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Ph.D. THESIS SUMMARY

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PROPAGAREA DE RADIOFRECVENȚĂ ȘI DEZVOLTAREA PROCEDURILOR PRIVIND POZIȚIONAREA SITE-URILOR 5G

RF PROPAGATION AND 5G SITE POSITIONING DESIGN

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Chapter 1

Introduction

In this thesis, we focus on three directions to contribute to the future 5G and beyond networks in terms of performance and efficiency. First, proposing a new radio resource management (RRM), specifically, a radio resource scheduling scheme, in which resource blocks are distributed to the users aiming to satisfy their needs and simultaneously keep a high overall performance. Secondly, we study the blockage phenomena impact on RISs aided 5G and beyond networks, where we investigate the various reasons for the blockage, and their effect on RISs aided high frequency band. Also, we evaluate the RISs aided 5G and beyond network performance. Third, we investigate the RIS technology implementation in 5G and beyond networks. In this context, we focus on the passive beamforming (PBF) challenge. Hence, we propose two promising solutions to overcome this issue.

1.1 Overview of 5G and Beyond Networks

1.1.1 MmWave and THz for 5G and Beyond Networks

The promising future 5G and beyond networks can be mainly enabled using mmWave and THz communication because they have many notable advantages. However, some challenges appear with the employment of up 6 GHz bands. In this subsection, we discussed this point.

1.1.2 The Blockage Occurrence in High Frequency Bands

The blocking phenomena and its impact on the high frequency bands is one of the main concerns that hinder these high frequencies from efficiently working for 5G and beyond networks, so we showed a brief introduction on it in this subsection.

1.1.3 Reconfigurable Intelligent Surface Technology

Nowadays, the key player, to eliminate the blockage impact in the 5G and beyond networks, is reconfigurable intelligent surfaces (RISs) implementation which play as an aid for these networks. So, it has become important to discuss it in this section.

1.1.4 The Concept of Heterogenous Networks

It is mandatory to give a brief background about the working principle of the heterogeneous network (HetNet) that is considered the core future wireless network and one of main concepts to enable positioning information based networks.

1.2 Thesis Directions

This thesis research can be mainly divided into three directions:

1.2.1 Designing QoS Based Radio Resource Scheduling Scheme

The importance of scheduling in 5G communication systems motivated us to propose a new and efficient possible scheduling scheme to be adapted to the 5G network aiming to provide high QoS for the UEs in eMBB applications.

1.2.2 The Dynamic Blockage Impact on 5G and Beyond Networks

In this part, we are concerned about the design of the 5G and beyond network considering the existence of the blockage phenomena, where we aim to meet the future link reliability (LR) and end-to-end latency requirements.

1.2.3 Solving RISs aided 5G and Beyond Networks Challenges

This part focuses on proposing new techniques that can help in overcoming the PBF challenge in RISs, considering the occurrence of the blockage. In this part, we suggest a PI based CB (PI-CB) scheme for RIS passive beamforming.

1.3 The Thesis Main Contributions

The major contributions of our thesis are recapped in the subsequent points:

- Proposing a quality of service based RRS for 5G eMBB use case aiming to enhance the overall system performance.
- Investigating the mobile blockers effect on RISs aided mmWave/THz networks, to be able to efficiently plan the 5G and beyond networks.
- Proposing a dynamic positioning information based codebook for RIS Passive Beamforming.

1.4 Thesis Architecture

Our thesis contains five chapters that deeply dive into the proposed solutions for enhancing the 5G and beyond networks.

Chapter 2

Related Works

This chapter gives a descriptive idea about the prior studies that discussed the same topics we will discuss in this thesis.

2.1 Radio Resource Scheduling in 5G Networks

The radio resource management (RRM), and especially the scheduling procedure, is a highly crucial step in the communication network. The literature is full of works that discuss scheduling in mobile communication systems and propose some techniques for it in 5G networks such as [1], [2], [3]. Also, some studies considered the blockage impact while scheduling UEs in 5G networks [4]. It is worth mentioning that these prior works considered some metrices while neglecting others. Moreover, if they consider different traffic types, they merely discuss them separately, which is an impractical assumption. Also, no deep discussions are provided for UEs satisfaction using these schemes, though this metric is highly vital. In addition, previous studies discussed common scheduling schemes or modify them to enhance the performance, however, they neglect the practical UEs requirement parameters.

2.2 The Blockage Impact on High Frequency Bands

In upper 6 GHz bands, the signal may be easily obstructed by three different types of blockage, namely static, dynamic, and self-blocking. Many works have explored the effect of these blockage types on communication systems [5], [6], [7]. The mobile blockers affect temporarily and frequently when they pass in front of the TX or RX. Also, the dynamic blockage is a result of several type of obstacles with various parameters, e.g., different types of vehicles, drones, humans, and robots, which have different dimensions, signal penetration characteristics, and speeds. In this context, several works have discussed the dynamic blockage effect in literature such as [8], [9], [7], [10], [11], [12], [13] and [14].

2.3 RIS Technology to Eliminate the Blockage Effect

To overcome the blockage effect, researchers have suggested the implementation of the RISs in the network. The RIS elements can be adjusted by controlling the RIS phase shifters, where a programable controller, that connects RISs with their associated BSs, is responsible for this process that is called RIS beamforming. Many prior studies have discussed the superiority of the RISs implementation to overcome the blockage effect in 5G and beyond networks [15], [16], [17], [18]. However, actually, the RIS can eliminate or reduce the effect of the blockage, but it cannot totally stop and overcome it. Hence, it is essential to study the blockage occurrence of in RISs aided systems.

2.4 RISs aided 5G and Beyond Networks Challenges

The implementation of the RISs as 5G and beyond network helpers has brought some challenges to the network, e.g., RIS beamforming.

2.4.1 The Challenge of RIS Passive Beamforming

For establishing the alternative LOS link, i.e. BS-RIS-UE, the configuration of the RIS elements shall be done. Mainly, the PBF approaches are divided into two major classes: first, CE and passive beamforming optimization (CE & O) schemes [19], [20], [21], [22], [23], [24], and the second is training a predefined CB to define the cascaded end to end channel, then be able to determine the best RP.

2.4.1.1 CE and PBF optimization based approaches

Several works have developed CE and PBF optimization (CE & O) based schemes for configuring RIS [20], [21], [22], [23]. These prior methods reduced the required overhead and complexity of the channel estimation, however, with large RIS implementation, these approaches still suffer high overhead. Moreover, the time consumption of these schemes is required in the online stage causing a long delay.

2.4.1.2 Predefined CBs based approaches

These schemes are more efficient in terms of the overhead and complexity required in the system to configure the RIS elements, hence they can guarantee a higher effective rate. Moreover, CBs based schemes are able to overcome propagation errors, and can be easily deployed in the communication systems without any further changes to the existing communication frameworks. Furthermore, these schemes allow the separation of the A-PBF process into two stages. In addition, the control signaling overhead is limited by the CB size thus a high reduction in the backhaul overhead can be achieved. Mainly, the approaches in this class have three stages, firstly, the design of the RIS CBs then, the training of these CBs, third, learning stage to select the best reflection pattern (RP) to be utilized in data transmission period. Several works have been suggested in the literature depending on the concept of CBs training to perform the passive beamforming [25], [26], [27], [28]. The challenges in the first two CB based schemes stages motivate us to develop our proposals, besides the limitations that we found in the related works.

Chapter 3

Proposed QoS based Radio Resource Scheduling Scheme

Radio resource scheduling is a crucial stage in the initial access of users, where an efficient distribution of the precious network resources among connected UEs is mandatory to optimize the performance in both the network and UEs side. The existing standards for 5G and beyond networks discuss several use cases and scenarios, also they provide complete definitions for the frame structure and its elements. However, no efficient RRS scheduling scheme is introduced. Moreover, implementing prior scheduling schemes without adaptation to the characteristics, specifications, and requirements of 5G and beyond networks cannot be a promising option. Hence, to this end, this Chapter presents a new quality of service (QoS) based radio resource scheduling approach, where we consider the channel conditions of the mmWave in 60 GHz band. Furthermore, our approach relies on the UEs channel qualities and their demands aiming to enhance the network performance, maintain fairness among UEs, and satisfy a higher number of UEs with their demands. Moreover, the blockage impact, which is inherent with the use of high frequency bands, is considered while evaluating the performance of the proposed scheme. **Error! Reference source not found.** lists the used symbols and notations through t his Chapter.

