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Analysis of LTE Radio Parameters based on Present and Future Networks.

A Dissertation Submitted in Partial Fulfillment of Requirement for the Degree of Bachelor of Science in Electrical and Electronic Engineering

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Declaration of Candidate

It is hereby declared that this thesis or any part of it has not been submitted elsewhere for the award of any Degree or Diploma.

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Abstract

Scheduler scheme in 4G LTE and its future releases, LTE-A an LTE-A Pro, is a major parameter which has direct impact on the UE demands (e.g. throughput) and efficiency. While deploying a new network at a particular site, we have to consider as to what scheduler needs to be adopted. Transmission mode, on the other hand, indirectly decides how much UE and also coverage area can be provided by the base stations (eNodeB). An extensive study of what transmission modes & scheduler are to be chosen for different sites, has been made in our book. The analysis was carried out by a MATLAB based non-commercial simulator where a downsized version of the original source was used, incorporating all the necessary network parameters, to better understand impacts of changing network parameter in a practical environment. Necessary simulations were carried out and results were observed. Based on the speculations, we reached some inferences, of which the most significant would be that, no one transmission mode or scheduler configuration is the absolute best. It all depends on what goals are to be achieved for a network at a particular site.

Another work was based on study of NOMA, a transmission technique based on PDMA, whose main focus is to increase the number of UE per cell, by using the power domain, i.e. the UE will have different power levels according to their position. Here a general discussion along with some drawbacks (ICI) and their possible feasible solutions were described in this book. Since, 5G network aims to provide a higher bandwidth with an increased number of users, NOMA is one of the feasible choices in terms of transmission techniques over OFDMA, due to its capability to accommodate higher number of users.

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Symbols and Acronyms

ASE	Average Spectral Efficiency
CoMP	Coordinated Multipoint
NOMA	Non-Orthogonal Multiple Access
TxD	Transmission diversity
OMA	Orthogonal Multiple Access
Tx	Transmitter
Rx	Receiver
FDMA	Frequency Division Multiple Access
TDMA	Time Division Multiple Access
CDMA	Code Division Multiple Access
PDMA	Power Division Multiple Access
MU MIMO	Multi User Multiple Input Multiple Output
MC MIMO	Multi Cell Multiple Input Multiple Output
RRH	Remote Radio Head
eNB	eNodeB
UE	User Equipment
GSM	Global System for Mobile Communications
FRA	Future Radio Access
MMS	Multimedia Messaging System
DVB	Digital Video Broadcasting
HDTV	High Definition Tele-Vision
RR	Round Robin
PF	Proportional Fair Sun
CQI	Channel Quality Indicator
OLSM	Open Loop Spatial Multiplexing
CLSM	Closed Loop Spatial Multiplexing
WPAN	Wireless Personal Area Network
NOMA JT	NOMA Joint Transmission

NOMA DCS	NOMA Dynamic Cell Selection
FFR	Fractional Frequency Reuse
ICI	Inter Cell Interference
SIC	Successive Interference Cancellation
TPA	Transmit Power Allocation
BS	Base Station
LTE	Long Term Evolution
QoE	Quality of user Experience
TBS	Transmit Buffer Status
MCS	Modulation and Coding Scheme
RE	Resource Element
RB	Resource Block
UWB	Ultra-WideBand networks
GFDM	Generalized Frequency Division Multiplexing,
UFMC	Universal Filtered Multicarrier,
FBMC	Filter Bank Multi-Carrier
MMW	millimeter Wave
LAS-CDMA	Large Area Synchronized Code-Division Multiple Access
OFDM	Orthogonal Frequency-Division Multiplexing
MCCDMA	Multi-Carrier Code Division Multiple Access
LMDS	Local Multipoint Distribution Service
SMS	Short Message Service
WWWW	World Wide Wireless Web
DAWN	Dynamic Ad-Hoc Wireless Networks
UMTS	Universal Broadband Telecommunications Service
WiMAX	Worldwide Interoperability for Microwave Access
Wi-Fi	Wireless Fidelity
LAN	Local Area Network
WAN	Wide Area Network

WSN	Wireless Sensor Network
IEEE	Institute of Electrical and Electronics Engineers

Chapter 1

Introduction

Communication is a constantly developing field. Due to the inexorable increment of the number of IoT (Internet of Things) devices across the globe, the prediction is that there will be at least 100 billion devices connected to wireless networks within the next decade [1]. Such a context will demand networks to be able to support as many users as possible without mitigating spectral efficiency and user fairness. For all kinds of wireless communication, multiple access is a requirement. The generations of communication technologies are differentiated on the basis of their multiple access schemes. All the prevalent multiple access schemes: frequency division multiple access (FDMA) for 1G, time division multiple access (TDMA) for 2G, code division multiple access (CDMA) for 3G and orthogonal frequency division multiple access (OFDMA) for 4G and 5G. Our work is mainly focused on 4G and partially on 5G. Although 4G is being used for several years, the upgrade to 5G hasn't been possible yet. Additionally, 4G has been launched very recently in many 3rd world countries such as Bangladesh.

In the more advanced digital cellular networks, the service area covered by providers is divided into small geographical areas called cells. The transmitted data is not always digital, such as, audio and video signals. The analog signals are in fact converted by an analog to digital converter and transmitted in the form of bits.

Our objective is to increase throughput and spectral efficiency by keeping transmission and reception as economic as possible. We have done that by changing various parameters of our LTE environment.

1.1 Evolution of Cellular Technologies

1G:

This is the first generation of cellular technologies where analog signals were transmitted and received. Only voice call was possible in this technology. This was later replaced by 2G.

2G:

The main difference between 1G and 2G is that the radio signals used by 2G are digital whereas those of 1G were analog. Digital transmission has lower power requirements and 2G introduced SMS, picture messages and multimedia messaging services. 2G uses FDMA or TDMA multiplexing techniques and GSM technology. 2G also supports more users per frequency band. Channel bandwidth is 30-200 kHz for voice transmission. Before the advent of 3G there are two intermediary stages of 2G: 2.5G and 2.75G which use GPRS and EDGE technologies respectively. 2.5G uses a packet switching technique and has a data rate of 44-171.2 kbps on the back of 9.6-19.2 kbps for 2G. 2.75G further enhances the data rate of 2.5G by supporting 384 kbps, more than double than that of 2.5G.

