP, or three way CoMP. The number of signals added will be one, two, and three respectively, whilst the rest of the signals not included in $\sum P_R$ is the interference powers, $\sum P_I$.

The Channel Capacity per User measure is determined from:

$$C = \begin{cases} 0, & CINR_{dB} < 1.8 \\ \alpha\ B\ log_2(1 + CINR), & 1.8 \le CINR_{dB} \le 22\ [14] \\ \alpha\ B\ log_2(1 + 158.5), & CINR_{dB} > 22 \end{cases} \quad (4)$$

Where α is the attenuation that is set to 0.63, B is the bandwidth per channel, and $CINR$ is in linear form.

Free Space Path Loss (FSPL) is considered for the HAP, given high minimum elevation angles, resulting in high probability of line of sight connectivity.

$$\text{FSPL} = 20\log10(d) + 20\log10(f) + 92.45 \quad (5)$$

Where d is distance between transmitter and receiver in km, and f is the carrier frequency in GHz. The constant results from the use of distance in kilometres, and GHz for frequency.

D. Bandwidth Allocation Scheme

In this work, as previously discussed in (2) there are two types of overlapping region known as CoMP regions. Based on fig.2, the overlap region of cell X and Y is defined as xy and yx. The xy region represents the region where the users associate with cell X, and cell Y is the secondary cell. The yx region represents the opposite of xy. The xyz region is part of the overlapping area involving cell x, y, and z. It is a region where the users in the xy and yx region receive the third signal from cell z. These representations apply to all other regions in fig.2. The two types of overlapping region are defined as follows:

1. *Two way CoMP region – An overlapping region invloving two cells for example as seen in fig.2. It is formed from the xy and yx regions.*
2. *Three way CoMP region – An overlapping region involving three cells as seen in fig.2. It is formed from the xyz,yzx, and zxy regions.*

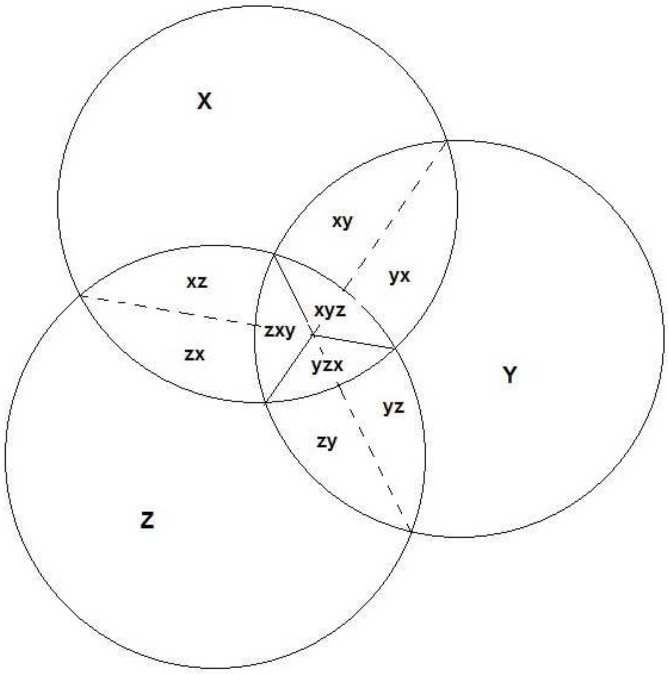

Fig.2. Overlapping cells diagram

Bandwidth allocation is non-trivial, particularly when implementing CoMP in HAP systems because of the high degree of tesselation and overlap. The cells that overlap will have to agree to allocate exactly the same bandwidth for the overlapping CoMP region. This allocated bandwidth cannot be reused by the involved cells. One way to allocate the bandwidth to CoMP and Non-CoMP regions is to allocate X% of the available bandwidth to CoMP region while the remainder is allocated to the Non-CoMP region. This will result in a inefficient use of bandwidth because the number of users in both regions is likely to be dissimilar. To counter this problem, our strategy is to take explicit account of the number of users belonging to the Non-CoMP and the CoMP regions when deciding how much bandwidth should be allocated to the two way CoMP region.