3.1 System Model

In this Chapter, we consider the eMBB use case, where a 5G WLAN serves several users with various applications, e.g., VR and video streaming.

3.2 Proposed approach

The 5G and beyond networks arise various applications that the UEs can experience, e.g., virtual reality and video streaming. Thus, the UEs demands become varied and as a result the sent packets to each UEs become different. Therefore, proposing scheduling based on UEs needs is a mandatory in the future networks. Consequently, we propose a QoS based proportional fairness scheduling approach,), where we modify and enhance the standard proportional fairness (SPF) mechanism. More, specifically, we modify the used priority function for each UE by combining a part to include the UEs demands effect. This part is the UEs required data rates relative to their maximum value, where the UEs with the maximum value is one of the UEs associated to the base station in the current frame. Algorithm 1, shown in Table 3-2, presents the steps of our QoS based PFS.

Table 3-2 Algorithm 1 for the proposed QoS based PFS approach.

Algorithm 1: Proposed QoS based PFS approach.
Input: R_{req_k}, R_k, r_k for all UEs
Output: Scheduling all UEs along the time frame
Start
1: **For** each time slot *n*
2: **Calculate** w_k using (6)
3: **Calculate** $P_k{}^*$ using (5)
4: **Sort** $P_k{}^*$ for all UEs
5: **Assign** current time slot to the UE k with the higher PF
6: **Update** R_k and R_{req_k} using (2) and (7), respectively
7: **End**
Stop

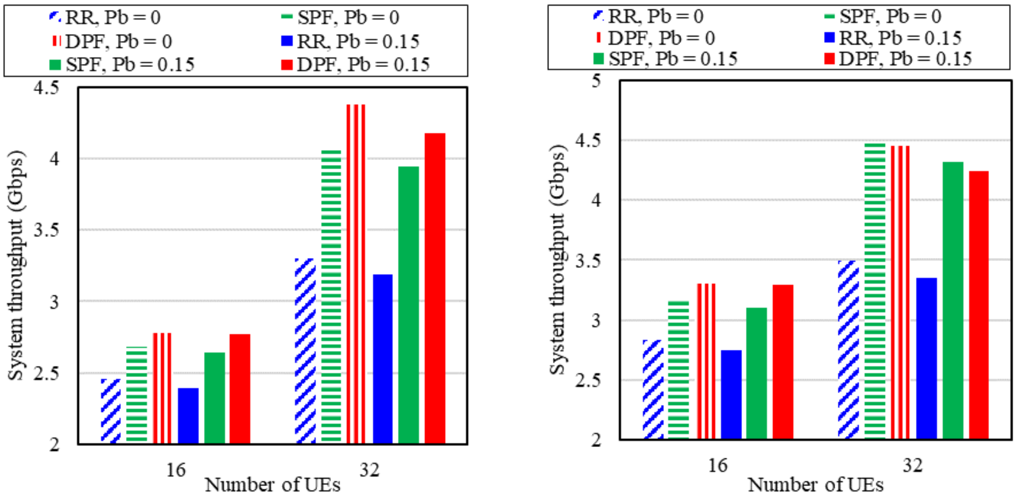
3.3 Performance Metrics and Simulation Scenarios

This section presents the performance metrics that are used to compare our proposed scheme to the state-of-the-art approaches. Moreover, we explain the simulation scenarios and parameters used for the studied environment.

3.4 Simulation Results

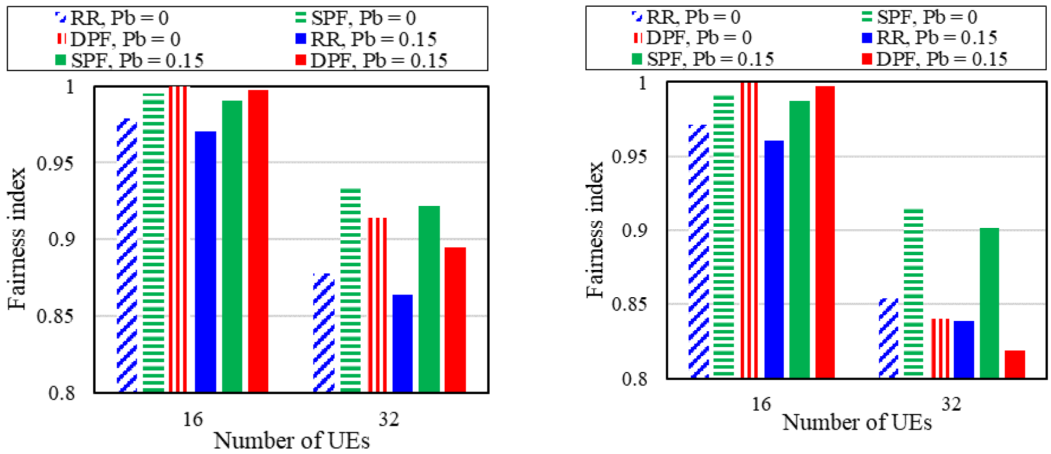
This section presents the proposed approach performance comparable to round robin and SPF scheduling schemes. The performance comparison between our proposal and RR and SPF schemes are shown in Figure 3-1 and Figure 3-2 from the network point of view. It is clear the superiority of the proposed QoS based PFS approach over RR and SPF schemes in 16 UEs case for both scenarios despite the blockage occurrence. Furthermore, based on Figure 3-2, it is notable that our DPF guarantees higher fairness in case of associating 16 UEs to the BS. The cumulative distribution functions (CDF) of the UEs satisfaction for 32 UEs case is presented in Figure 3-3, considering no blockage and 0.15 blockage probability under the study of the two traffic scenarios.

We investigate why the total throughput and fairness of the proposed scheme are lower than the SPF ones in the 32 UEs case in the second scenario. Thus, in Figure 3-4, we present the average throughput per UE for each application out of the four considered ones, i.e., 4K, 8K videos, weak, and strong interaction VR.



(a) *(b)*

Figure 3-1 Total throughput of QoS-PFS, SPF, and RR approaches in 16 and 32 UEs cases, w/wo blocking occurrence, if (a) S1 and (b) S2, are adopted.



(a) *(b)*

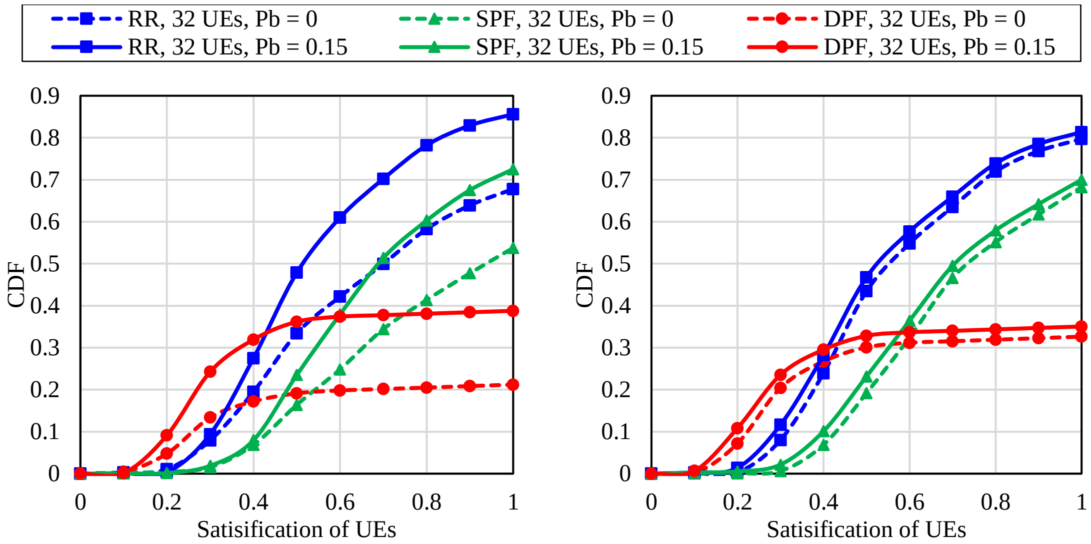
Figure 3-2 Fairness index of QoS-PFS, SPF, and RR approaches in 16 and 32 UEs cases, w/wo blocking occurrence, if (a) first and (b) second scenarios, are adopted.