3G:

The massive upgrade from 2G had a huge impact in the communication world allowing video transmission for the first time. The basic 3G version of telecommunication uses CDMA and has a data rate of at least 144 kbps pushing it up to 1.92 Mbps. Bandwidth for 3G is 15-20 MHz. Applications of 3G further include wireless voice telephony, mobile Internet access, fixed wireless Internet access, video calls and mobile TV. The later releases of 3G are 3.5G and 3.75G supporting massive data rate upgrades. The data rates of 3.5G are 14 Mbps (DL) and 5.76 Mbps (UL) while that of 3.75G are 42 Mbps (DL) and 12 Mbps (UL).

4G:

3G is not enough to fulfill the needs of future high-performance applications like multi-media, full-motion, wireless teleconferencing. Multiple standards for 3G make it harder to roam and operate across networks, so a scheme with higher data rate was developed. 4G is the fourth rendition in wireless communication. 4G is an all IP-based system using OFDMA that is capable of 100 Mbps for high mobility and 1 Gbps for low mobility with end-to-end quality of service (QoS) and high security. It can support higher number of user equipment (UEs) with smoother handover. Its maximum bandwidth is 100 MHz.

4G is most widely used now. It has even made its way up to third world countries and thus this is the point of our focus. Our work strongly focuses on how to improve throughput in 4G communication under various scenarios.

5G:

5G is the next generation radio access technology. It increases the data rate of 4G from 1000 Mbps to a minimum of 10,000 Mbps, i.e. at least ten times faster than 4G. The theoretical latency of 5G data transmission is supposed to be 1ms which is yet to be achieved. 5G is supposed to be launched in 2020 worldwide. This new standard will use a new band of radio spectrum from 4G. 5G will use “millimeter waves”, broadcast at frequencies between 30 and 300 GHz. 5G will support 100 times more devices than 4G in this up and coming age of IoT.

Millimeter Waves:

Millimeter waves are radio waves within the frequency range of 30-300 GHz. It has attracted a lot of attention due to its capacity to meet the requirements of 5G network. Although the available bandwidth of mm-Wave frequencies is promising, the propagation characteristics are significantly different from microwave frequency band in terms of path loss, diffraction, fading etc. In general, the overall loss of mm-Wave systems is higher than that of microwave systems for point-to-point link because mm-Wave cannot pass through solid objects. However, the small wavelengths of mm-Wave enable large numbers of antenna elements to be deployed in the same form factor, so it will provide high spatial processing gains that can theoretically compensate for the path loss. The performances may differ depending on the transmission mode, e.g. beamforming.

1.2 Network Planning

Generally, the term ‘Network Planning’ refers to the problem of a given location where connectivity is to be provided using a set of nodes, at minimum cost, network geometry considering the hardware, the antenna type and orientation and radio transmission powers and other parameters. There must be a balance among power, interference, performance (throughput, spectral efficiency and latency). The objective of network planning is to interconnect different equipment in order to share the allocated resources among several users. Network planning comprises of a sole objective is to be achieved. Our work is to achieve higher overall throughput without compromising much of the spectral efficiency and user fairness by altering the relevant parameters.

The main advantage of network planning is being able to simulate different scenarios without having to implement them in real life. In fact, implementing each and every theoretical scenario can be very costly, inefficient and it will also hamper the regular services of the communication system. Network planning can be performed by using various simulation software.

Our work has been done via MATLAB based simulations which consider even the most fundamental parameters of 4G communication, e.g. physical parameters of transmitter and receiver, scheduler configuration, transmission modes etc.

1.3 Literature Review

System level simulators are the basis of deploying new network technologies [19], since it can evaluate the performance of the networks beforehand. These simulators help to decide whether the deployment would be efficient or not. There are various simulators, most of them have their physical layer model based on the post equalization SINR and also provides us with pre-calculated fading parameters including interference. Fading parameters are taken from practical cases and they are pre-generated offline vastly reducing computational complexities. It also provides with various kinds of transmission mode with the freedom to tweak it to the operator's need to a certain degree depending on whether the simulator is commercial or academic.

Amongst the physical parameters, the height difference between the eNB and the UE is prominent. As we know, if the height of the base station is higher, it provides better coverage area and less interference. But recently, a theoretical discovery was made on the fact that for Ultra-Dense Network (UDN), if the absolute height difference between the eNB and UE is greater than zero, the more it increases from zero, the network performance in terms of coverage area and ASE will continuously decrease towards zero [5]. The main problem of ASE crash or the reduction of ASE to zero, can be either mitigated by reducing the size of the eNBs to the average UE height, pro-active muting of eNBs, cooperation of eNBs, dynamic beam tracking etc. which is a topic for future research.

Resource allocation to the users are done on the basis of various scheduling algorithms [2,6,8,9,10,12,13,15,16]. Definitely, all the algorithms designed have their pros and cons related to other network parameters like density, mobility transmission mode etc. No one scheduler can claim the absolute best spot, which is the main basis of our analysis and gives rise to the extensive comparative study associated with needs of the users. The tradeoffs need to be considered while using any scheduler configuration, and whether it satisfies majority.

Moreover, a heterogeneous network [6, 9] can also be used to boost the throughput of the users, where the coverage area is lesser, by means of a repeater, or in technical terms the most popular ones are femtocells and Remote Radio Head (RRH).

Generally, the transmission mode used for the LTE case is Closed Loop Spatial Multiplexing (CLSM) and nowadays every cell is designed considered to be ultra-dense networks, with some exceptions in hand. The main concern is the ever-changing parameter, the UE mobility [8]. Since, on average, in practical scenarios, no UE remains fixed in its position, rather they are moving at different velocities almost all the time. As a result, handover occurs all the time, which brings us to take new approach to decide on which scheduler configuration will be most suitable for a particular case.

Fairness index [17] proposed by Raj Jain, is a fundamental variable in cellular communication. It defines how fair a scheduler is to the users. But there is some tradeoff between fairness index and efficiency of data transmission or more specifically the spectral efficiency. Analyzing the commonly-used α-fair tradeoff policy, it is shown that, except for the case of $M = 2$ users, this policy does not necessarily achieve the optimal Efficiency-Jain tradeoff. In particular, it is shown that, when the number of users $M > 2$, the gap between the efficiency achieved by the α-fair and the optimal Efficiency- Jain tradeoff policy can be unbounded, for the same Jain's index.