To determine the bandwidth allocation for the three way CoMP region, the number of CoMP users in the two way and three way CoMP regions is considered. Based on fig.2, the bandwidth allocation for the two way CoMP region (BA_2) and three way CoMP region (BA_3) can be calculated as follows:

$$BA_2 = \frac{Total\ Bandwidth}{No.of\ users\ in\ cell\ x} \times No.of\ users\ in\ the\ xy\ region \quad (6)$$

$$BA_3 = \frac{BA_2}{No.of\ users\ in\ xy\ \&\ yx} \times No.of\ users\ in\ the\ xyz\ region \quad (7)$$

III. Results And Discussion

A simulation has been carried out based on the system layout shown in fig.1 above, with the parameters as presented in table 1. The simulation is repeated with varying PLD values from 0 – 19 dB in which will determine how many users are included in the CoMP regions. Fundamentally, CoMP will directly enhance the CINR level of a user, but its use will reduce the bandwidth allocation per user. This will decrease overall capacity will to start decrease when the reduced bandwidth is not compensated for by the enhanced CINR arising from CoMP.

TABLE I. SIMULATION PARAMETERS

Parameter	Value
HAP Transmit Power	40 dBm
Receiver Antenna Gain	0 dBi
HAP Antenna Gain (Boresight)	27.9 dBi
Carrier Frequency	2.6 GHz
Noise Power	-130 dBW
CNR Threshold	9 dB
CINR Threshold	0 dB
Number of Users	2900

Fig.3 shows the relationship between the mean CINR level and the mean capacity of the users. It can be seen that the CINR level is approximately proportional to PLD level, so as the PLD increases, the CINR increases. This is because, according to fig. 5 when PLD is increased, more users are included in the CoMP region, so more users will experience an increase in their CINR due to receiving two or three signals. However, the capacity, *C*, which has direct involvement with the bandwidth allocated to the users (see equation (4)), declines after reaching 9-11 dB PLD. According to fig. 4, Non-CoMP user capacity and CoMP user capacity do not show any sign of decreasing, but the overall user performance still decreases after 11 dB PLD. This is because, in relation to fig. 5, the percentage of CoMP users increases as the PLD increases. After 11 dB PLD, the CoMP user group becomes big enough to provide a significant negative contribution to the overall system capacity as a whole, resulting in the drop in overall capacity per user, as shown in fig.3.

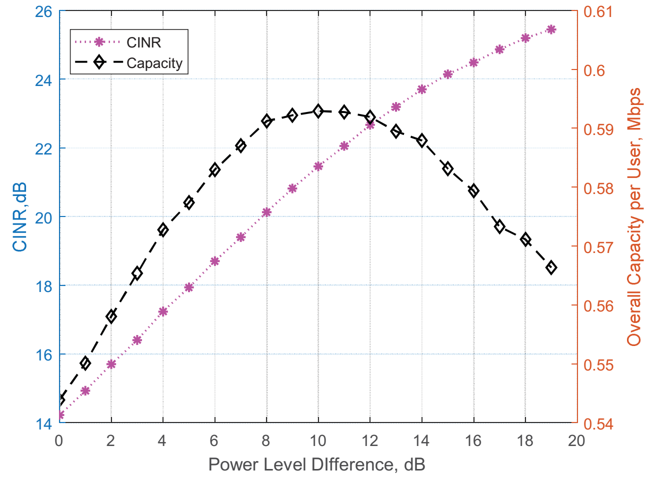

Fig.3. Mean CINR and overall capacity per user across PLD levels

The performance in terms of mean capacity level is broken down into Non-CoMP and CoMP user capacity levels, an average performance of the whole group, and the 5th percentile is shown in fig. 4 below. As seen in fig. 4, the mean and the 5th percentile of Non-CoMP user capacity keeps increasing. This is because some Non-CoMP users are allocated more bandwidth after CoMP is applied to the system. The mean CoMP user capacity shows only a slight improvement as a result of three way CoMP activation. The reason behind this is because a certain bandwidth will be taken from the bandwidth allocated beforehand to the two way region and reserved for the three way region. This will result in some limit to the bandwidth for the CoMP users. To balance this trade-off between CINR and capacity, an optimum value of PLD must be decided.