3.5 Summary

This Chapter mainly discussed the following points:

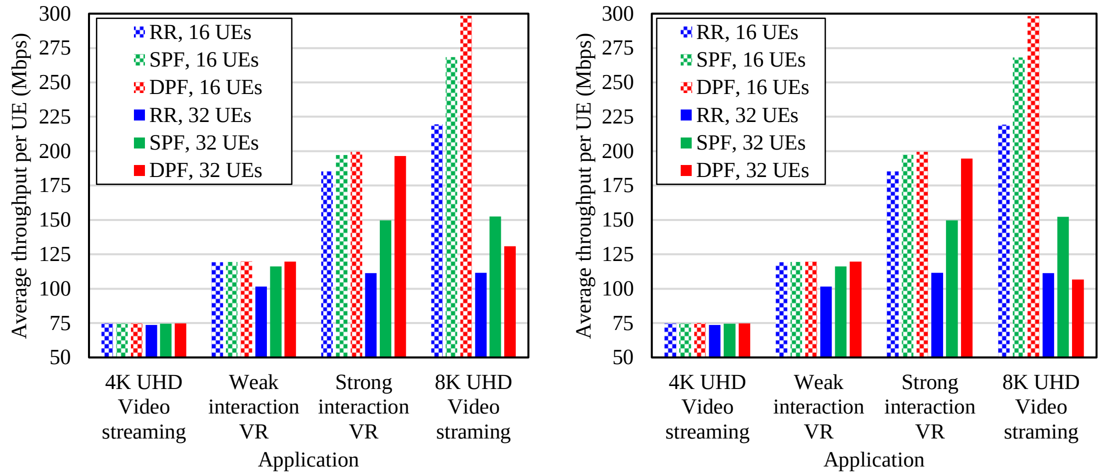
- First, we proposed a new QoS based PFS approach, where both the UEs channel qualities and demands are considered to distribute the mmWave BS resources.
- Secondly, the study in this Chapter considered the blockage event in the network, so we studied the blockage probability versus the blocker density, then we tool the practical assumptions while evaluating the performance of the different scheduling approaches including the proposed one.
- In the simulation results, we proved that the proposed scheme guarantees better total system throughput, fairness, UEs satisfaction, and average throughput per UE than the existing scheduling algorithms, i.e., SPF and RR, considering varied

traffic and different eMBB applications such as 4K, 8K video streaming, weak and strong interaction VR.



(a) *(b)*

Figure 3-3 CDF of UEs satisfaction of all scheduling schemes if (a) first scenario and (b) second scenario with 32 UEs are adopted.



(a) *(b)*

Figure 3-4 Average throughput per UE of QoS-PFS, SPF, and RR mechanisms, when (a) S1, and (b) S2, are employed.

Chapter 4

Dynamic Blockage Impact on RISs aided 5G and Beyond Networks

This Chapter is a complete study on the mobile blockers' impact on RISs aided 5G and beyond networks, where high frequency bands, namely mmWave and THz bands, are considered. Through this Chapter, our main focus is to deduce a mathematical model to describe the blockage phenomena and its impact. In which, we present different blocking metrics, i.e., the blockage probability, the blockage frequency, and the blocking duration. Furthermore, aiming to plan the RISs aided networks, we study the prior metrics versus the BSs/RISs density, then show the effect of network specifications, e.g., communication range and antennas' heights, on the implemented BSs/RISs, considering the target of achieving certain link reliabilities that match the 5G and beyond networks. Moreover, the performance of RISs aided networks is studied in terms of spectral efficiency (SE) and energy efficiency (EE), besides showing the effect of the RISs elements number and the transmitter SNR. This study can be highly useful for efficient planning of RISs aided networks.

4.1 System Model

This sections presents system model architecture of RISs aided networks considering various blockage types. Then, it introduces the BSs and RISs models, thereafter, the static, self and dynamic blockage models are described. In addition, we show in this section the channel model of the RISs aided systems beside their SE and EE.

4.1.1 The RISs aided System Architecture

4.1.2 BSs and RISs Model

The model of the BSs and RISs locations follows a homogeneous Poisson Point Process (PPP) with densities λ_M and λ_L, respectively.

4.1.3 Static, Self, and Dynamic Blockage Models

- The static blockage model can be defined depending on random shape theory as [6], where static blockers are permanent objects.
- The user's own body causes the self-blocking zone, where it blocks the signal from the TX to the UE RX.
- Homogeneous PPP describes the dynamic blockers distribution in the network with density λ_{bl} which is united in blockers per m^2 (bl/m^2).

4.1.4 RISs aided System Model

This section presents our studied use case, system architecture, and performance metrics, i.e., spectral efficiency (SE) and energy efficiency (EE), of the network.

4.2 Blockage Model in RISs aided Systems

In this section, first, we will deduce the mathematical blockage model for single BS-UE or RIS-UE link, then we will generalize it to multi BSs-UE or RISs-UE links case.

4.2.1 The Model of Dynamic Blockage for a Single BS-UE or RIS-US Link

Assuming a single BS-UE or RIS-UE link, r_{m_i} and r_{l_j}, present the two dimensional distances from the ith BS to the UE or from jth RIS to the UE, respectively. The the ith BS-UE and jth RIS-UE links blockage probability can be written, respectively, as

$$P\left(BB_i^d|m,r_{m_i}\right)=\frac{\alpha_i}{\alpha_i+\mu}=\frac{\frac{C_M}{\mu}r_{m_i}}{1+\frac{C_M}{\mu}r_{m_i}},\forall i=1,\dots,m, \tag{4.22}$$

$$P\left(BR_j^d|l,r_{l_j}\right)=\frac{\alpha_j}{\alpha_j+\mu}=\frac{\frac{C_L}{\mu}r_{l_j}}{1+\frac{C_L}{\mu}r_{l_j}},\forall j=1,\dots,l. \tag{4.23}$$

4.2.2 The Model of Dynamic Blockage for multi BSs-UE and RISs-US Links

In this subsection, we will model the dynamic blockage of multi LOS BSs-UE and RISs-UE links by generalizing the prior model to multi nodes case.

4.2.2.1 Coverage probability

At first, the BSs/RISs are in coverage, when the BSs/RISs can supply to the UE an accessible link which is not obstructed by static or self-blockers.

Lemma 1: The distributions of the available BSs-UE links numbers, $\mathcal{M}$, and the available RISs-UE links numbers, $\mathcal{L}$, that are not obstructed by static or self-blockers, follow Poisson distribution.

Proof: See Thesis Appendix.