CoMP (Coordinated Multipoint) is a scheduler [3] where a UE is connected to more than one eNBs and receives its message from all the eNBs. As a result, there is a better transmission efficiency, which is obvious for the static case, since it takes the message with least interference at the cost of increased latency and backhaul traffic, which potentially reduces the throughput. But in case of UE mobility, there is further degradation of SINR. So various schedulers have been compared for CoMP with dense networks and high velocity UE. Amongst the chosen CS (Coordinated Scheduling) schedulers, C-CS (Centralized CS) outperforms D-CS (Distributed CS) in all cases, also C-CS provides a higher fairness index. It is due to the fact that in C-CS has a centralized eNB which decides for all the resource allocation, but in D-CS resource allocation is done in all eNBs, as a result of which there is ICI (Inter Cell Interference).

One more key problem of CoMP is that due to UE being connected to multiple eNBs, the data set increases significantly. Managing this data set is also tedious, for which a method called runtime precoding [11] is implemented. It accounts for coherent transmissions while keeping the additional complexity to a minimum.

MM-Wave [2, 14] is an important technology for the establishment of 5G cellular communication. Since it was predicted earlier that the congestion of network would gradually increase, for which we will need more bandwidth, so as a result the use of mm-wave became more prominent in these cases. In order to improve capacity and service quality in urban areas where there is presence of ultra-dense network, the cellular network architecture needs to support higher spatial reuse. So some campaigns were carried out in the past amongst which the 28 GHz building penetration and reflection campaign in New York City, 28 GHz urban propagation campaign in New York City and 38 GHz cellular urban propagation campaign in Austin by researchers for collecting practical data on the nature of mm-wave and how well it practically performs in a practical scenario. The main components that those researchers accounted for are: angle of arrival (AOA), angle of departure (AOD), path loss, RMS delay spread and building penetration and reflection capabilities of mm-wave.

LTE-V is a comparative and almost similar study of LTE technologies [1]. It differentiates in the form that it specializes in high mobility UE networking i.e. with vehicles. Since we are dealing with high velocity UE in this case, the communication with eNBs which are rather static, compromises the spectral efficiency, throughput, while increasing the latency. So, in 3GPP release 14, LTE-V adopted Side Link (SL) channel communication, which promotes the inter UE communication. These are yet to be deployed since various parts of it are quite unexplored, so a comparison was made amongst the channel with dynamic characteristics in terms of throughput and BLER (Block Error Rate) against few radio parameters which will facilitate for further insight into the matter.

Non-orthogonal multiple access (NOMA) has gained tremendous attention in developing fifth-generation (5G) wireless networks and beyond mobile connectivity strategies[21,22,42] .The basic concept behind NOMA is to serve more than one user in the same resource block, e.g. a time slot, subcarrier, spreading code, or space[23,32]. With this, NOMA promotes massive connectivity, reduces latency, enhances user fairness and spectral efficiency, and increases reliability compared to multiple access orthogonal (OMA) techniques.

As an applicant for FRA multiple access system, a downlink non-orthogonal multiple access (NOMA) scheme is suggested where multiplexed users are performed on the transmitter side in the power domain [31,39,44] and on the receiver side multi-user signal separation on the basis of successive interference cancellation (SIC) [42]. Two coordinated BSs using Alamouti code is suggested to support a common cell-edge user in [32] for a coordinated two-cell transmission. SISO channels are taken into consideration in [32]. MIMO beamforming is employed in NOMA such that the MIMO channels are transformed into multiple paralleled SISO channels and signals to multiple users are superimposed. [27,28,33,37,38] For the MIMO channel, coordinated beamforming schemes are developed based on interference alignment for a two-cell downlink system in [33], where interference channels (IFCs) are taken into account. Each user is assumed to have a single data stream [33]. The issue of precoder model optimization is explored in multi-cell MIMO downlink IFCs [34], taking into account multiple data sources for each user.

Chapter 2

4G & 5G

The world's telecommunications infrastructure has made a big leap in recent years. Cellular wireless technology has undergone 4 to 5 waves of technological innovation and development over the last few decades, namely from 1 G to 5G. First generation (1 G) was used analogically only for voice calls. The second generation (2 G) is a digital technology that facilitates text message. Mobile technology of the third generation (3 G) offered a higher rate of data transmission, increased capacity and multimedia aid. The fourth generation (4 G) combines 3 G with broadband networks to enable cellular wireless internet, an upgrade of mobile technology that overcomes 3 G's shortcomings. It also increases the capacity and reduces the energy cost. 5 G stands for 5th-generation mobile technology and is poised to be a new mobile industry innovation that has changed the way cell phones are used at a very high bandwidth. To continue to ensure the viability of mobile communication networks over the next decade, it is necessary to identify and develop new technology solutions that can adapt to future challenges. In view of the anticipated exponential increase in mobile traffic size, e.g. beyond a 100-fold increase in the next decade, significant gains over capability and reliability of user experience are needed in the 2020s-era.

2.1 Concept of 4G LTE

Along with Ultra Mobile Broadband (UMB) and Wi-Max (IEEE 802.16), 4 G LTE is one of several existing 4G networks. LTE means Long Term Evolution, it is a 4G wireless communications protocol developed by the 3rd Generation Partnership Project (3GPP) intended to provide up to 10x the speeds of 3G networks. During stationary mode, 4 G networks should provide a maximum speed of more than 100 Mbits per second with an average speed of 20 Mbits per second while driving. Despite Verizon and AT&T offering 4G LTE networks and Sprint introducing a latest 4G Wi-Max network, the major cellular providers have started to introduce 4G services. 4G networks are designed to deliver IP speech, information and video transmission at rates of at least 100 Mbit per second and up to 1 Gbit per second. It is being established to satisfy the QoS and speed criteria for future applications such as wireless broadband communication, Multimedia Messaging System (MMS), video messaging, interactive television, HDTV content, Digital Video Broadcasting (DVB), limited voice and data services, and other bandwidth-using service providers. It is foreseen that 4 G wireless networks will be understood in the early 2010s, but numerous predecessor systems and facilities have arrived late.

2.2 Basic Features of 4G

- Theoretical data rate of 4G LTE-Advance is 1 Gbps for downlink & 500Mbps for uplink.
- There are several scheduling techniques available that prioritize maximizing any of the key performance parameters of the system including the most possible algorithms being proportional fair (PF), round robin (RR), best CQI.
- LTE supports multiple MIMO methods to increase performance, including heterogeneity distribution (TxD), closed loop spatial multiplexing (CSLM), open loop spatial multiplexing (OLSM) etc.
- LTE's main goals are to provide high-speed data, enhanced spectral efficiency and lower latency. As it advances on the basis of UMTS, LTE uses multiple access (OFDMA) orthogonal frequency division for downlink communications eliminating inter-symbol interference (ISI). NOMA technique is also used in 4G for better spectral efficiency & a large number of users.
- To boost UEs efficiency, several features have been added in its recent releases, femto-cells are one of many possible approaches.
- It is combination of Combination of Wi-Fi and Wi-MAX.
- It must facilitate global roaming through various mobile or wireless networks. It provides much more choice in the collection of vendors.

