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Capacity and Interference Analysis for Heterogeneous Mobile Communication Networks

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Abstract

Increasing demand for data traffic in cellular networks has become one of the characteristics of our new lives. However, the spectral efficiency is approaching its theoretical limits. Therefore, further improvements in network capacity require increasing the density of networks. On the other hand, in already existing dense node cellular networks, the gain of cell splitting is extremely limited because of inter-cell interference. Moreover, the high cost of base stations discourages this approach. Therefore, in response to the capacity challenge, the industry is developing a new solution to accommodate the increasing capacity demand. In 4G, LTE-advanced has adopted heterogeneous networks to be the main solution to capacity demand by adding small cells (Pico cells, Femtocells) underlay the large existing cells (micro cells). The novelty of this work is in the integration of RIS with CoMP HetNets under stochastic geometry modeling for single and multi-RIS interference scenarios. Simulation results show that RIS-assisted coordination improves SINR at the cell edge by about 3–4 dB compared to the uncoordinated case. Also, the sum rate increased by around 10–15 bit/s/Hz, in the case without RIS, to nearly 75–85 bit/s/Hz with RIS. To obtain the same BER, the required SNR can be reduced by 5–8 dB by increasing RIS elements.

Keywords

heterogeneous network, Stochastic geometry, interference management, RIS

1 Introduction

The exponential increase in mobile data traffic poses a significant challenge in maintaining spectral efficiency. Traditional methods to improve spectral efficiency are approaching theoretical limits, which require innovative solutions to increase capacity. Heterogeneous networks (HetNets), which integrates various cell types such as macro cell (a very high BS or a Satellite coverage), micro cells (mid-size Base stations, BS), small cells (including pico cell) and small base stations, home base stations (formally known as femtocells), Reconfigurable Intelligent Surfaces (RIS), device to device communications (D2D), and Universal aerial vehicle UAV tethering have emerged as promising methods to face these challenges by allowing more efficient spectrum reuse and increasing network density [1–5].

Despite their potential, the effectiveness of HetNets is constrained by interference in dense cellular networks [2–4]. Recent interference management in the hexagonal grid, while a good model, often suffers from limited network performance due to the complex and dynamic nature of modern wireless communication networks.

Reconfigurable Intelligent Surfaces (RIS) are a revolutionary technology designed to improve interference management and enhance capacity in HetNets. RIS are engineered surfaces with controllable electromagnetic properties that can dynamically modify signal reflections to improve communication quality [6–8]. RIS can significantly improve HetNet performance by intelligently directing the signal and mitigating interference.

Then, the industry has developed and standardized heterogeneous networks to accommodate the increasing demand for data traffic. This is achieved by adding smaller base stations (Micro, Pico, and Femtocells) inside the existing large macro cell, as shown in Fig. 1 [9].

Hybrid RIS-Assisted interferences mitigation has been discussed in [8, 10, 11].

In 5G standards, many service providers have already launched their small cells [1, 11]. A small cell is a low-power, low-cost radio access node that receives licensed and unlicensed spectra and has coverage of several hundred meters. However, microcells may have a range of up

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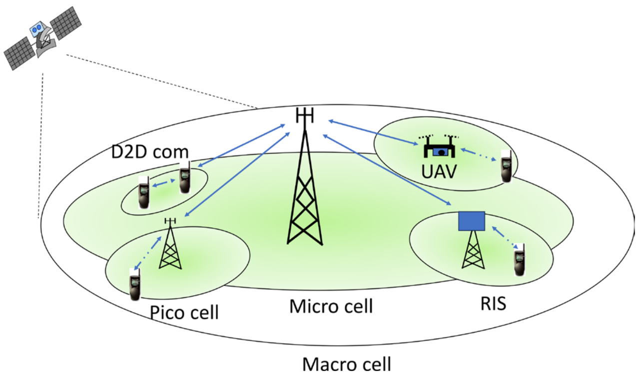

Fig. 1 Architecture of heterogeneous networks with RIS and D2D communications

to several kilometers. More details on base stations in the heterogeneous network are depicted in Table 1.

This paper explores the integration of RIS into heterogeneous mobile networks, focusing on spectral efficiency enhancement and interference management.