Corollary 1: *Let CB^{LOS} denotes the event that at least one LOS BS-UE link is available to cover the UE in the interested area of the circle $C_M(o, R_M)$, and self or static blockers don't affect this link. And, let CR^{LOS} denotes the event that at least one LOS RIS-UE link is available to cover the UE in the interested area of the circle $C_L(o, R_L)$, and self or static blockers don't affect this link. Thus, these events probabilities can be defined as*

$$P(CB^{LOS}) = P_{\mathcal{M}}(m \neq 0) = 1 - P_{\mathcal{M}}(0) = 1 - e^{-\gamma_{\mathcal{M}}}, \tag{4.28}$$

$$P(CR^{LOS}) = P_{\mathcal{L}}(\ell \neq 0) = 1 - P_{\mathcal{L}}(0) = 1 - e^{-\gamma_{\mathcal{L}}}. \tag{4.29}$$

Lemma 2: The total obtainable links number for establishing a connection between the BS and the UE, whether this connection is direct or indirect through the RIS, can be defined as N, where $N = \mathcal{M} + \mathcal{L}$. Hence, using random variable transformation principles [53], *the number of N links follows a Poisson distribution with parameter γ, where $\gamma = \gamma_{\mathcal{M}} + \gamma_{\mathcal{L}}$, and can be expressed as*

$$P_N(n) = \frac{\gamma^n}{n!} e^{-\gamma}. \tag{4.30}$$

Corollary 2: Let C^{LOS} denotes the event that at least one LOS BS-UE or LOS RIS-UE link is available to cover the UE, and self or static blockers don't affect this link. Thus, this event probability can be defined as

$$P(C^{LOS}) = P_N(n \neq 0) = 1 - P_N(0) = 1 - e^{-\gamma}. \tag{4.31}$$

4.2.2.2 Blockage probability

Theorem 1: *The marginal LOS blockage probability of all BSs-UE links and all RISs-UE links can be defined as*

$$P(BB^{LOS}) = e^{-a_M p \lambda_M \pi R_M{}^2}, \tag{4.36}$$

$$P(BR^{LOS}) = e^{-a_L p \lambda_L \pi R_L{}^2}, \tag{4.37}$$

Proof: See Thesis Appendix.

The total blockage phenomena occur, if all BSs-UE and RISs-UE links, N, are blocked at the same time. Noting that the blockage independently affects the BSs-UE and RISs UE links. Thus, the joint blockage probability of all BSs-UE and RISs-UE links, $P(B^{LOS})$, can be defined as

$$P(B^{LOS}) = P(BB^{LOS})P(BR^{LOS}) = e^{-p\left(a_M \lambda_M \pi R_M{}^2 + a_L \lambda_L \pi R_L{}^2\right)}. \tag{4.42}$$

Moreover, the conditional the blockage probability of all links given their total coverage probability, $P(B^{LOS}|C^{LOS})$, can be expressed as

$$P(B^{LOS}|C^{LOS}) = \frac{e^{-p\left(a_M \lambda_M \pi R_M{}^2 + a_L \lambda_L \pi R_L{}^2\right)} - e^{-\gamma}}{1 - e^{-\gamma}}. \tag{4.43}$$

4.2.2.3 Expected blockage duration

Theorem 2: *The all n links conditional expected blockage duration, when they are blocked at the same time, given their coverage event, C^{LOS}, can be defined as*

$$E[T^{LOS}|C^{LOS}] = \frac{e^{-\gamma}}{\mu(1-e^{-\gamma})} Ei[\gamma], \quad (4.45)$$

here $Ei[\gamma] = \sum_{n=1}^{\infty} \frac{\gamma^n}{n \times n!}$ *is a series that can be expressed as exponential integral function* [54].

Proof: See Thesis Appendix.

4.2.2.4 Expected blockage frequency

Theorem 2: The expected blockage frequency given the coverage, $E[\zeta^d/C^{LOS}]$*, can be expressed as*

$$E[\zeta^d/C^{LOS}] = \frac{E[\zeta^d]}{P(C^{LOS})} = \frac{\mu\rho(1-a_{\mathcal{M}})^{1/2}(1-a_{\mathcal{L}})^{1/2} e^{-\rho(1-a_{\mathcal{M}})^{1/2}(1-a_{\mathcal{L}})^{1/2}}}{1-e^{-\rho}}. \quad (4.48)$$

Proof: See Thesis Appendix.

4.3 Numerical Evaluation

The valuation of the mathematical blockage model is presented in this part, where various blockage metrics are shown. Furthermore, the results obtained using the stochastic geometry based model are compared and validated with a numerical simulation conducted by MATLAB platform. In addition, the impact of several network specifications is studied, where we discuss the effect of BSs/RISs density on the blockage metrics. Moreover, we find out the required BSs and RISs densities in the network. Also, the performance of the RISs aided network is studied. Moreover, we study the superiority of using RISs in the future networks, where we show the performance versus SINR and RISs elements number. Table 4-1 shows the 5G and beyond networks' requirements, i.e., link reliability and end-to-end latency, in the first two columns, where we aim to design the network to achieve these needs to be able to provide high QoS and QoE for the UEs in the network. Meanwhile, the last column presents the corresponding required BSs/RISs number in the studied environment.

Table 4-1 Reliability and Latency Requirements.

Applications	**Reliability**	**End-to-end delay**	**Number of required BSs/RISs under studied area of interest**	
			$\lambda_{bl} = 0.5$ **bl/m²**	$\lambda_{bl} = 1$ **bl/m²**
5G (eMBB, URLLC, mMTC)	Five-nines	≤ 10ms	12	15
Beyond 5G (reliable eMBB, URLLC, mMTC, URLLC +eMBB)	Six-nines	1ms	15	18
6G (MBRLLC, mURLLC)	Seven-nines	≤ 1ms	18	22

4.3.1 Mathematical Model Evaluation and BSs/RISs Density Impact

Figures 4.3, 4.4, and 4.5 present the blockage metrics given the coverage versus the BSs/RISs density in RISs aided systems comparable to BSs standalone systems. In these figures, we can see the matching and coinciding between the results obtained from the mathematical and simulation analysis, however, small deviations are notable in some cases. Figures 4.3, 4.4, and 4.5 clarify the obtained enhancement in the blockage metrics because of using the RISs comparable to the case of using BSs alone.

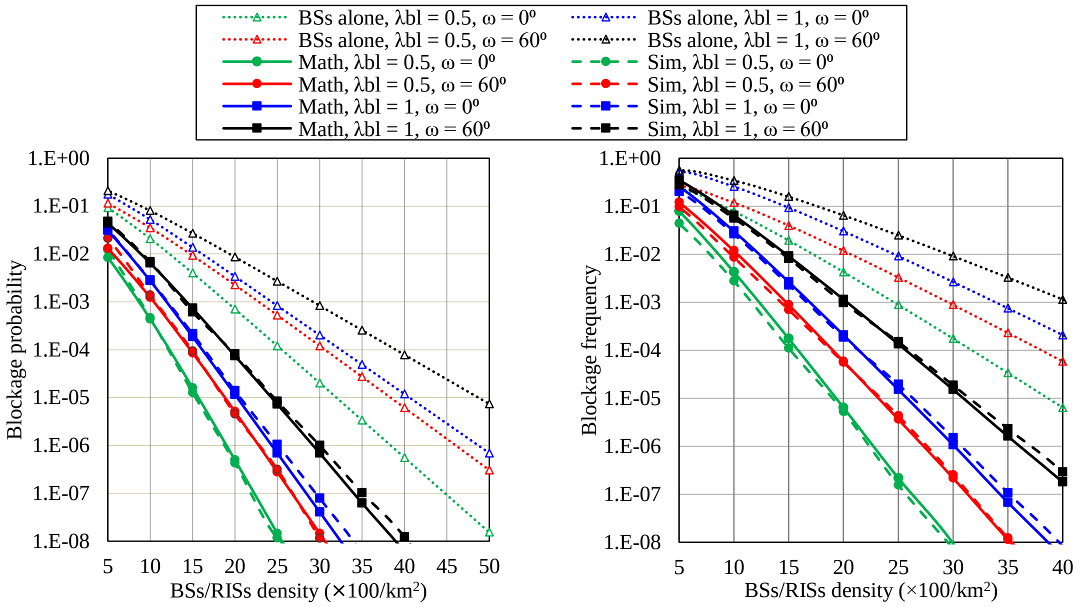


Figure 4-1 Conditional dynamic blockage probability given the coverage versus BSs/RISs density.

Figure 4-2 Conditional expected dynamic blockage frequency given the coverage versus BSs/RISs density.