The key technologies needed for 4G are listed below:

OFDM

Orthogonal Frequency Division Multiplexing (OFDM) offers not only clear advantages for the quality of physical layers, but also a mechanism for improving the performance of layer 2 by providing an extra degree of freedom. The time domain, the space domain, the frequency domain, and even the code domain can be exploited using ODFM to optimize the use of radio channels. This enables very reliable communication with decreased flexibility of the transmitter in multi-path settings. It is also compliant with other developments for development such as intelligent antennas and MIMO. It is also feasible to use OFDM modulation as multiple access technology (Orthogonal Frequency Division Multiple Access; OFDMA).

Multiple-input Multiple-output (MIMO)

MIMO utilizes multiplexing of signals between multiple transmission antennas (multiplex space) and time and frequency. It is well adapted for OFDM, as individual time symbols can be interpreted as long as the OFDM waveform is properly designed for the channel. In theory, when obtaining several multiple path signals, MIMO is more effective. Research and simulations are still subject to success in cellular deployments. Nonetheless, the benefit in spectrum efficiency is commonly agreed to be directly linked to the minimum number of antennas in the connection.

Handover and Mobility

Information and speech transmission systems are considered focused on cellular IP software. Cellular IP strategies are sluggish, but with classical methods (hierarchical, fast mobile IP) can be accelerated. Such approaches refer to information and likely to voice as well. There is the same option in OFDM as in CDMA, utilizing macro-diversity. In the case of OFDM, MIMO makes efficiency benefits macro-diversity storage. Implementation of macro-diversity, though, means hierarchical MIMO storage and synchronous transmissions.

Caching and Pico Cells

Network storage and switches render service delivery simpler. It expands the MAC scheduler's functionality in cellular networks, as it enables the transmission of real-time resources. Only when the radio conditions are favorable will assets be devoted to information. Through pico-cellular coverage, even if reception / transmission is delayed for a few seconds, high data rate (non-real-time) networks can be provided. The geographic area within which information can be received / transmitted can therefore be configured without reducing intervention. For situations where the bit rate is a peak, information transmission is favored.

Coverage

By adding new technologies (possibly in overlay mode) and gradually increasing density, coverage is achieved. For example, consider a WiMAX deployment: first the parent coverage is deployed; then it becomes denser by inserting discontinuous pico-cells, after which the pico-cell becomes denser yet discontinuous. This approach can double a traditional cellular system's efficiency.

CONCEPT OF 5G:

5G Technology stands for mobile technology of the 5th generation which began in the late 2010s. Facilities that could be seen in 5 G networks provide far better connectivity and coverage rates. 5 G should concentrate on the Wireless World Wide Web (WWWW). Work on the advancement of World Wide Wireless Web (WWWW), Dynamic Ad-Hoc Wireless Networks (DAWN) and Real Wireless World includes various wireless and broadband systems such as third-generation mobile networks (UMTS- Universal Broadband Telecommunications Service, cdma2000), LTE (Long Term Evolution), Wi-Fi (IEEE 802.11 wireless networks), WiMAX (IEEE 802.16 wireless and mobile networks). 5G technology provides incredible network capacities and the ability to link unlimited quantities of calls and limitless data transmission within the new mobile operating system. It has a bright future as it can accommodate the latest devices and provide its users with luxurious handsets. Perhaps 5G technologies will take over the world market in the next few days. It is a cellular packet switched network with wide coverage and high performance. It utilizes OFDM, millimeter wave technology or NOMA allowing 20 mbps bandwidth and 2-8 GHz frequency bands. Fifth generation should be smarter software that unrestrictedly interconnects the whole planet. It is expected to release this generation around 2020. The Internet of Things (smart home appliances, connected vehicles, etc.) is expected to grow rapidly over the next 10 years, creating a network capable of having billions of connected devices.

2.3 Basic features of 5G

- 4G networks are theoretically able to achieve average download speeds of one gigabit per second, although it is never that effective in actual practice. This would grow to 10Gbps for 5G.
- LAS-CDMA (Large Area Synchronized Code-Division Multiple Access), OFDM (Orthogonal Frequency-Division Multiplexing), MCCDMA (Multi-Carrier Code Division Multiple Access), UWB (Ultra-wideband), Network-LMDS (Local Multipoint Distribution Service), and IPv6 enable the 5th cellular mobile Internet networks.
- Internet protocol version 6(IPv6), where the mobile IP address of the guests is determined by position or associated network.
- Networks for high altitude stratospheric station platform (HAPS). 5 G communication systems network software was proposed to be based on beam division multiple access (BDMA) and team collaborative relay strategies in a Korean research and development project.
- 5 G will also get the most out of any piece of spectrum across a broad range of available regulatory spectrum paradigms and frequencies — from small bands under 1 GHz and mid bands between 1 GHz and 6 GHz to medium bands known as millimeter waves.
- It will support 100 times the capacity of traffic and network efficiency.

2.4 Challenges faced by 5G

- Standardization is one of the major challenges confronting 5G. Multiple groups are already working to develop specifications of interoperability, historical continuity to older technologies (4 G, 3 G), or ensuring that the network is future-proof.

- 5G is likely to rely on higher-frequency bands, at least in part. There is more space available in these airwaves, but at these high frequencies, signals cannot reach nearly as far as they can over the frequencies used for 4 G, contributing to a poor connection.
- For interconnecting different engineering activities, there is no specific architecture. There is a need for a common governing body which provides a common platform for all engineering practices to manage interconnectivity concerns as well as knowledge sharing.
- It can also cause interference, including houses, trees and even bad weather. In counter that, more base stations need to be built by operators to ensure better coverage and to use antenna technology such as MIMO.

2.5 Key 5G Technologies

Millimeter-Wave technologies

The use of far higher frequencies in the frequency spectrum opens up additional space and also offers the potential of a broad channel bandwidth-possibly 1-2 GHz. However, this poses new challenges for handset development where there are currently maximum frequencies of around 2 GHz and 10-20 MHz bandwidths in use. With 5 G, frequencies over 50GHz are expected and this will pose many real challenges in terms of circuit design, engineering, and also how the device is used as such frequencies do not move so far and are swallowed by barriers almost entirely.

