

## The Performance Investigation of Cooperative Multicast with CP Combining in Hexagonal Network and Small Cell Network

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**Abstract.** With the rapid development of broadband mobile data services, small cell networks are more and more popular to enable high capacity wireless access. Unplanned small cells network, which is described as random network (RN), brings new characteristic different with conventional hexagonal network (HN). This paper mainly investigated the performance of cooperative multicast in HN and RN respectively, where CP combining signal processing is employed. The tractable expressions about the coverage and signal to noise ratio (SNR) distribution of cooperative multicast are derived. It is illustrated by analyses great gain is obtained through cooperation in both HN and RN and the BS power needed to ensure 95% coverage reduced by about 30% when only two BSs are employed to cooperative multicast. Since, given the same BS transmission power and BS distribution density, HN will be energy efficient than RN. Therefore a larger number of BSs with low transmission power should be deployed in RN so that it is possible to be energy efficient as HN.

### Introduction

With the rapid development of mobile applications, high data rate is needed to meet the demands of subscribers. It is expected that the number of mobile broadband subscriptions will be 9 billion by the end of 2018 <sup>[1]</sup> and the data traffic will grow over 300% by 2017 to 21 Exabyte <sup>[2]</sup>, which presents great challenges to the cellular networks. New technologies are needed to enable high data rate access. Recently years, small cell network shows great talent to meet the capacity demands and had attracted lots of attention in both industrial and academy. Different with conventional hexagonal network (HN), small cell network is based on random network (RN) topologies and Poisson point process (PPP) is widely used to mode the distribution of small cells <sup>[3-5]</sup>. Paper <sup>[3]</sup> firstly compared the performance of HN and RN, the analyzes illustrated that RN is the same accurate as HN to describe the real network and it is believed that PPP model will be much more suitable to capture the characteristic of 4G network <sup>[4]</sup>. <sup>[5]</sup> studied the spectrum allocation and femto access polices in two-tier RN <sup>[5]</sup> and the corresponding success probability for each tier is derived. The energy efficiency problem in RN is studied in <sup>[6]</sup> where a tradeoff scheme of energy efficient cellular networks with small cells is proposed. These papers mainly pay much attention to single cell and didn't consider the cooperation of BS. Paper <sup>[7]</sup> investigated the outage probability of multi-cell CoMP network with zero force beamforming technology. A user-centric adaptive clustering method is proposed in <sup>[8]</sup>, which is outperforms than static clustering scheme <sup>[9]</sup>. In summary, a few literatures investigated the cooperative in RN by so far.

Moreover, It is noted that mobile video has exceeded half of the total mobile data traffic in 2011 <sup>[10]</sup> and is expected to grow with a speed of 60%. As one spectral efficient method for video services, multicast transmission plays a key role in cellular networks. It had been defined by the third generation partnership project (3GPP) <sup>[11]</sup>. The signal processing for BS cooperative multicast is different with unicast since many cooperative BSs multicast the same message simultaneously and the mobile station (MS) could receive multiple copies of the signal from different BSs. Assuming the CP is long enough to combine all the signals arriving within the cyclic prefix (CP) duration, thus a stronger signal could be constructed in BS cooperative multicast, which is known as CP combining.

Therefore, this paper focuses on multicast service in RN aiming to provide the same performance as that in HN. We analyze the performance of BS cooperative multicast, where one MS is served by more than one BSs and the CP combining signal processing is employed. The close expression about the coverage and signal to noise ratio (SNR) distribution function in RN and HN are obtained respectively, which significantly simplified the complex simulations since the influence of different parameters could be easily presented by this expression.

The rest of the paper is organized as follows. Section 2 describes system model as well as CP Combining signal processing. Next, in Section 3, coverage performance analysis is carried out with BS cooperative multicast. Section 4 presents numerical results. Finally, conclusions are drawn in Section 5.