Stochastic geometry and the Poisson point process (PPP) will be employed to model and analyze the spatial distribution and performance impacts of RIS in HetNets. Furthermore, the paper delivers advanced interference mitigation methods, adaptive algorithms, and resource allocation strategies that are facilitated by RIS. This way provides a comprehensive framework to optimize the overall performance of HetNet.

The paper contributes the following:

- Integration between RIS and CoMP into HetNets with stochastic geometry modeling
- Novel SINR expressions for RIS-assisted CoMP systems.
- Comparative analysis of interference mitigation strategies, including eICIC, FeICIC, and CoMP.
- Modeling multiple RIS on the performance of interferences in modern wireless communications.

Furthermore, the proposed RIS-assisted interference mitigation framework has a high potential for vehicular communications scenarios, as dynamic topology and dense deployments show a critical challenge. Using the stochastic geometry and coordinated multi-point communications, such a model can be used for high-throughput Vehicle to Everything (V2X) communications in 5G/6G systems.

Table 1 Heterogeneous networks specification [4, 12, 15]

Type of node	Transmit power	Coverage	Access
Micro cell	32 dBm	Few km	Open to all UEs
Pico cell	23 dBm	≤ 100 m	Open to all UEs
Femto cell	≤ 23 dBm	≤ 50 m	Restricted
RIS	-	300 m	Open to all UEs

Despite extensive work on RIS-assisted HetNets and CoMP coordination, current studies often deal with these techniques separately. Furthermore, providing a stochastic geometry analytical framework to capture multi-tier interferences coupling, RIS assisted links with CoMP coordination in the same model needs to be studied. The impact of deploying multiple RIS panels, including inter-RIS inteference remain insuffecient to be characterized in tractable SINR calculations. Therefore, this paper proposes an integrated framework combining RIS, ICIC/FeICIC, and CoMP, and provides sufficient SINR formulation for single and multi-RIS deployments.

The remainder of this paper, Section 2, presents the system model, providing more details for RIS HetNets and the application of stochastic geometry models for different cell sizes. Section 3 discusses interferences between cells, as well as some methods to mitigate them. Section 4 discusses the RIS Interference. Section 5 shows the main results of the paper, and Section 6 summarizes the main findings of the paper.

2 System model

2.1 Network description

Design and analysis of interference management for a multitier cell structure and spatial Distribution in a heterogeneous network, a rigorous yet simple model. However, even in a traditional single-tire cellular network (grid-based, as shown in Fig. 2), interference modeling remains a significantly challenging issue. Applying the conventional interference model used in a regular grid structure requires extensive Monte Carlo simulations. Furthermore, inaccurate results may arise due to unrealistic assumptions [2–4]. This is because base stations no longer follow traditional grid deployment, and their position exhibits a random distribution. The independent deployment of small cells, known as femtocells, introduces additional topological randomness to the network, as shown in Fig. 2 [1].

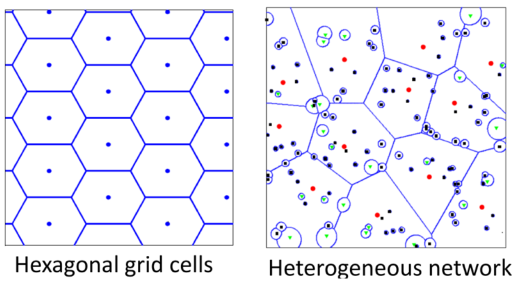

Fig. 2 Comparison between hexagonal grid (to the left) and heterogeneous network typologies (to the right)

A stochastic geometry approach model has been adopted for a Heterogeneous network. It proves itself as a powerful statistical and mathematical tool for the analysis and design of wireless networks with random typologies. Stochastic geometry is the study of random spatial patterns and depends on point processes and random tessellation as well [10].

2.2 Point process (PP)

By point process, the stochastic geometry abstracts the network and captures the system properties. In this section, we will learn what a spatial point process is with some examples, and then we will consider a stationary point process. Later, a matching PP is selected to model the positions of the network entities. This matching pp is the Poisson Point Process (PPP).

Assume a point process φ in $\mathbb{R}^2$, which is a two-dimensional space, as a random variable in a spatial point process taking values in the space N, which is the set of all sequences $\varphi \subset \mathbb{R}^2$.

To explain that, a trivial but interesting example can be taken for a point process: let the set B be in the set A:$B \subset A$. If the random point x is uniformly distributed in a bounded A, then [10]:

$$pr(x \in B) = |B|/|A| , \tag{1}$$

where $|B|$ is the cardinality of set B.