Massive MIMO

MIMO is used in various systems from Wi-Fi to Wi-Fi, etc. Because of the antenna dimensions and wavelength spacing, the use of microwave frequencies opens up the possibility of using several hundreds of antennas on single equipment.

Future PHY / MAC

It will offer many possibilities for managing multiple control systems from the use of modern modulation technologies including GFDM, Generalized Frequency Division Multiplexing, FBMC, Filter Bank Multi-Carrier, UFMC, Universal Filtered Multicarrier, and other schemes. All of these must be produced. Higher processing rates usable by the time 5 G is deployed indicate multi-carrier networks do not need to be orthogonal as in OFDM. It offers much more versatility.

Adaptive array antenna

These antennas pledge to improve wireless network capability by offering enhanced security through position-location capabilities. This methodology avoids intrusion by spatial-altering-position location through direction-end measurements and through angle-of-arrival channel sounding calculation creation of enhanced channel models.

Ultra-Wideband networks (UWB)

Wi-Fi, Wi-Max and wide-area wireless networks are already considered to be long-range network technologies. Yet networks such as WPAN require short-range radio technology, which allows to achieve higher bandwidths (around 4000 Mbps) but at low energy levels (UWB network) to transmit information from host devices to devices nearby, i.e. ranges of about 10 meters or so. A higher level of latency (4000 Mbps) is almost 400 times faster than the wireless networks of today.

5G software

5G will be a single unified IP specification for multiple wireless networks and a streamlined internet mix, incorporating wireless technologies such as IEEE802.11, LAN, WAN, PAN and WWW. 5G would require radio-defined code, packet layers, packet deployment, consistency in encryption, etc.

REASONS FOR REQUIREMENT OF 5G NETWORKS

5G is a new type of network: a technology system that will not only strengthen the mobile broadband infrastructure of today, but will also extend mobile networks to serve a large range of devices and applications and link new industries with improved performance, capacity and expense. 5G would redefine a wide range of sectors from shopping to healthcare, infrastructure and media, and everything in between. As revolutionary as automobiles or energy, we see 5G as engineering. Although 4G LTE has focused on delivering mobile broadband networks even better than 3G, 5G is planned to be a single, more versatile system that not only elevates mobile broadband functionality, but also embraces new services such as mission-critical connectivity and vast IoT. 5G will also support all types of spectrum (licensed, shared, unlicensed) and bands (low, medium, high), a wide range of deployment models (from traditional macro cells to hotspots) and new ways of connecting (such as device-to-device and multi-hop mesh). This technology will provide advance billing limitations that the modern era's most beautiful and efficient.

Chapter 3

Network Parameters

The parameters, which, if changed, puts an impact on the network and its components like channel quality are classified as network parameters. These parameters are the fundamentals of our network planning. They help us to understand and better grasp the practical scenarios where we had to face various unknown factors beforehand. The main advantage, also can be dubbed as the sole importance of network planning is that, we can select the most suitable, efficient, and customer satisfactory services for a particular geographical region from many alternatives and then physically implement it. Physically implementing a network requires a lot of capital, so if it has to be practically implemented, rather than virtual implementation, the telecommunication industries would not have prospered this far. Here in this chapter, we will try to cover some of the prominent network parameters based under two sub-sections namely Physical and Non-physical parameters.

3.1 Physical Parameters

Physical parameters are specifically eNB and UE oriented, since channel, being basically wireless does not depend on any of the physical parameters.

eNodeB Parameters

The physical parameters of eNodeB are:

Site altitude

The site selected for an eNB must be within reasonable height. Or if the site is at a higher altitude, we can reduce the height of the eNB to adjust to our requirements. In general there must be clearance level between eNB and UE to get proper coverage. But if the site selected is too high, then the intermediate spacing between UE and eNB will be more which is not desirable. But if the site selected is at a lower position than the normal UE height level then the signal cannot be properly received by UE. It is a common notion that, a higher height for an eNB is preferred. But within a research, it was theoretically found that, if the absolute height difference between eNB and UE is more than zero, then coverage probability along with ASE will continuously decrease towards zero. So, it is desired in ideal conditions that eNB and UE will be at same height level.

eNB height

It defines the height of eNB or more specifically for clear understanding, the transmitting antenna. The height should be chosen such that it has maximum coverage area and minimum ASE crash. In a sense, it serves the same purpose to that of the site altitude, but in this case, we have more freedom than that of altering the site altitude.

Mechanical downtilt

The term downtilt refers to the ‘tilting down’ or more specifically angle of inclination of an antenna. It is the physical downtilt of an antenna, hence the name mechanical. It is generally used when we want to reduce interference or to provide coverage to a certain area. The tilting is done through specific accessories on the antenna bracket rather than changing the signal phase. When applying mechanical tilt, coverage area in the central area is reduced, but the coverage area in the side directions are increased.

Number of eNBs in a specific area

Number of eNBs can be increased or decreased according to demand, if the cells are ultra-dense networks, in that case we might need more eNBs for proper coverage and optimum throughput. Nevertheless, the fact remains that, increasing the eNB number in a particular area will improve the throughput, spectral efficiency, fairness index, but it will also increase our intital cost, if unnecessary eNBs are added.

Number of transmitters & receivers

The number of transmitters and receivers in eNB plays a vital role in the fine tuning of the sent and received data. The more the number of the transmitters and receivers, the better the throughput will be. The average throughput increases considerably by increasing number of transmitters and receivers along with the spectral efficiency, the main downside of increasing the number of transmitters and receivers is the cost of the eNBs increase significantly and the power for transmission also increases. There will also be some complexities while choosing the best received data as there has to be more correlating operations involved.

Antenna azimuth and elevation

Antenna azimuth defines the degree at which the antenna is positioned and elevation of antenna refers to the height at which the antenna is. Basically, the eNB comprises of the feet and the antenna. The antenna elevation is the height of the antenna from the feet.

Number of panels

For 2D antenna, generally we use multiple panels which again comprise of multiple antennas in them. So safely we can say that, the antennas we use in our practical scenarios are not a single antenna, but a composite one comprised of many antennas, as they give us better performance. Here each panel are classified into horizontal or vertical panels based on their arrangement.

Spacing between panels

There must be a minimum spacing between panels so that the signals of the panel do not interfere with each other. It is given in terms of wavelengths (generally 2.5 lambda) [20].