4.3.2 The Impact of BSs/RISs Heights, Communication Range, and Dynamic Blockers Density

In this subsection, we present the impact of BSs/RISs heights, communication range, and blockers density on the BSs/RISs density, that is required to achieve 5G and beyond LRs, in Figures 4.6, 4.7, and 4.8, respectively. In the first two studies, we fix the dynamic blocker density at 0.5 and 1 bl/m2, while the self-blocking angle at 60°.

4.3.3 RISs aided Systems Performance under The Dynamic Blockage Occurrence

To evaluate the blockage occurrence effect on the system performance, we studied the performance versus the BSs/RISs density, transmitter SNR and RISs elements numbers in Figures 4.9-14 in the original thesis.

4.4 Summary

This Chapter discussed the following points:

- First, presenting a stochastic geometry based mathematical model for the dynamic blockage occurrence.

- Based on the blockage metrics, a planning of RISs aided networks can be done, where we studied the effect of the BSs/RISs density.
- Third, we present the network specifications, e.g., communication range and BSs/RISs altitudes, impact on the design of the network in terms of required BSs/RISs density, Moreover, we show the impact of the blocker density on the BSs/RISs density.
- Finally, the performance of RISs aided network is studied in terms of spectral efficiency and energy efficiency.

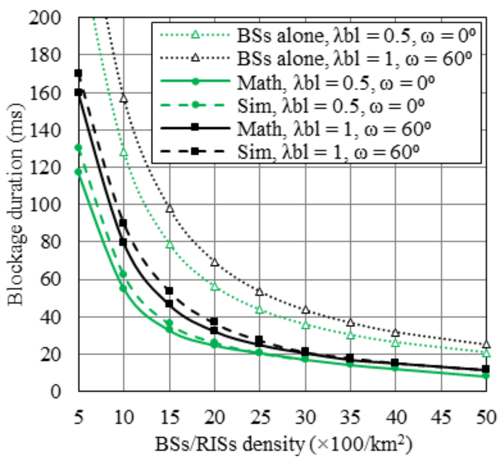


Figure 4-3 Conditional expected dynamic blockage duration given the coverage versus BSs/RISs density.

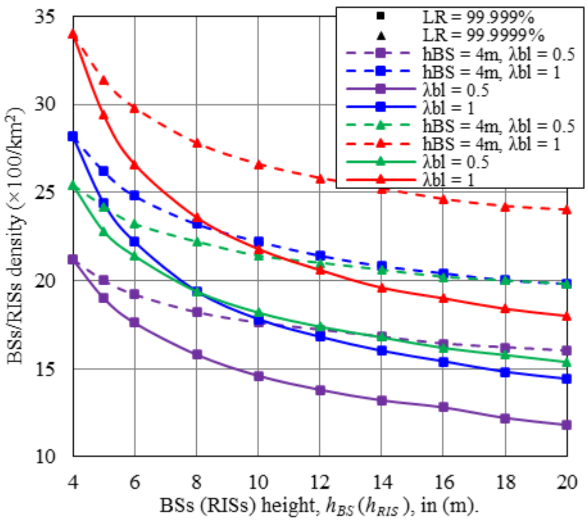


Figure 4-4 The required BSs/RISs density to obtain defined LR versus various BSs and RISs heights in RISs aided networks.

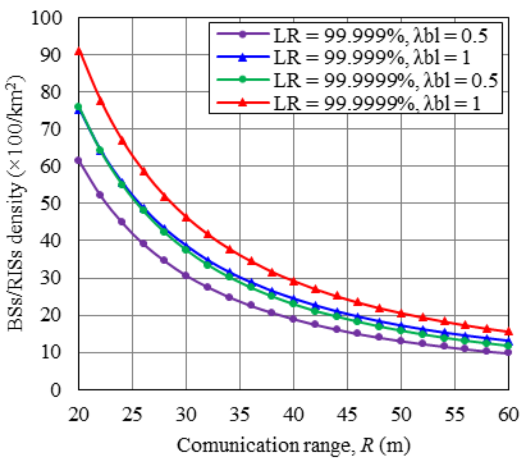


Figure 4-5 The required BSs/RISs density to obtain defined link reliability versus various communication range, R.

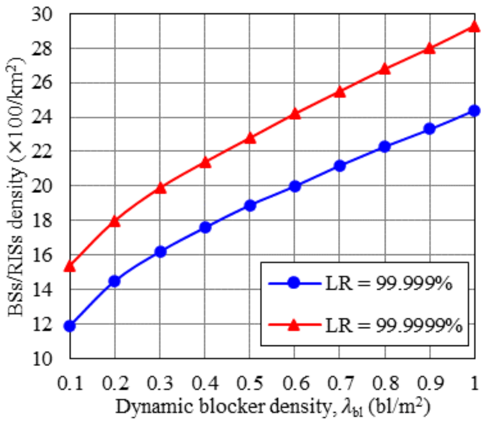


Figure 4-6 The required BSs/RISs density to obtain defined link reliability versus various blocker density, λ_{bl}.

Chapter 5

Solving RISs aided Networks Passive Beamforming Challenge

This Chapter focuses on providing a promising solution to RISs passive beamforming challenge. Our suggested solution is mainly depending on the availability of the UEs positioning information in the future networks aiming to overcome the limitations of the current codebook based PBF schemes. First, we design a dynamic and environmentally descriptive positioning information based codebook (PI-CB), then train the RIS configurations whether using the entire PI-CB or a partial version of the it. The partial PI-CB is constructed based on the matching check between the stored PI and the PI of the UEs requiring the BS services, hence further reduction in the overhead and complexity can be achieved comparable to searching over the full PI-CB. The two proposed PI-CB schemes guarantee better performance in respect of the effective obtainable data rate due to the low required overhead and complexity when adapting them. Furthermore, we prove that our schemes can be adapted in various use cases and channel conditions, however obtaining a high performance, because our CBs are environment independent. Noting that, to best of our knowledge, this is the first work in the literature that provides a descriptive steps and discussion regarding PI based PBF in RISs aided networks considering single and multiuser MISO system. Also, it clarifies the RIS size and positioning error impacts on the proposed schemes.

5.1 System Model

Determination of the A-PBF vectors is done using channel estimation based schemes or predefined CB based schemes aiming to achieve a certain objective function (OF) that normally maximizes a specific target metric, e.g., UEs sum rates, energy efficiency, etc. In our work, we jointly determining A-PBF vectors at the BS and RIS aiming to maximize the total UEs rate. The joint optimizing of A-PBF vectors OF is hard to solve within a short time. As the RIS is placed in fixed location, in front of buildings and walls, also the BS is fixed, determining $\mathbf{W}$ can be done once at the BS. This active beamforming (ABF) process can be performed by CE based schemes [31], or any suitable ABF scheme in literature [32]. Therefore, determining the PBF vector, i.e., RIS configuration pattern, $\boldsymbol{\Theta}$, has become our main focus, where we will depend on training predefined CBs concept to estimate the end-to-end BS-UEs channels.

5.2 Proposed PI Based Codebook Techniques

This section introduces the two proposed PI-CB schemes that we adapt for PBF process in RIS aided system. The proposed frameworks target enhancing the system depending on improving the first and second stages of the CBs based schemes.

5.2.1 Full PI-CB Design and Link Establishment Stages

The proposed full PI-CB is shown in Table 5-1. This PI-CB is flexible and adaptable depending on the environment; thus, it can efficiently and easily be designed in various use cases and scenarios. Figure 5-1 shows the procedure of the proposed full PI-CB scheme, noting that this procedure describes the CB design and BS-RIS-UEs link establishment framework in the first Q time frames. Thus, the proposed full PI-CB training overhead is $O(QK)$, meanwhile its computational complexity is $O(QMK^3)$.

Table 5-1 Proposed designed full PI based codebook.