Another example, a binomial point process (BPP) on a set A is the superposition of N independent uniformly distributed points on the set A. Let $B \subset A$ [10], then

$$Pr(\varphi(B) = k) = \binom{N}{k}\left(\frac{|B|}{|A|}\right)^k \left(1 - \frac{|B|}{|A|}\right)^{N-k} , \tag{2}$$

where k is a number of nodes in the set.

Stationary point process: this means that the point process is invariant with respect to translations, so the point process looks statistically similar from any point in space. The density of a stationary point process φ is defined as:

$$\frac{E[\varphi(B)]}{|B|} , \tag{3}$$

where $E[\varphi(B)]$ is the expected value of $\varphi(B)$.

A stationary Poisson point process is the most widely used model for the spatial locations of nodes due to:

- It is analytically tractable, mathematically convenient, and widely adopted for modeling random BS deployments.
- No dependence between node locations.
- There is a random number of nodes.
- It can be defined on the entire plane.

The formal definition of a stationary Poisson point process ϕ of density λ is characterized by two things:

1. The number of points in a bounded set $A \subset \mathbb{R}^2$ has a point distribution with mean, i.e.,

$$pr(\phi(A) = n) = \exp(-\lambda|A|)\frac{(\lambda|A|)^n}{n!} . \tag{4}$$

2. The number of points in disjoint sets is independent, as shown in Fig. 3, i.e., for $A \subset \mathbb{R}^2$, $B \subset \mathbb{R}^2$ and $A \cap B = \emptyset$, which means that $\varphi(A) \perp \varphi(B)$.

$$E[\varphi(B)] = \sum_{n=0}^{\infty} n \exp(-\lambda|A|)\frac{(\lambda|A|)^n}{n!} = \lambda|A| , \tag{5}$$

which follows the mean of a Poisson random variable.

Hence,

$$\frac{E[\varphi(A)]}{|A|} = \lambda , \tag{6}$$

the expression above does not depend on the set A, which means that the PPP does not depend on the coverage area but on the density of nodes in heterogeneous networks.

The main symbols used in the analytical formulation are summarized in Table 2.

2.3 Voronoi tessellation

In a heterogeneous network, by drawing a line that bisects the distances between BSs in Fig. 4, the Voronoi tessellation shape will appear as in Fig. 4 on the left.

Now, by using PPP to model the Heterogeneous network, we obtain a distribution like that in Fig. 4, which looks very similar to the original deployment of base stations of Voronoi tessellation in Fig. 4. The only drawback in PPP is that due

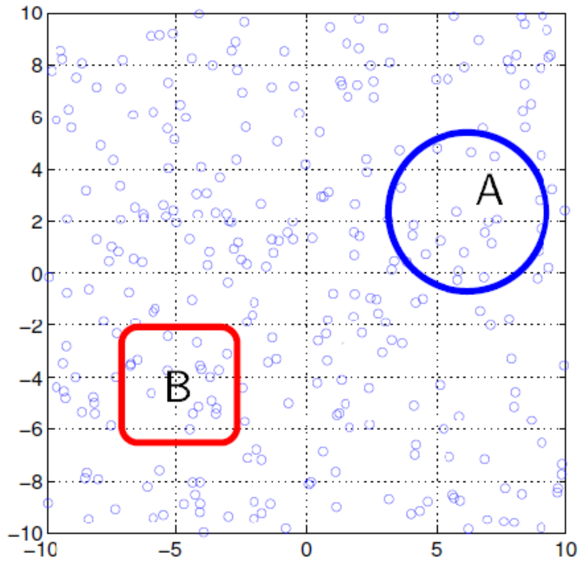

Fig. 3 Poisson point process (PPP) of density $\lambda = 2$.

Table 2 Symbol meaning table

Symbol	Meaning
ϕ_J	PPP of BSs in tier (J)
λ_J	Density of tier (J)
P_J	Transmit power of tier (J)
η	Path-loss exponent
H	Rayleigh fading gain
K	Number of RIS elements
α	FeICIC power reduction factor
Z_i	Noise power
SINR	Signal-to-interference-plus-noise ratio

to the independence of the location of base stations, the base stations may be located so close. However, this weakness is offset by two advantages: the natural inclusion of different cell sizes and shapes, besides the lack of edge effects [11].