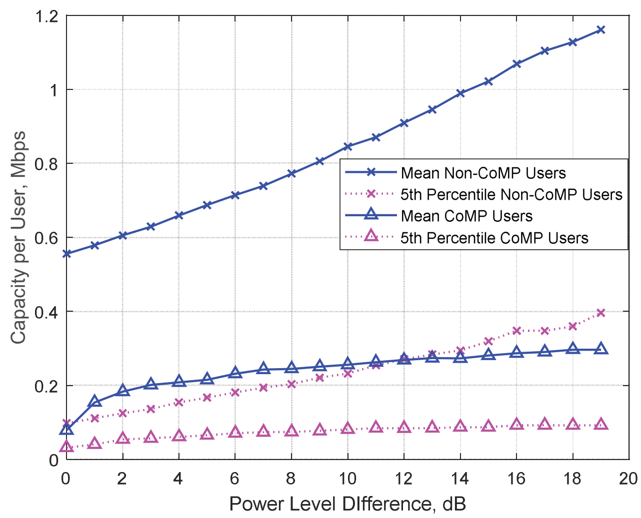

Fig.4. Comparison of capacity level between Non-CoMP and CoMP users

While in fig.5 shows the percentage of CoMP and non-CoMP users when the PLD is increased. It can be seen that the percentage of CoMP users keeps increasing, while the percentage of non-CoMP users does the opposite. This is because when the PLD increases, the acceptance range of received power level becomes larger, thus allowing more users into the CoMP region.

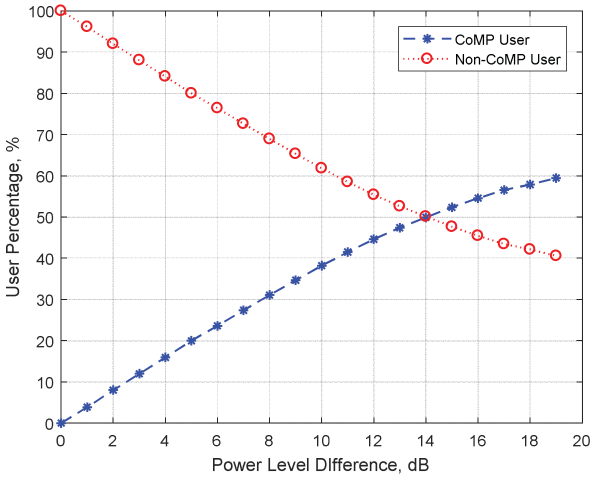

Fig.5 The percentage of CoMP and Non-CoMP users across PLD levels

We present a cumulative distribution function (CDF) of 3, 9, and 19 dB PLD overall capacity per user performance as shown below in fig. 6 to find the optimum value of PLD in this scenario. As shown in fig. 6, the higher the PLD, the greater the number of users are included in the CoMP region, so 3, 9, and 19 dB PLD performances represent small, medium, and large CoMP regions respectively. When the 3 dB PLD performance with the lowest CoMP user percentage is compared to Non-CoMP performance it shows a slight improvement. For 9 dB PLD, it can be seen that all users steadily increase their capacity compared to Non-CoMP, which means that all users gain benefits from CoMP. As the percentage of CoMP users increase with a 19 dB PLD, it is shown that only approximately 20% of the users benefit from CoMP, while the rest have the capacity lower than Non-CoMP. This is caused by more bandwidth sharing being required among the CoMP users which results in reduction of their capacity.