## System description

An orthogonal frequency division multiplexing (OFDM) based downlink transmission cellular system is investigated, where a single antenna is assumed [12]. Suppose there are  $N$  cooperative multicast BSs and they all transmit the same multicast data simultaneously with the power  $P_{BS}$ , thus one MS could receive multiple copies of the signals. Moreover, assuming that the length of CP is longer than the maximum delay of the equivalent multipath channel, then all the signals arriving within the CP duration could be added up to construct a stronger signal. Therefore after synchronization and FFT at the destination, the received signal at MS  $k$  is given by

$$\begin{aligned} Y_k &= \sum_{i=1}^N \sqrt{P_{BS}} \cdot A_i \cdot D_{i,k}^{-\gamma} H_{i,k} x + \eta_k \\ &= \sqrt{P_{BS}} H_k x + \eta_k \end{aligned} \quad (1)$$

where  $A_i \cdot D_{i,k}^{-\gamma}$  represents the path loss from the BS  $i$  to MS  $k$ ,  $A_i$  is a constant,  $D_{i,k}$  stands for the distance between BS  $i$  and MS  $k$  and  $\gamma$  is the path loss parameter.  $H_{i,k}$  is the Rayleigh channel fading with an average power of 1 and follows systemic complex Gaussian distribution.  $x$  represents the transmitted symbol with unit power and  $\eta_k$  is the zero mean Gaussian noise with a variance of  $\sigma^2 = N_0 B$ , where  $N_0$  is the power spectrum density of the Gaussian noise and  $B$  is the

cellular system bandwidth. Moreover,  $H_k = \sum_{i=1}^N A_i \cdot D_{i,k}^{-\gamma} \cdot H_{i,k}$  is the channel impact from all the cooperative BSs including path loss and relay fading. Therefore, the SNR of  $Y_k$  is given by  $SNR_k = P_{BS} |H_k|^2 / \sigma^2$ .

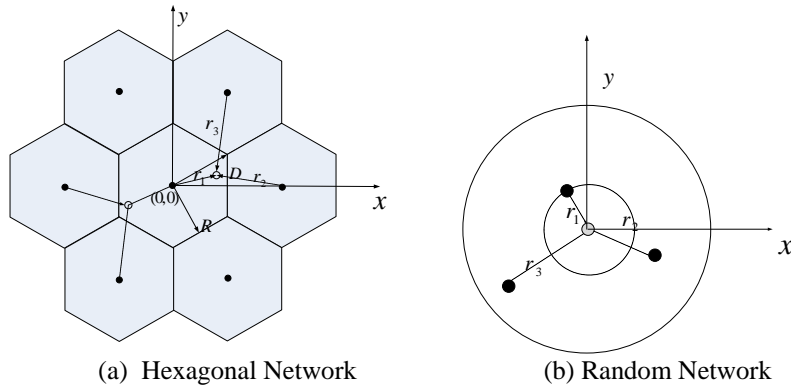


Figure 1. System Description of Hexagonal Network and Random Network

Assume that the multicast data rate is  $R_m$ , then the required  $SNR_m$  can be obtained as  $SNR_m = 2^{R_m/B} - 1$  according to Shannon theory. Therefore, the SNR of received signal  $SNR_k$  must

be no less than  $SNR_m$  such that MS  $k$  could successfully decode the multicast data. Moreover, it is further supposed that all MSs are uniformly distributed in the hexagonal cell with a radius of  $R$ , and we model the small cell distribution with PPP of density, which represents the average number of small cell on unit area. Since the coverage area of one cell with radius  $R$  is  $6R^2/\sqrt{3}$  in HN [13], the parameter  $\lambda$  is set to be  $\left(\frac{6R^2}{\sqrt{3}}\right)^{-1}$  in RN for purpose of comparison with HN.

## Bs cooperative multicast

### Hexagonal network.

The coverage of cooperative multicast is much more complicated due to the CP combining signal processing. It is assumed that one MS  $k$  is served by the nearest  $N$  BS which are labeled by BS 1 to BS  $N$ , as shown in Fig 1(a), the success probability of MS  $k$  is impact by the distance vector  $z = \{r_1, r_2, \dots, r_N\}$  where  $r_i$  stands for the distance between MS  $k$  and the  $i$  th cooperative BS and meet  $r_1 < r_2 < r_3 \dots < r_N$ . Thus as described before, the success probability of MS  $k$  could be presented as:

$$P(SNR_k \geq SNR_m) = \exp\left(-\frac{SNR_m \cdot \sigma^2}{P_{BS} \cdot \sum_{i=1}^N A_i \cdot r_i^{-\gamma}}\right) \quad (2)$$