Number of antenna elements

For 2D antenna, there are multiple panels which contain multiple antennas arranged in an array (also called phased array). The signals of multiple antennas are combined together to achieve better performance compared to single antenna. Also, they provide higher gains (transmitter) and diversity reception (receiver). Here each antenna is classified as horizontal or vertical elements based on their arrangement in the array.

Spacing between panels

There must be a minimum spacing between antennas in the panel so that the signals of the antennas do not interfere with each other. It is given in terms of wavelengths (generally 0.5 lambda) [20].

Distance between eNBs

The distance between eNBs specifies the distance between eNBs, which is an essential part, because there might be interference between transmissions of eNBs if the distance between eNB is too less. If the distance is too high, then some areas might be out of coverage for the eNBs. So an optimal distance has to be selected between the eNBs so that there is optimal coverage & also no interference.

Distance between eNB and UE

The distance between eNB and UE generally signifies the minimum distance between eNB and UE for getting proper coverage from the eNB.

RRH

RRH (Remote Radio Head) is basically the same RF circuitry of the eNB enclosed in a small outdoor module. It also includes ADC (Analog to Digital Converter), DAC (Digital to Analog Converter) & up and down converters. It basically reinforces the signal transmitted, including some other functions like operation and management processing capabilities and a standardized optical interface to connect to the rest of the base stations. It also increases a base station's efficiency and facilitate physical location gap coverage problems.

Femtocell

A femtocell is the smallest type of cell in the cellular technology, which is used to expand a cellular network connectivity by a very small margin. Like other small cells, femtocell does not require centralized hub. Femtocell are used in home and offices since it is an easy to setup device, and an existing broadband connection can be used as a femtocell. It is an effective alternative to RRH where we need to expand coverage area by a little, and there are some cost constraints.

UE

The parameters of User Equipment (UE) are:

Distribution

The distribution of UE has a significant impact on the average throughput of the cell. The geometry of distribution as well as the number of UE per cell provides a great impact on the peak & average throughput of UE throughout the cell. If the UE are distributed in such a way that, there are more UE near to the eNB rather than being at the cell edge, the peak throughput and the average throughput will increase, rather than being distributed on the cell edge. On another aspect, if we keep a lower number of UE per cell, then throughput will obviously be greater than that of more UE per cell.

Speed

The mobility of UE is the greatest concern amongst the UE physical parameters, since nowadays the mobility of the UE is the most unpredictable variable. For static cases, since there is no mobility, no handover occurs as such have a higher spectral efficiency, throughput and fairness index.

Height

UE height is also a considerable parameter, because since UE height is also a variable parameter. The main focus for maximum coverage and better throughput, we have to consider the absolute height difference between eNB and UE, and the eNB height is not changeable so we have to consider an average range of day to day general heights.

Slant angle

The UE slant angle though a parameter, is not basically very important, because the receivers used in the UE are generally omnidirectional. The slant angle mainly depends on the antenna polarization. For linear polarization the receiver slant angle is considered to be 0 degrees ideally, and for cross polarization, receiver slant angle is considered to be 180 degrees ideally.

3.2 Non-physical Parameters

Non-physical parameters are basically classified on the basis of eNB, UE and channel. These parameters define the resource allocations, response time and various other parameters which are virtual in nature, i.e. physical alterations of these parameters are not possible in a direct way. These parameters involve the general RF alterations centering the signal as its basis.

eNodeB

The non-physical parameters of eNB are:

Antenna gain

Antenna gain is a relative measure of the antenna's ability to direct or concentrate the RF signal on a specific direction compared to a hypothetical lossless isotropic antenna and is measured in terms of decibel.

Antenna Polarization

The electrical plane determines the polarization of the signal generated or received by the antenna. Based on that, there are two types of polarization of the antennas considering from 2D viewpoint: Linear and Cross polarization. The slant angle of the antenna depends on the polarization of the antenna.

Electrical downtilt

In electrical downtilt, the tilting can be done by changing the signal phase of each of the antenna elements. Amongst the mechanical and electrical tilts, electrical one provides more flexibility, since it provides more flexibility and ease of optimization. But the equipment for electrical downtilt is costlier than that of mechanical one. In case of electrical downtilt, coverage area suffers a uniform reduction in all sides, so the overall gain of the antenna is reduced.

Transmission power

The change of transmission power affects the throughput and also ASE. More transmission power means more throughput and higher ASE. But as in the number of transmitters and receivers, the cost will also increase.

Transmission modes of transmitter

The transmission mode refers to the mechanism of transferring data between two devices connected in a network. So, for a transmitter, it only involves sending of data. There are various types of transmission modes based on transmitter, which are suitable for different cases, depending on the size, density, cost and terrain of the network.

Scheduler Configuration

It refers to the method of allocating resource blocks (RBs) for UE. Various types of scheduler configuration are there, which are differentiated on the basis of throughput, ASE fairness index & cell throughput

UE

The non-physical parameters of User Equipment (UE) are:

Receiver Noise

Receiver noise is the internal noise or built-in noise of the UE equipment. All equipment consist of some noise which cannot be eliminated. Normalized value is considered to be 9 decibels.

Thermal Noise Density

Thermal noise density of the receiver arises due to the radiation patterns emitted by the UE which interferes with the channel radiation, resulting in thermal noise. This can be minimized enhancing the noise cancellation equipment of the UE.

Antenna Polarization

The electrical plane determines the polarization of the signal generated or received by the antenna. Based on that, there are two types of polarization of the antennas considering from 2D viewpoint: Linear and Cross polarization. . The slant angle of the antenna depends on the polarization of the antenna. This parameter is similar for both UE and eNBs.

Channel Parameters

The channel parameters are:

Frequency

Channel frequency defines what kind of signal we have to send over the channel. It also changes the property of the signal wave and also has an impact on the size of the transmitting antenna.

Bandwidth

It is the difference between the higher and lower frequencies in a continuous band of frequencies. In simple terms, it is the frequency range occupied by a modulated carrier signal.

Feedback channel delay

Feedback channel delay is the delay experienced by the eNB while UE sends data. Hence it is also termed as uplink delay. There are basically two types of data that UE sends to the eNB: the CQI reports and the ACK.

CQI indicator

This indicates the channel quality of a particular channel. It ranges from 1-15 in case of 4G and 5G. The best channel is denoted by 15 and the worst one is denoted by 1. The higher the channel quality the higher the modulation & coding scheme, code rate and better modulation techniques.