Therefore, the models are quantitatively compared to the customary grid model. It is clearly intuitive to see that interferences limiting the performance of the networks are independent of the intensity of the base stations. Increasing the number of base stations does not improve nor degrade the probability of coverage inside the cell and the average achieved rate by the users. This behavior can be explained as follows [4, 12]: as the number of base stations increases the average distance between base stations and their users decreases, which leads to an increase the desired signal power.

However, the aggregate interference increases by the same proportion of the desired signal. Hence, the SIR remains constant. Therefore, the coverage probability and average rate can be improved through interference management techniques, such as frequency reuse, multiple-input multiple-output (MIMO) antennas [14], or by inter-cell cooperation, which is what we will focus on in the next section.

We consider a two-tier (J = 2) HetNet consisting of micro and pico BSs whose locations are modeled as independent PPPs ϕ_{Mi} and ϕ_{Pi} with densities of λ_{Mi} and λ_{Pi}, respectivelty. Users are distributed independently and associated with the BS offering the maximum long-term average received power. Path loss is modeled as $L(d) = d^{-\eta}$, with $\eta > 2$ and small-scale fading is assumed to be Rayleigh, i.e., H~exp(1). Shadowing can be incorporated as long-normal fading and is ignored here for tractability. RIS panels are deployed to assist cell-edge users by introducing an additional reflected path whose phase shifts are optimized for coherent combining at the receiver.

The simulation procedure adopted for the RIS-assisted HetNet evaluation is summarized in Algorithm 1.

3 Interference mitigation techniques

In Heterogeneous network, the micro cells are already deployed by 2G service providers in the networks, yet cannot provide a high data rate without increasing the spectrum, which is an unfeasible option. However, adding small cells, such as Pico cells, within the networks can provide high data rates. Pico cell offers small area coverage, low power consumption, and is less expensive. As we mentioned in the introduction of this paper, that due to scarcity of spectrum

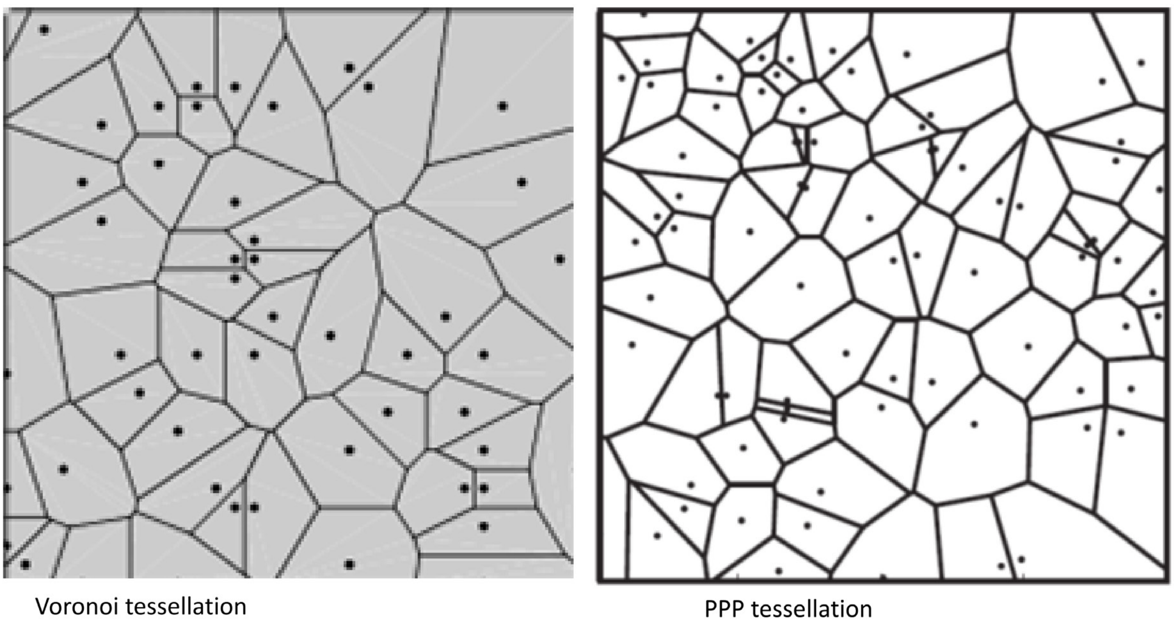

Fig. 4 Voronoi and PPP-based tessellation in HetNet deployment.