Next, consider the fact that the hexagonal cell is systematic, the average success probability (coverage) in the cell is the same with that of a triangle area, such as Region D (as shown in Fig1 (a)). Assuming that the position of BS 1 is set to be the origin (0, 0) and the axis are built as Fig 1 (a), the other cooperative BS coordinates could easily be obtained. So for one MS of coordinates (x, y), the distance between MS and cooperative BS  $i$   $r_i$  is a function of  $x$  and  $y$  and thus the average success probability of MS which is uniformly distrusted in Region D could be given by:

$$\begin{aligned} S_{HN}^C &= \iint_D P(SNR_k \geq SNR_m) \cdot f_D(x, y) dx dy \\ &= \iint_D \exp\left(-\frac{SNR_m \cdot \sigma_{noi}^2}{P_{BS} \cdot A_1 \cdot \sum_{i=1}^N r_i(x, y)^{-\gamma}}\right) \cdot \left(\frac{R^2}{2\sqrt{3}}\right)^{-1} dx dy \end{aligned} \quad (3)$$

where  $f_D(x, y) = \left(\frac{R^2}{2\sqrt{3}}\right)^{-1}$  is the pdf of one MS with coordinate (x,y) in region D. Since MS is uniformly distributed in region D, the pdf is a constant and is only related with the area of region D. Thus the coverage of cooperative multicast in HN is derived.

### Random network.

This subsection focuses on average success probability of MS in random network. With the same assumption that MS  $k$  is served by the nearest  $N$  BSs and the distance vector is  $z = \{r_1, r_2, r_3, \dots, r_N\}$ , where  $r_1 < r_2 < r_3 < \dots < r_N$ , therefore the average success probability in the cell could be expressed as:

$$S_{RN}^C = \int P(SNR_k \geq SNR_m) f(z) dz \quad (4)$$

where  $f(z)$  is the joint probability distribution function of vector  $z$  and the key is to obtain the joint pdf of the distance vector  $z$ .

According with the property of PPP<sup>[14]</sup>, the joint pdf of  $\{r_1, r_2, \dots, r_N\}$  could be given by:

$$f(r_1, r_2, \dots, r_N) = \exp(-\lambda \pi r_N^2) (2\pi\lambda)^N \prod_{i=1}^N r_i \quad (5)$$

Therefore, the average success probability could be given by:

$$\begin{aligned} S_{RN}^C &= \int P(SNR_k \geq SNR_m) f(z) dz \\ &= \int_{r_{N-1}}^{\infty} \int_{r_{N-2}}^{\infty} \dots \int_0^{\infty} \exp\left(-\frac{SNR_m \cdot \sigma_{noi}^2}{P_{BS} \cdot A_1 \cdot \sum_{i=1}^N r_i^{-\gamma}}\right) \exp(-\lambda \pi r_N^2) (2\pi\lambda)^N \prod_{i=1}^N r_i dr_1 dr_2 \dots dr_N \\ &\quad \underbrace{r_i^2 = x_i}_{r_i^2 = x_i} \int_0^{\infty} \int_0^{r_3} \dots \int_0^{r_2} \exp\left(-\frac{SNR_m \cdot \sigma_{noi}^2}{P_{BS} \cdot A_1 \cdot \sum_{i=1}^N x_i^{-\gamma/2}}\right) \exp(-\lambda \pi x_N) (\pi\lambda)^N dx_1 dx_2 \dots dx_N \end{aligned} \quad (6)$$

Given a fixed SNR threshold  $SNR_m$  for multicast services, the corresponding average success probability (or coverage) has been obtained, Moreover, the pdf of SNR in the cell  $f(SNR)$  can also be obtained by derivation of the cumulative distribution function of SNR.

## Performance evaluations

The system parameters are shown in Table I where the radius  $R$  of HN is 1000m. The coverage threshold for multicast is set to be 95%, which means that more than 95% MS should successfully receive the data for multicast services.

Table I: System Parameters

Carrier Frequency	2.5G
Frequency Band $B$	10M
Path Loss from BS to UE $\overline{PL}_{BS} (dB)$	$17.39 + 37.6 \log_{10}(d[m])$
Path Loss parameter $\gamma$	3.76
Noise Power Spectrum $N_0$	-169dBm/Hz
Cell Radius R	1000m
BS power	46dBm
Coverage for multicast	95%