Path loss

Path loss is the difference between transmitted power & received power caused by signal level attenuation due to free space propagation, scattering, diffraction and reflection. There are basically three types of path loss models based on analytical studies and measurements taken in various practical scenarios and each model is defined for a definite environment and a frequency range: Empirical model, Deterministic model, Semi-Deterministic model.

Fading

It is the variation of signal over time and frequency. There are various reason for fading, like multipath propagation, shadowing etc. There are basically two types of fading based on the distance that UE moves:

Small scale fading

When UE moves at a short distance, there is a rapid change of signal levels. As a result, constructive and destructive interference of multipath components occur which result in small scale fading.

Large scale fading

When UE moves at a large distance, then fading occurs due to path loss as a function of distance and shadowing by large elements such as building, terrains and other structures. This type of fading is referred to as large scale fading. Shadowing is a slow fading process that is characterized by median path loss between the transmitter and receiver in fixed locations.

Chapter 4

Simulations

The point of this thesis is an extensive comparative study of various LTE radio communication scenarios. This study is done by altering the network parameters mentioned in the previous chapter. This section will comprise of the various simulations and the point of these simulations. Vienna Simulators LTE-A: A System Level Simulator was used to perform all our simulations. Every simulation involved taking the statistics of the cells, the network map and the comparison of results in a graph.

SNR & CQI Mapping

In case of 4G LTE and the later releases, presumably for the 5G cases too, there will be 15 different channel quality level depending on various factors as depicted on Table 4.1, ranging from channel with CQI 15 being the best to channel with CQI 15 being the worst. Here, a comparison of the SNR with BLER was done to better understand the impact of CQI with our studies.

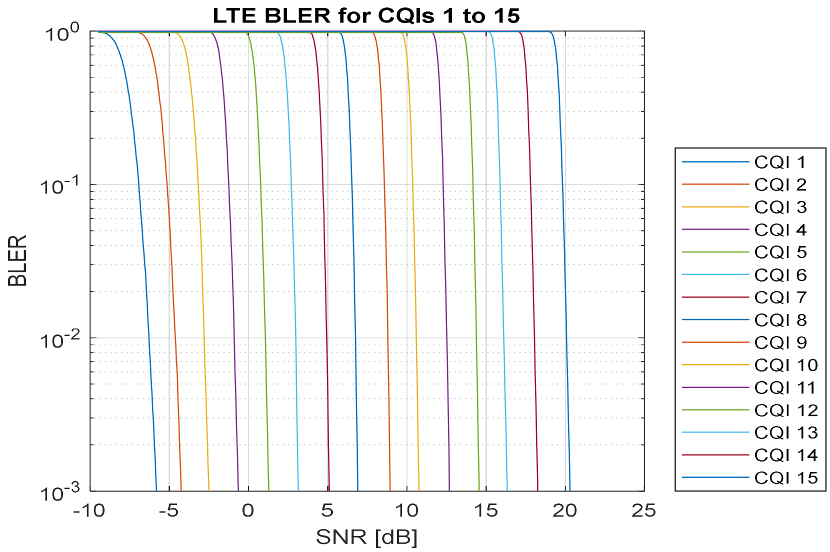


Figure 4.1: BLER vs SNR for different channels

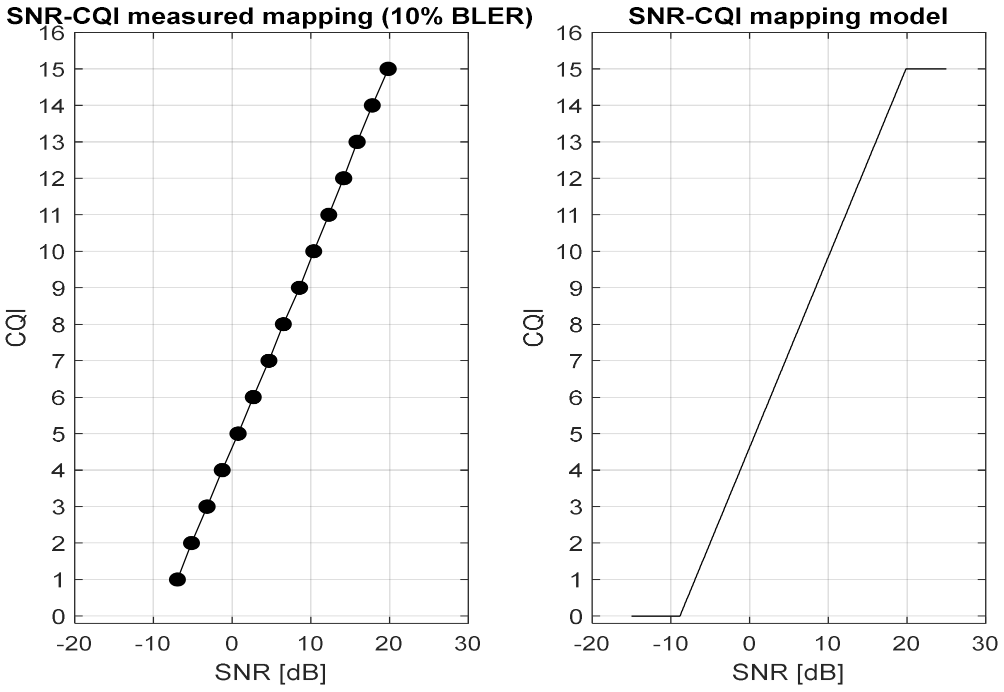
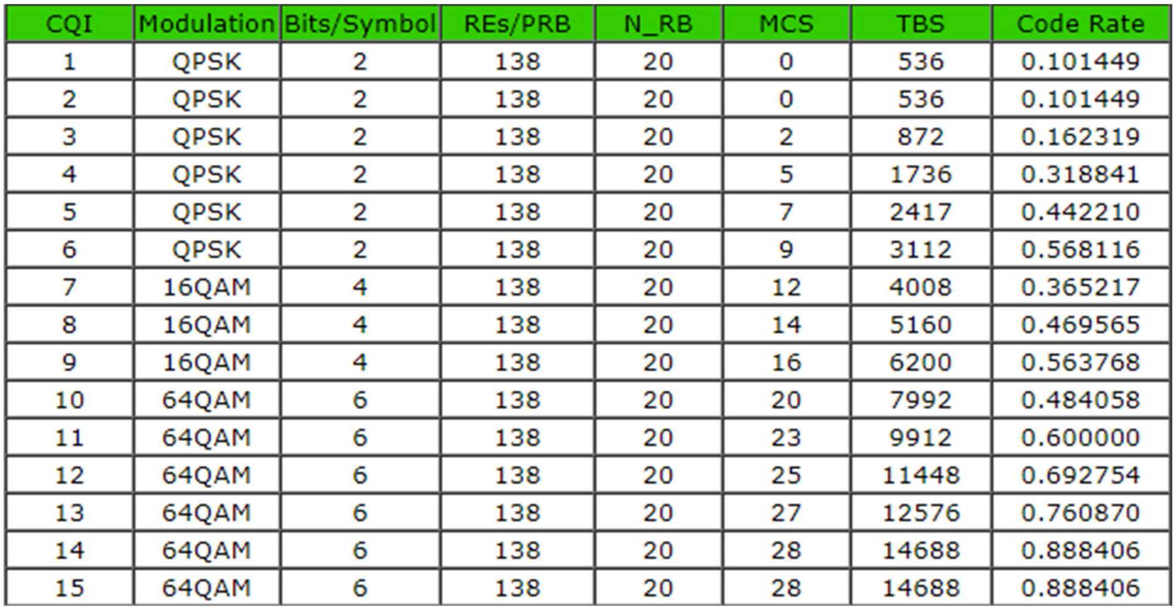