Algorithm 1 RIS assisted HetNet simulation

Initialize network parameters:
  $\lambda_{macro}, \lambda_{micro}, \lambda_{pico} \leftarrow$ BS densities
  $P_{macro}, P_{micro}, P_{pico} \leftarrow$ Transmit powers
  Define user distribution and locations
  $K \leftarrow$ Number of RIS elements
Generate BS positions using **P**oisson **P**oint **P**rocess (PPP)
Deploy RIS units randomly or strategically
for each simulation iteration **do**
  for each user **do**
    Identify serving BS (based on max-SINR or REB rule)
    Compute channel coefficients: $H_{macro}, H_{micro}, H_{pico}$
    Compute RIS gain: $H_{RIS} = \sum_{n=1}^{K} \beta_n g_n$
    Apply interference mitigation:
      if eICIC: mute macro subframe
      if FeICIC: scale macro Tx power by α
      if CoMP: enable coordinated joint transmission
    Compute received signal: $Y = H_{BS}X + H_{RIS}X_{RIS} + Z$
    Compute SINR
  end for
  Record SINR, throughput, and BER
end for
for $K \in \{1, 5, 10, 20, \text{and } \infty\}$ do
  Repeat simulation and collect performance metrics
end for
Analyze and plot SINR, throughput, and BER trends

leads to the sharing of spectrum within cells. Nevertheless, spectrum reuse can lead to significant interference, which must be dynamically managed through inter-cell interference reduction. We will obtain such a solution for all network users. The authors in [10, 11] discuss several approaches for interference mitigation, including reinforcement learning, game theory, and coordination.

In reinforcement Learning, the action of agents (transmitting devices) is based on a trial-and-error strategy. The agent wants to find which actions lead to the bigger reward by trying all possible schemes. A reinforcement learning agent must identify actions that yield higher rewards by choosing between previously taken actions and exploring new actions.

In game theory, agents look like players in a board game, trying to produce strategies in order to maximize their earning, depending on recent strategies taken by their opponents, have been based on their opponents. a^* is the action that maximizes the utility function $u(a)$ of the player

Coordination: Inter-Cell Interference Coordination (ICIC) is a very efficient way to mitigate the interferences. This technique has been adopted by LTE release 8 and has been enhanced in release 10 for LTE [1, 10, 11]. Later, we discuss enhanced intercell interference coordination, then further enhanced intercell interference coordination and coordination of multi-point CoMP [11–12].

$$a^* \in \underset{a \in A^u}{argmax}\ u(a) \tag{7}$$

3.1 Enhanced inter-cell interference coordination

In a heterogeneous network, to allow a user to obtain service from a low coverage and power cell (Pico cell) in the existence of a Micro cell with a strong downlink signal, the Pico cell has to operate power control and data channel interference coordination with the dominant micro cell interferences, and users need to be able to ensure interference cancellation. Let's assume that we have received a signal Y_i in a user (end, then the received signal will be:

$$Y_i = H_{Mi} X_{Mi} + H_{Pi} X_{Pi} + Z_i\,, \tag{8}$$

where H_{Mi}, H_{Pi} and are the Rayleigh channel coefficients for the signal from Micro and pico cells, respectively. X_{Mi} and X_{Pi} are transmitted signals from micro and pico cells, respectively and Z_i includes noise and other interference residual terms.

Now, if the desired signal is the pico cell signal, then there will be a very strong interference signal coming from the Micro cell. One possible solution is to mute the microcell at specific times, allowing only the pico signal and RIS to be active.

Inter-Cell Interference Coordination is a critical technique for heterogeneous network deployment. Essentially, the basic eICIC technique involves resource coordination among interfering cells so that the interfering cells will leave some resources to provide control and data transitions to the victim user. However, when the micro cell mutates, the Pico cells may expand their coverage to serve additional users, as no other cell is providing service at that time. That also achieves balancing in the load between micro and Pico cells through this expansion. This is called range expansion bias [1, 9], which is illustrated in Fig. 5.