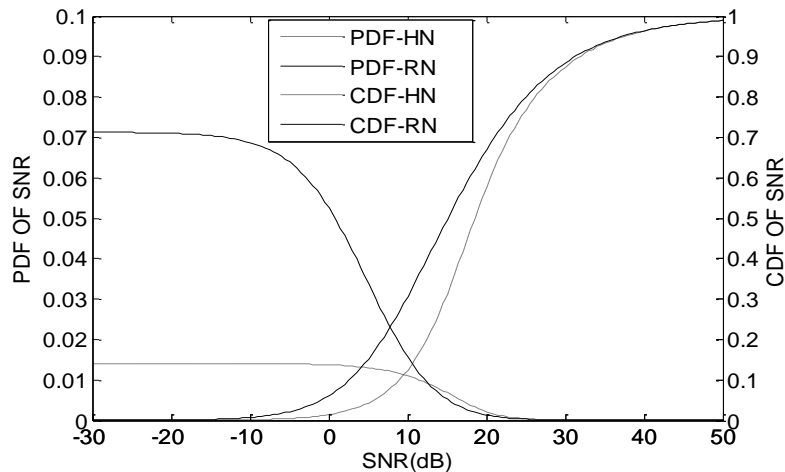


Figure 2. SNR distribution comparison in RN and HN without cooperative multicast

Firstly, the pdf and cdf of SNR in single cell is shown in Fig2 where the BS power is set to be a 46dBm. It can be seen that the pdf has a high value in RN when the SNR is low than about 12dB. Particularly, when SNR is below 0 dB, the pdf value in RN and HN are 0.07 and 0.015 respectively, the value in RN is almost fifth times as that in RN, which means the number of MS with SNR low than 0dB will be fifth times as that in HN. Therefore, RN has a poor performance than HN. The same conclusions could also be obtained through cdf curves where a huge gap could be seen. The reason is that HN could provide more uniform coverage because of the regular deployment of BS.

Next, given the same multicast rate and aiming to provide the same coverage 95%, the BS power needed in HN and RN are shown in Fig.3 as a function of multicast rate  $R_m$ . It can be seen the BS power needed increased with the multicast data rate. Without cooperative multicast, when the data rate is set to be 1.2bps/Hz, 14W will be sufficient to ensure the coverage in HN while RN needs 66W. However, the BS power significantly reduced to 10W and 42W respectively only with two cooperative BSs, whereas 36.4% and 28.6% power are saved compared with the sceneries without cooperation. Thus great improvement can be obtained through cooperation and RN has a larger power reduction through cooperation. Moreover, it can be seen that given the same BS power and BS density, HN has a better performance than RN; therefore, aiming to be energy efficient as HN, large number of the cooperative BSs with low power should be deployed in RN to take advantage of path loss gain and diversity gain. Therefore the total energy could possibly be reduced.

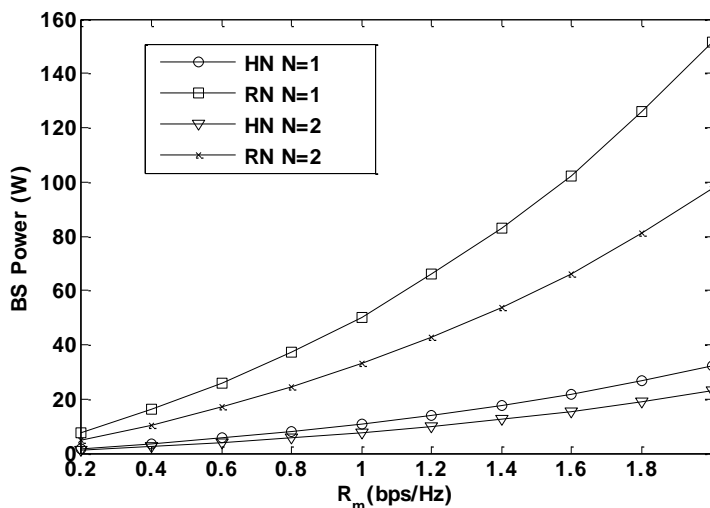


Figure 3. BS power needed to ensue coverage as a function of multicast rate.

## Conclusions

This paper investigated the BS cooperative multicast in HN and RN, where CP combining signal processing is employed. The following conclusions are drawn:

The close expression of BS cooperative multicast in HN and RN has been obtained such that the performance could be evaluated through numerical expression. The coverage is significantly increased through cooperation in HN and RN and the power needed to ensure a given coverage decreased by 30% when two BSs would like to attend the cooperative multicast.

Aiming to be energy efficient as HN, large number of the cooperative BSs with low power should be deployed in RN to take advantage of path loss gain and diversity gain.

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