Index	1	2	q	...	$Q-1$	Q
Positioning matrix	$\mathbf{P}_1$	$\mathbf{P}_2$	$\mathbf{P}_q$	...	$\mathbf{P}_{Q-1}$	$\mathbf{P}_Q$
PBF vector	$\boldsymbol{\theta}_1^*$	$\boldsymbol{\theta}_2^*$	$\boldsymbol{\theta}_q^*$	...	$\boldsymbol{\theta}_{Q-1}^*$	$\boldsymbol{\theta}_Q^*$

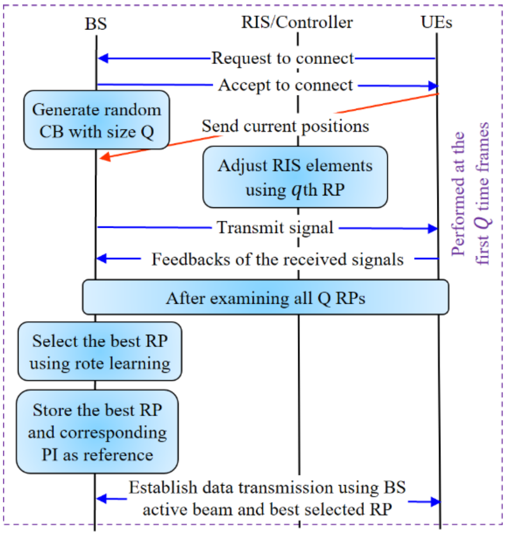


Figure 5-1 The procedure of the proposed full PI-CB scheme.

5.2.2 Proposed Partial PI-CB Scheme

In this subsection, we explain the steps of the proposed partial PI-CB technique, which is developed to further decrease the system overhead hence improving the overall system performance as shown in Figure 5-2. This PI-CB framework declines the system overhead to $O(Q_cK)$ and computational complexity to $O(Q(K^2(3^2+1)-1)+Q\log Q+Q_cMK^3)$. Moreover, its frame structure is similar to the one used in other CB based schemes, except in it, lower training symbols are required due to using a group of candidates codewords.

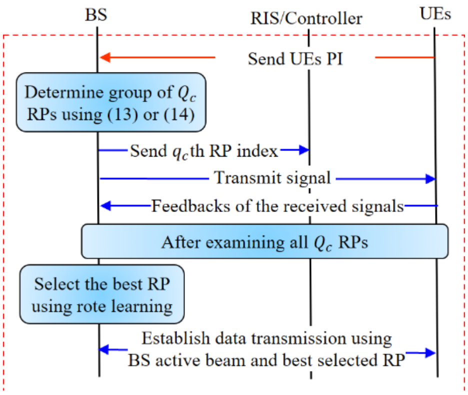


Figure 5-2 The proposed partial PI-CB scheme.

5.3 Numerical Simulation

This section discusses the proposed PI-CB schemes performance comparable to two benchmark mechanisms, namely CE & AO based scheme [22] and randomly generated CB based scheme. Also, we prove the outperformance of the proposed techniques in terms of the overall effective achievable rate, the system overhead and complexity. Furthermore, the superiority of the proposed PI-CB is proven with larger RIS under rapidly changing channels. In addition, the number of candidates RPs impact on the system performance is discussed, besides the effect of channel coherence time. Consequently, we can give an insight into the optimal number of candidates codewords to be chosen in RPs training group to guarantee balance between the obtained performance and the system overhead and complexity. Moreover, we study the robustness of the proposed partial PI-CB schemes against the localization error.

5.3.1 Scenarios and Simulation Parameters

In the numerical results, we consider RIS aided SU and MU MISO systems.

5.3.2 Results

5.3.2.1 The impact of different environments and CB size on the proposed full PI-CB approach

The proposed PI-CB scheme performance is shown in **Error! Reference source not found.**, and **Error! Reference source not found.**, for 2 UEs and 4 UEs, respectively, comparable to CE&AO based and random CB based schemes. Generally, our PI-CB approach proves its performance superiority over randomly generated CB based scheme under all cases and scenarios.

5.3.2.2 The impact of the candidate RPs number on channel coherence time on the proposed full and partial PI-CB approaches

In Figure 5-5, we emphasize on the proposed partial PI-CB based approach comparable to other schemes, i.e., full PI-CB, random CB, and CE&AO based schemes. In the partial PI-CB approach, the selected number of candidate RPs in the training group out of the entire CB effects the overall performance. Based on this study results, we can argue that the partial PI-CB scheme can still obtain high performance despite the reduction done in the system overhead due to training only a group of codewords.

Figure 5-6 (a) and (b) show the effective achievable rates when adapting various PBF schemes for single and multiusers cases, respectively, aiming to discuss the time-variant channel impact on our PI-CB schemes. Moreover, this part proves that the prior CE&AO performance is not real, because it assumes unlimited available training slots.

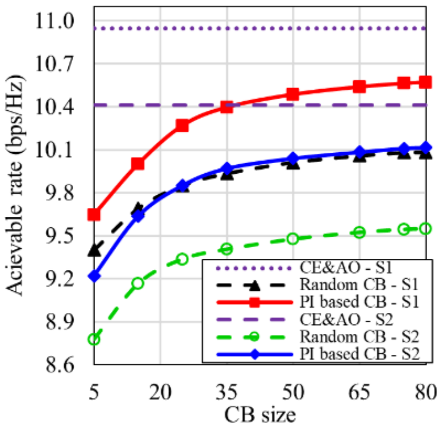


Figure 5-3 The achievable rate of all schemes in 2 UEs MISO case.

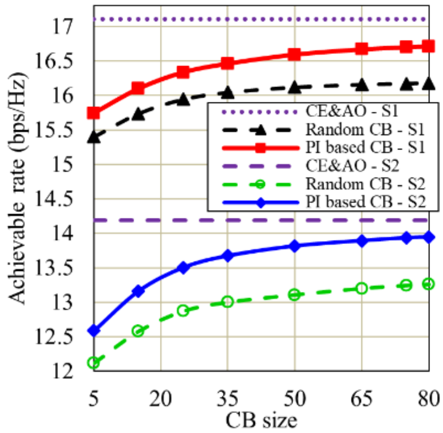
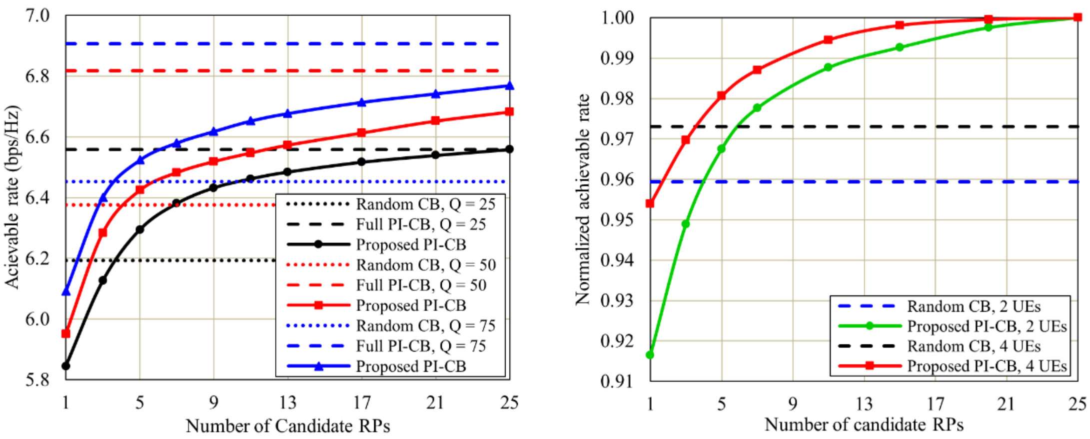