3.2 Further enhanced inter-cell interference coordination

In eICIC, although the Pico cell users obtain a high data rate, Micro cell users get less capacity because they are served for just half of the time. Therefore, to overcome

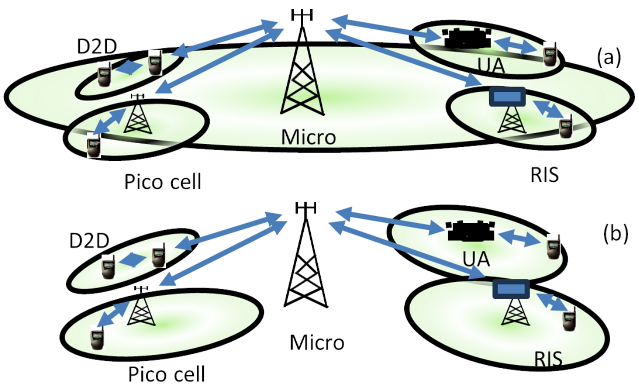

Fig. 5 eICIC mechanism and range expansion in heterogeneous network

this, another solution has been developed that is: in Eq. (8), instead of muting the Micro cell, it can reduce the power in the subframe time of the Pico cell transmitter or in the direction of the Pico cell, then the users of Pico cell will overcome the interferences of micro cell and the users of Micro cell will get their continuous service. This technique has been stated by LTE Advanced Rel. 11 [4], it is also called soft reuse. In other words, the Micro cell transmits with reduced power during the coordinated sub-frames (CSF) to serve only its adjacent users. This subframe power reduction during CSF is shown to enhance the heterogeneous network performance significantly in terms of the trade-off between cell edge and average throughput.

Now, in terms of the signal-to-interference and noise ratio for the Pico cell user SINR_i in FeICIC:

$$\mathrm{SINR}_i = \frac{P_{Pi}\left\|H_{Pi}\right\|^2}{\alpha P_{Mi}\left\|H_{Mi}\right\|^2 + \left\|Z_i\right\|^2}, \tag{9}$$

where $\alpha \in [0,1]$ denotes the power reduction factor in FeICIC: Setting $\alpha = 0$ corresponds to eICIC muting, while $\alpha = 1$ corresponds to no eICIC case. To clarify more, we can associate that with Fig. 5, for $\alpha = 1$, this relates to Fig. 5 (a) and for $\alpha = 0$ related to Fig. 5 (b).

4 RIS interference

4.1 Limited RIS in the system

For a single RIS, we can write Eq. (8) as Eq. (10):

$$Y_i = H_{Mi}X_{Mi} + H_{Pi}X_{Pi} + H_{rx-\mathrm{RIS}}\theta H_{tx-\mathrm{RIS}}X_{\mathrm{RIS}_i} + Z_i, \tag{10}$$

where, $H_{rx-\mathrm{RIS}}$ and $H_{tx-\mathrm{RIS}}$ are the contribution of the RIS-reflected signal and θ is the reflection coefficient on the RIS. The Channel coefficient here can be expressed as

$$H_{\mathrm{RIS}} = \sum_{n=1}^{K} \beta_n g_n \tag{11}$$

representing the combination of K reflection elements, their reflection coefficients β_n and the channel g_n from BS to RIS for $H_{tx-\mathrm{RIS}}$ and from RIS to the user for $H_{rx-\mathrm{RIS}}$.

The signal-to-interference noise ratio in Eq. (9) will become

$$\mathrm{SINR}_i = \frac{P_{Pi}\left\|H_{Pi}\right\|^2 + P_{\mathrm{RIS}_i}\left\|H_{rx-\mathrm{RIS}}\theta H_{tx-\mathrm{RIS}}\right\|^2}{\alpha P_{Mi}\left\|H_{Mi}\right\|^2 + \left\|Z_i\right\|^2}. \tag{12}$$

4.2 For multiple RIS

For multiple RIS we can write Eq. (10) for different M RIS, as there is no inter-RIS interference, as Eq. (13) [8]:

$$Y_i = H_{Mi}X_{Mi} + H_{Pi}X_{Pi} + \sum_{s=1}^{K} H_{rx-\mathrm{RIS}_s}\theta_s H_{tx-\mathrm{RIS}_s}X_{\mathrm{RIS}_s} + Z_i, \tag{13}$$

where s is the index for RIS in the system. However, when there is inter-RIS interference, the received signal will become:

$$Y_i = H_{M_i}X_{M_i} + H_{P_i}X_{P_i} + \sum_{s=1}^{K} H_{rx-\mathrm{RIS}_s}\theta_s H_{tx-\mathrm{RIS}_s}X_{\mathrm{RIS}_s} + \sum_{s=1}^{K}\sum_{l=1,\ l\neq s}^{K} H_{rx-\mathrm{RIS}_s}\theta_s H_{rx-\mathrm{RIS}_l}\theta_l H_{tx-\mathrm{RIS}_l}X_{\mathrm{RIS}_s} + Z_i \tag{14}$$

where:

$$\sum_{S=1}^{K} H_{rx-\mathrm{RIS}_S}\theta_S H_{tx-\mathrm{RIS}_S}X_{\mathrm{RIS}_S},$$

is the desired RIS contributions, and:

$$\sum_{S=1}^{K}\sum_{l=1,\ l\neq S}^{K} H_{rx-\mathrm{RIS}_S}\theta_S H_{rx-\mathrm{RIS}_l}\theta_l H_{tx-\mathrm{RIS}_l}X_{\mathrm{RIS}_S},$$

is the inter-RIS interference.

To express the SINR, we write the total power of the useful signal. Let's define:

$$P_{\mathrm{signal}} = \left\|H_{P_i}X_{P_i} + \sum_{s=1}^{K} H_{rx-\mathrm{RIS}_s}\theta_s H_{tx-\mathrm{RIS}_s}X_{\mathrm{RIS}_s}\right\|^2, \tag{15}$$

and the interference:

$$P_{\mathrm{interference}} = \left\| \begin{matrix} H_{M_i}X_{M_i} + \sum_{s=1}^{K}\sum_{l=1,\ l\neq s}^{K} \\ H_{rx-\mathrm{RIS}_s}\theta_s H_{rx-\mathrm{RIS}_l}\theta_l H_{tx-\mathrm{RIS}_l}X_{\mathrm{RIS}_s} \end{matrix} \right\|^2. \tag{16}$$

Hence,

$$\mathrm{SINR}_i = \frac{P_{\mathrm{signal}_i}}{\alpha P_{\mathrm{interference}_i} + \left\|Z_i\right\|^2} \tag{17}$$

We are also going to study the impact of increasing the number of RIS $\rightarrow \infty$ on the BER and the overall performance of the system.

5 Results

Monte Carlo simulations are conducted over $\mathbf{10^4}$ independent network realizations. Table 3 demonstrates the main

Table 3 Simulation parameters values

Simulation parameter	Values
Micro BS density (λ_{Mi})	2
Pico BS density (λ_{Pi})	10
Path-loss exponent (η)	3
Bandwidth (B)	10–20 MHz
Noise density	−174 dBm/Hz
RIS elements (K)	1, 2, 10, 20, $\rightarrow \infty$
Tx Powers	From Table 1

parameters values in this simulation. BS locations are generated using PPP deployment within a circular region, and wrap-around is applied to reduce edge effects. For each realization, users are placed uniformly, and performance metrics (SINR, sum rate, BER) are averaged across users and realizations. RIS phase shifts are optimized to maximize the desired signal power at the intended user.

Fig. 6 demonstrates a significant improvement in SINR for users near the cell edges due to RIS-enabled CoMP. This is a direct consequence of better signal alignment and reduced interference from neighboring cells. The SINR enhancement showcases the effectiveness of combining RIS with ICIC, especially in scenarios with high user density or overlapping coverage areas.

The results show improvements in fairness between users, with cell-edge users getting the most benefits. Such techniques align with the aim of mitigating the disparity in service quality between central and edge users in HetNets.

Fig. 7 shows the coverage probability improvements demonstrating that RIS and ICIC together ensure robust communication for a larger fraction of users, even in interference-prone environments.