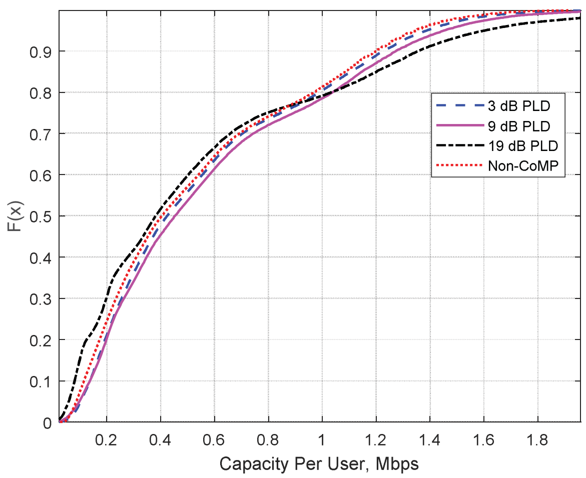

Fig.6. CDF graph of users' capacity of the system

In fig. 7 contour plots for both scenarios; without CoMP and after CoMP are presented for comparison to show the effect of implementing CoMP spatially. It can be seen that in (a), the region in between most HAP cells (overlapping region) is dark in colour which indicates that the users are suffering and the user capacity is close to zero. However, after CoMP was implemented in the system it can be seen that the overlapping region in between the cell (CoMP region) is brighter in colour. It means that the interference problem at the edge of the cells is successfully solved. The 22 beams shown is an example which covers only the high density user areas to illustrate the effect of CoMP rather than maximizing overall coverage. Areas that are white are not covered. Note that users are randomly distributed across the service area.

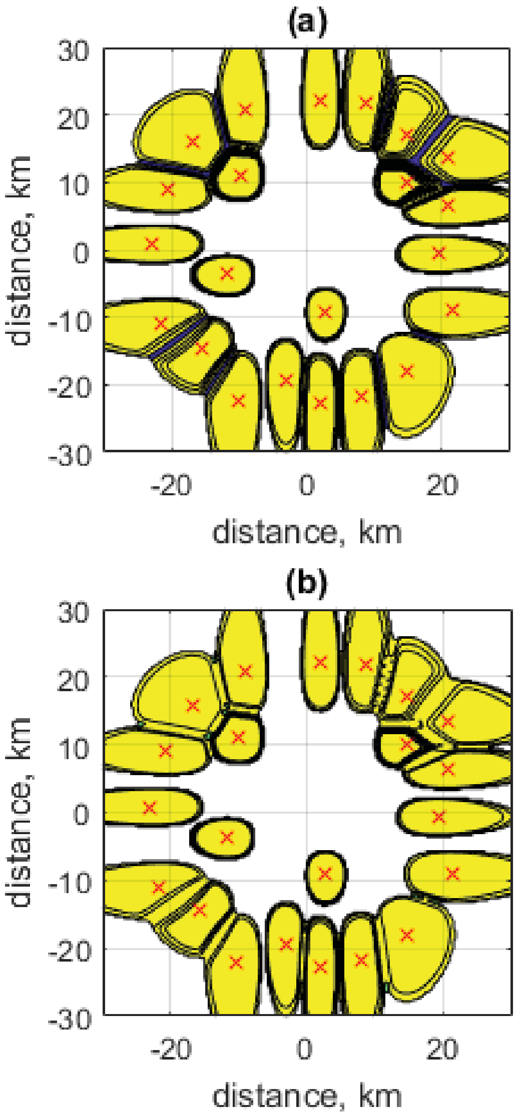

Fig.7 Contour plot of 22 beams over 30 km radius service areas: (a) Without CoMP (b) After CoMP with 9 dB PLD

V. CONCLUSION

In order to enhance the wireless performance in future HAP networks, this paper has investigated how user-centric JT-CoMP can be implemented for a HAP system to improve user CINR levels and capacity at the cell edge as well as the performance of overall users in the system. A range of 0 – 19 dB power level differences (PLDs) have been considered which determines how many users will be included in the CoMP region. We have shown that as the CoMP user percentage increases, the overall CINR level will keep increasing, but there is a trade-off with capacity. There is an optimum power level difference which will maximize the capacity for a particular HAP spot beam (cellular) scenario. Typically, a power level difference of 9 dB will maximise overall mean capacity.

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