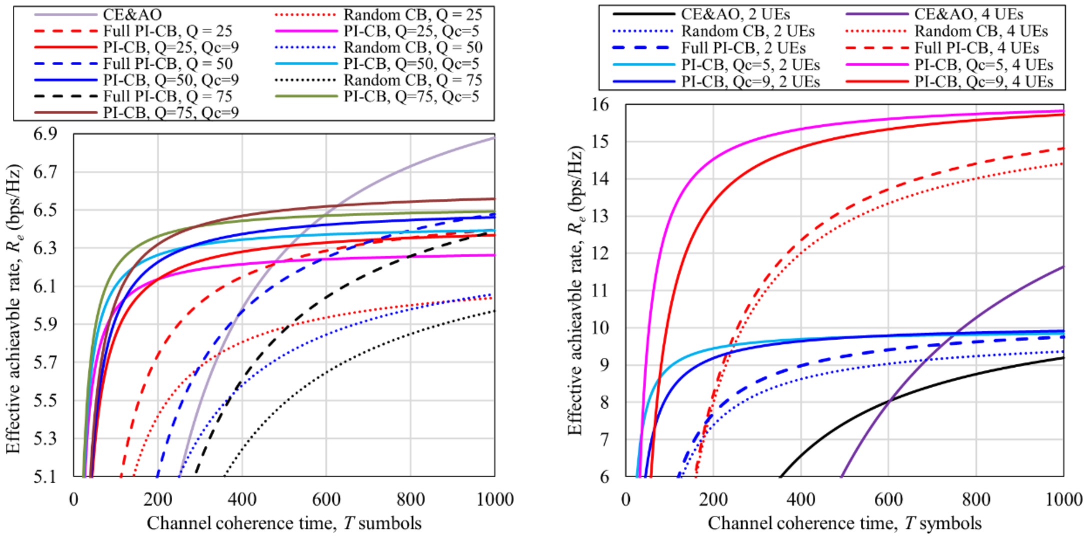
Figure 5-4 The achievable rate of all schemes in 4 UEs MISO case.



(a) *(b)*

Figure 5-5 (a) the PI-CB approaches' achievable rate in SU case assuming various CB sizes, (b) the normalized achievable rate of the PI-CB approaches in MU case assuming $Q = 25$, versus various number of candidate RP.

Based on Figure 5-5 and Figure 5-6, we can notice these insights: first, adapting the partial PI-CB scheme using $Q_c = 5$ and $Q = 25$ is the minimum requirements to achieve better performance than the CE&AO and random CB based approaches. Second, for more robust and higher performance under slow and medium time-variant channel conditions, it is recommended to use 9 candidate RPs. Moreover, a balance between achieved performance and computational complexity of selecting the candidate codewords can be done by choosing an applicable initial CB size, where this complexity is $\mathcal{O}(Q(K^2(n^2+1)-1)+Q\log Q)$, that means it linearly increases depending on CB sizes. Also, increasing of CB size doesn't mainly enhance the performance, as it saturates generally after $Q=75$, however, this CB size increase complicates the system. Finally, the proposed partial PI-CB scheme can guarantee higher effective achievable rates though multiusers scenarios and rapidly changing channels conditions are considered.



(a) *(b)*

Figure 5-6 The effective achievable rate when employing full or partial PI-CB compared to CE&AO and random CB based schemes, when Q_c equals 5 and 9, (a) in SU scenario assuming different CB sizes, (b) in MU scenario assuming $Q=25$.

5.3.2.3 The RIS elements number effect on the performance of the system

Figure 5-7, and Figure 5-8 show the proposed full, partial PI-CB, random CB, and CE&AO based schemes effective achievable rates, R_e, versus the RIS elements number in 2 UEs and 4 UEs cases, respectively.

The overhead of the RPs training aiming to estimate the channel is a vital factor that generates the system delay and complexity; however, the reflection pattern optimization process significantly impacts on the system complexity due to the requires process for configuring a high number of RIS elements. Note that the applied AO method needs a complexity of $\mathcal{O}(N_i N^{4.5})$, where N_i denotes the iteration number in AO algorithm [24]. On contrary, the proposed PI-CB scheme best RP selection complexity, or other CBs based approaches complexity, is $\mathcal{O}(QNK^3)$, that is notably lower comparable to the AO based scheme complexity, also the CB based scheme complexity is independent of the RIS elements number. Moreover, adapting the partial PI-CB scheme reduces this complexity as it replaces Q with Q_c which is lower.

Consequentially, Q and Q_c choosing shall be done carefully, considering the coherence time of the channel, to balance between the effective achievable rate and the system complexity. The computational complexity order of the best RP selection when adapting the partial PI-CB, full PI-CB, random CB and CE&AO approaches versus the

RIS elements number in SU and MU cases is shown in **Error! Reference source not found.** in our thesis.

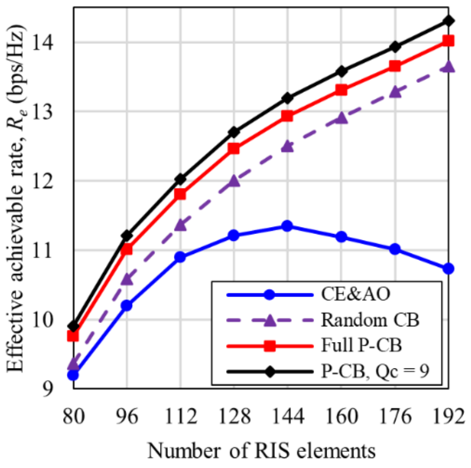


Figure 5-7 The PI-CB schemes effective achievable rate comparable to CE&AO and random CB based schemes rates in 2 UE case.

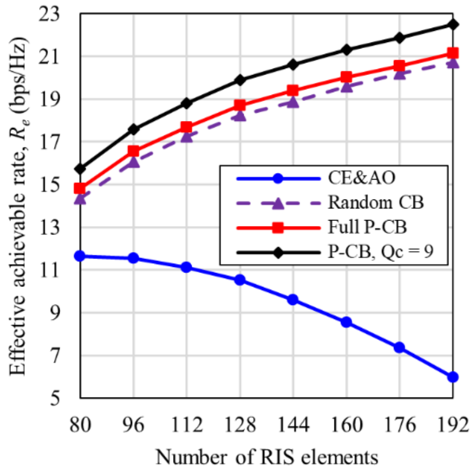


Figure 5-8 The PI-CB schemes effective achievable rate comparable to CE&AO and random CB based schemes rates in 4 UE case.

5.3.2.4 The localization accuracy impact on the proposed partial PI-CB approach

The positioning error slightly affects the achievable rate, especially when the group of training RPs contains a higher number of candidate codewords. These results can prove that the optimal number of candidate codewords selection can preserve the partial PI-CB scheme performance even if the provided positioning information has high error, and we can notice that this optimal number is 9 candidate RPs in our partial PI-CB approach. Furthermore, by adopting the proposed scheme with 9 elected RPs, a better performance can be achieved.

5.4 Summary

This Chapter mainly discussed the following points:

- First, we proposed an environmentally aware PI-CB approach for RIS passive beamforming to overcome low performance and high overhead issues.
- Second, for further enhancing, we propose a partial PI-CB scheme based on utilizing the stored UEs PI.
- Third, we consider different environments and dynamic channels’ conditions to prove the ability of obtaining high performance using the proposed schemes.
- Moreover, we studied the impact of the candidate RPs number on the performance of the partial PI-CB approach. Furthermore, we discuss the effect of the RIS size and the positioning error on the full and partial PI-CB based schemes performance.

Chapter 6

Conclusions, Publications, and Future Research Suggestions

In this thesis, we focused on three directions to contribute to future 5G and beyond networks.

6.1 Conclusions and Main Contributions of the Thesis

For the first direction, we propose a new scheduling scheme to be adapted in 5G network aiming to provide high QoS for the UEs in eMBB applications. For the second direction, we are concerned about the design of 5G and beyond networks considering the existence of the blockage phenomena, where we aim to meet the future requirements of link reliability and end-to-end latency. In the third part of the thesis, we suggest two PI-CBs schemes for RIS passive beamforming to overcome the limitations existing in the prior CB based methods.