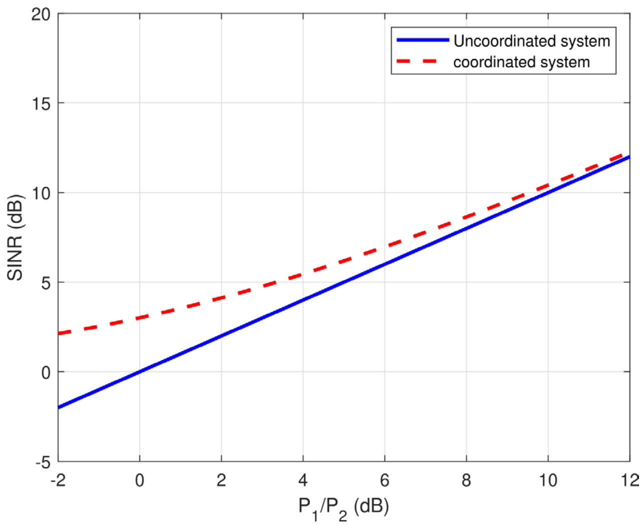

Fig. 6 Throughput comparison: coordinated vs. uncoordinated systems

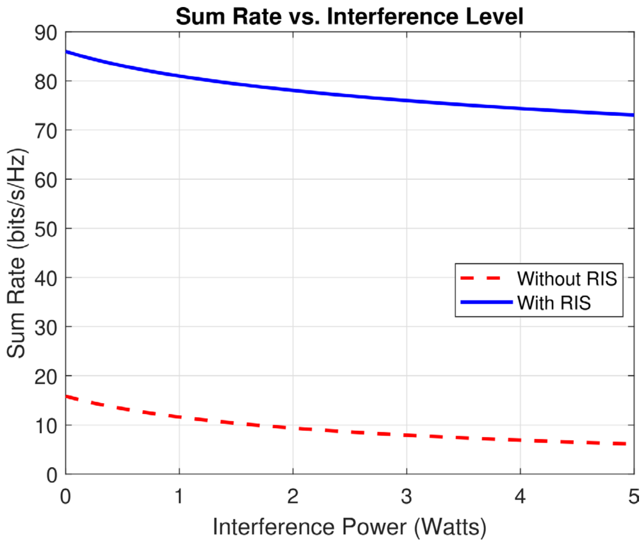

Fig. 7 Sum rate vs. interference level: LTE HetNet (without RIS) and RIS-assisted enhanced (with RIS).

To align with LTE HetNet baselines as shown in Fig. 7, without RIS, which represents the conventional LTE interferences coordination without RIS assistance. And, with RIS represents RIS enhaced coordination. RIS-assisted shows a high sum rate improvement and strong cell edge reliability under high interference.

RIS provides passive beamforming gain by coherently reflecting energy toward the desired user while reducing leakage toward interference directions. This increases the useful received power and effectively improves SINR, especially under dense interference.

Fig. 8 shows the significant role of RIS in improving cellular systems. As we increase the number of RIS, we improve the performance of the system.

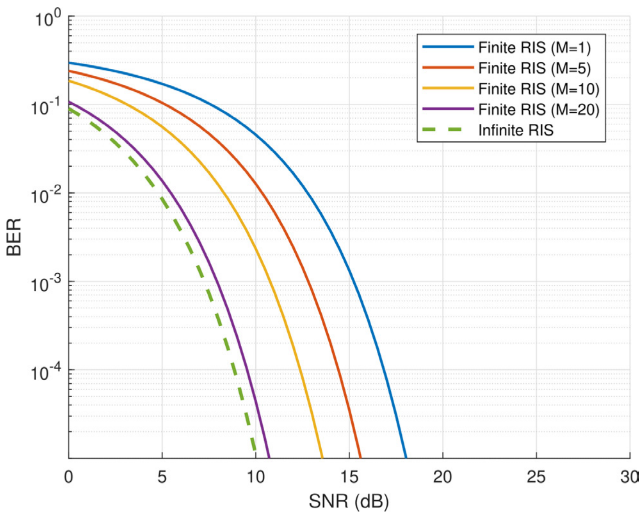

Fig. 8 Impact of increasing RIS elements on BER performance

The coherent combining gain grows with the number of elements K, which reduces the required SNR for a target BER.

6 Conclusions

This paper proposed a unified framework for capacity enhancement and interference mitigation in HetNets by jointly employing CoMP transmission, RIS, and stochastic-geometry-based spatial modeling. Simulation results shows tht RIS assisted coordination increases the sum rate from approximately 15bit/s/Hz to 85 bit/s/Hz under low interferences and maintains around 74 bit/s/Hz under strong interference. Further RIS improves cell edge SINR by 3 to 4 dB. Increasing RIS size yields up to 5 to 6 dB SNR saving at BER = 10^{-3}. Future work will incorporate spatially consistent channel models, hardware impairments, and optimize RIS placement under multi-tier user scenarios.

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