6.2 Overview of Additional Research Contributions

During the PhD stage, several works have been done and presented as published papers, however they are not included in the Chapters of this thesis aiming to preserve the coherence and the tightness of the thesis. These works provide some insights and contributions to the communication society, and they are:

- Demand based Proportional Fairness Scheduling for 5G eMBB Services
- A Survey on the Human Blockage Effects on the mmWave Communication Systems Performance
- The Human Blockage Effect on The RIS aided Sub-THz Communication System Performance
- The Impact of The Human Blockers on ARIS Assisted D2D Networks
- Two RISs Optimal Placement in Beyond 5G Indoor Network
- RISs Optimal Placement in Multi RISs aided Wireless System
- Neural Network Based RISs-UEs Association
- A Codebook Solution based on RXs Directions for RIS Passive Beamforming
- Fingerprint Based CB for RIS PBF Training

6.3 List of Publications

6.3.1 Journals Papers

1) **A. M. Nor**, O. Fratu and S. Halunga, "The Mobile Blockers Impact on RISs Aided mmWave/THz Communication Systems," in *IEEE Open Journal of the Communications Society*, vol. 5, pp. 3151-3169, 2024, doi: 10.1109/OJCOMS.2024.3398505. (Q1, IF: 7.9)
2) **A. M. Nor**, O. Fratu and S. Halunga, "Positioning Information-Based Codebook for Reconfigurable Intelligent Surface Passive Beamforming," in *IEEE Open Journal of the Communications Society*, vol. 4, pp. 3115-3130, 2023, doi: 10.1109/OJCOMS.2023.3334474. (Q1, IF: 7.9)
   WOS:001162986000002
3) S. Hussein, O. A. Omar, **A. M. Nor**, O. Fratu, S. Halunga and A. S. Mubarak, "Reconfigurable Intelligent Surfaces-assisted Enhanced Spatial Modulation for Future wireless networks," in *IEEE Access*, doi: 10.1109/ACCESS.2023.3339644
   WOS:001127145600001. (Q1, IF: 3.9)
4) **Nor, A.M.**; Fratu, O.; Halunga, S. Fingerprint Based Codebook for RIS Passive Beamforming Training. Appl. Sci. 2023, 13, 6809. doi: 10.3390/app13116809. (Q2, IF: 2.7)
   WOS:001005655400001
5) **A. M. Nor**, Octavian Fratu, and Simona Halunga. 2022. "Quality of Service Based Radio Resources Scheduling for 5G eMBB Use Case" Symmetry 14, no. 10: 2193, doi: 10.3390/sym14102193. (Q2, IF: 2.7)
   WOS:000873685500001
6) **A. M. Nor**, Simona Halunga, Octavian Fratu, "Survey on positioning information assisted mmWave beamforming training" in *Ad Hoc Networks*, Vol. 135, 2022, 102947, doi: 10.1016/j.adhoc.2022.102947. (Q1, IF: 4.8)
   WOS:000842936100001
7) **A. M. Nor**, Simona Halunga, Octavian Fratu, "Neural Network Based IRSs-UEs Association and IRSs Optimal Placement in Multi IRSs Aided Wireless System", Sensors, 2022, no. 14: 5216, doi: 10.3390/s22145216. (Q2, IF: 3.9)
   WOS:000833162500001

6.3.2 Conferences Papers

1) **A. M. Nor**, O. Fratu and S. Halunga, "The Human Blockage Impact on ARIS Assisted D2D Communication Systems," 2023 12th International Conference on Modern Circuits and Systems Technologies (MOCAST), Athens, Greece, 2023, pp. 1-4, doi: 10.1109/MOCAST57943.2023.10176475.
   INSPEC:23454101
2) **A. M. Nor**, S. S. Sefati, O. Fratu and S. Halunga, "RXs Directions based Codebook Solution for Passive RIS Beamforming," 2023 IEEE International

Black Sea Conference on Communications and Networking (BlackSeaCom), Istanbul, Turkiye, 2023, pp. 330-335, doi: 10.1109/BlackSeaCom58138.2023.10299786.
INSPEC:24124380

3) **A. M. Nor,** O. Fratu and S. Halunga, "The Effect of Human Blockage on The Performance of RIS aided Sub-THz Communication System," 2022 14th International Conference on Computational Intelligence and Communication Networks (CICN), Al-Khobar, Saudi Arabia, 2022, pp. 622-625, doi: 10.1109/CICN56167.2022.10008332.
INSPEC:22513833
4) **A. M. Nor** et al., "Demand based Proportional Fairness Scheduling for 5G eMBB Services," 2022 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom), 2022, pp. 263-268, doi: 10.1109/BlackSeaCom54372.2022.9858321.
WOS:000865848800046
5) **A. M. Nor,** "Joint Proportional Fairness Scheduling Using Iterative Search for MmWave Concurrent Transmission," 2022 IEEE International Black Sea Conference on Communications and Networking (BlackSeaCom), 2022, pp. 257-262, doi: 10.1109/BlackSeaCom54372.2022.9858130.
WOS:000865848800045
6) **Nor, A.M.,** Fratu, O., Halunga, S. (2022). Optimal Placement of Two IRSs in Beyond 5G Indoor Network. In: Future Access Enablers for Ubiquitous and Intelligent Infrastructures. FABULOUS 2022. Lecture Notes of the Institute for Computer Sciences, Social Informatics and Telecommunications Engineering, vol 445. Springer, Cham. https://doi.org/10.1007/978-3-031-15101-9_3
INSPEC:22208247
8) S. S. Sefati, O. Fratu, **A. M. Nor** and S. Halunga, "Enhancing Internet of Things Security and Efficiency: Anomaly Detection via Proof of Stake Blockchain Techniques," 2024 International Conference on Artificial Intelligence in Information and Communication (ICAIIC), Osaka, Japan, 2024, pp. 591-595, doi: 10.1109/ICAIIC60209.2024.10463516.
INSPEC:24872688
9) S. S. Sefati, **A. M. Nor**, S. Halunga and O. Fratu, "A Novel Routing Protocol based on Prediction of Energy Consumption and Link Stability in Mobile Internet of Thing (MIoT)," *2022 25th International Symposium on Wireless Personal Multimedia Communications (WPMC)*, Herning, Denmark, 2022, pp. 12-16, doi: 10.1109/WPMC55625.2022.10014984.
WOS:000947852500005
10) O. Fratu, **A. M. Nor**, S. Halunga and Z. D. Zaharis, "RF Propagation and Interferences Challenges for UAVs Swarm Detection and Positioning," *2022 25th International Symposium on Wireless Personal Multimedia Communications (WPMC)*, Herning, Denmark, 2022, pp. 501-504, doi: 10.1109/WPMC55625.2022.10014750.
WOS:000947852500081

6.4 Possible Future Extensions

Through our investigations in this thesis and the other research papers related to 5G and beyond network enhancement topic, many ideas have come into our mind. However, due to the time, we couldn’t study or apply these improvements. Moreover, some thoughts are outside of my knowledge and experience as a PhD student. In the following, I will try to give a brief discussion about how some improvements can be added to enhance the methods and the algorithms that we suggested in our works.

Regarding radio resource management topic:

- MIMO system shall be considered instead of MISO to increase the network performance regarding the throughput.
- Moreover, adapting MIMO systems will open the direction for further research because UEs clustering and scheduling should be jointly performed and optimized to maximize the overall network performance.
- Moreover, available context information, e.g., UEs positions, data rates, links reliability, and latencies, should be considered when performing UEs clustering and scheduling.

For the topic of the impact of the blockage phenomena on 5G and beyond network performance, we suggest the following extensions:

- First, studying the blockage impact on more generalized networks, where flying RISs, BSs, UEs can exist.
- Moreover, the system performance of the hybrid and stacked RISs aided networks can be investigated considering the blockage occurrence.
- In addition, link blockage expectation algorithms shall be developed in RISs aided networks to be able to eliminate the blockage impact on the RIS-UE link. Regarding blockage expectation between the BS and UE in mmWave networks, some prior works [33], [34], [35] have achieved good results.

Regarding passive beamforming challenge:

- we suggest designing more dynamic CBs.
- In addition, updated CI can play a role in updating the group of the trained RPs, when the received signals at the UEs are reduced due to UEs mobility.
- Moreover, new techniques can be suggested for the learning stage in the CB based PBF schemes.

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