Figure 4.2 SNR and CQI mapping

Table 4.1: Modulation information of different CQI



CQI	Modulation	Bits/Symbol	REs/PRB	N_RB	MCS	TBS	Code Rate
1	QPSK	2	138	20	0	536	0.101449
2	QPSK	2	138	20	0	536	0.101449
3	QPSK	2	138	20	2	872	0.162319
4	QPSK	2	138	20	5	1736	0.318841
5	QPSK	2	138	20	7	2417	0.442210
6	QPSK	2	138	20	9	3112	0.568116
7	16QAM	4	138	20	12	4008	0.365217
8	16QAM	4	138	20	14	5160	0.469565
9	16QAM	4	138	20	16	6200	0.563768
10	64QAM	6	138	20	20	7992	0.484058
11	64QAM	6	138	20	23	9912	0.600000
12	64QAM	6	138	20	25	11448	0.692754
13	64QAM	6	138	20	27	12576	0.760870
14	64QAM	6	138	20	28	14688	0.888406
15	64QAM	6	138	20	28	14688	0.888406

After this, we compared the available scheduler configurations, on a common ground at a time. Here, we changed different parameters to observe the changes in results. Parameters subjected to change were: UE velocity, channel frequency & bandwidth and lastly number of transmitters and receivers (Figure 4.54- 4.59). All of the simulations were done using transmission mode CLSM.

UE still, Frequency 2 GHz, Bandwidth 10 MHz, Round Robin

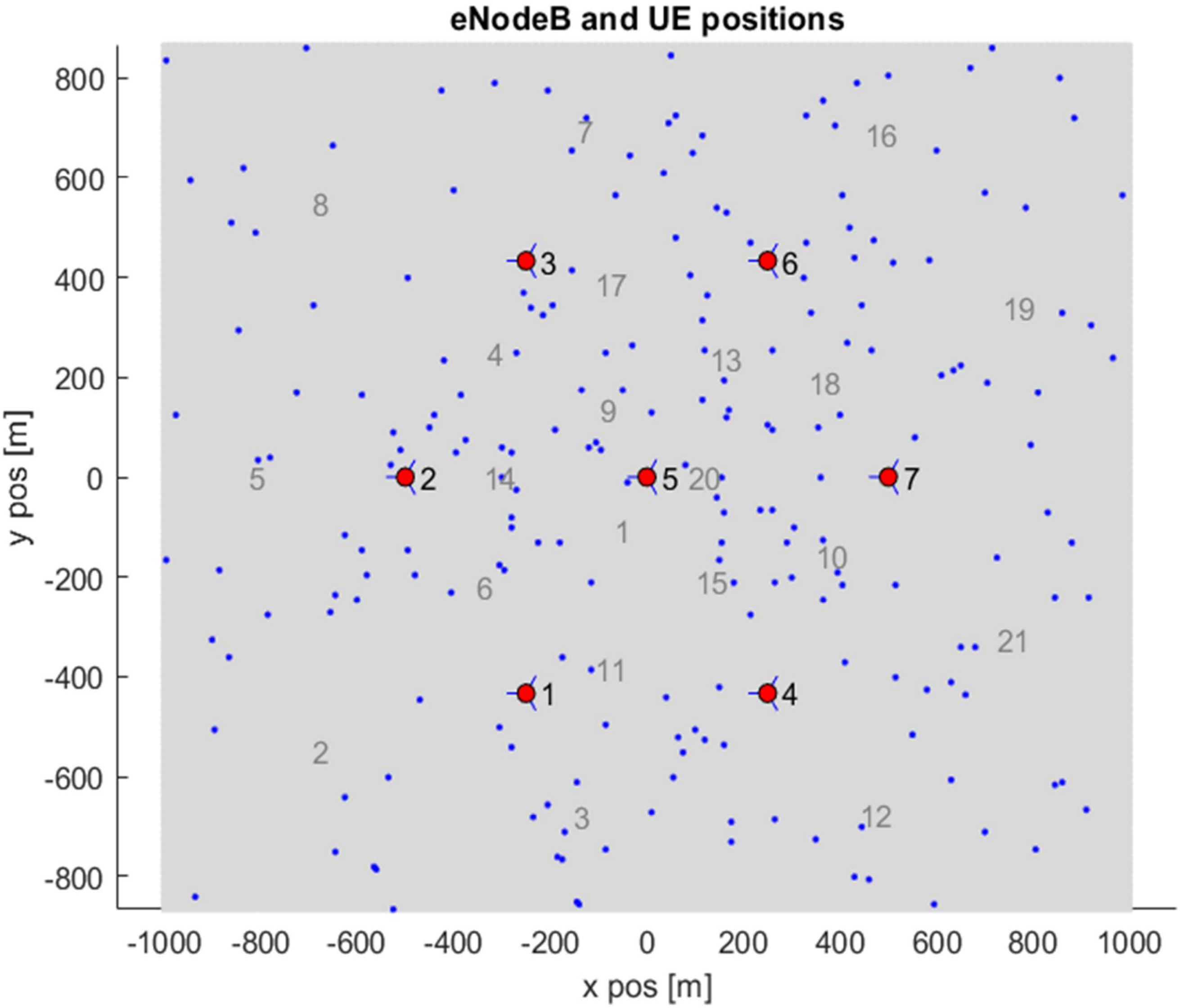
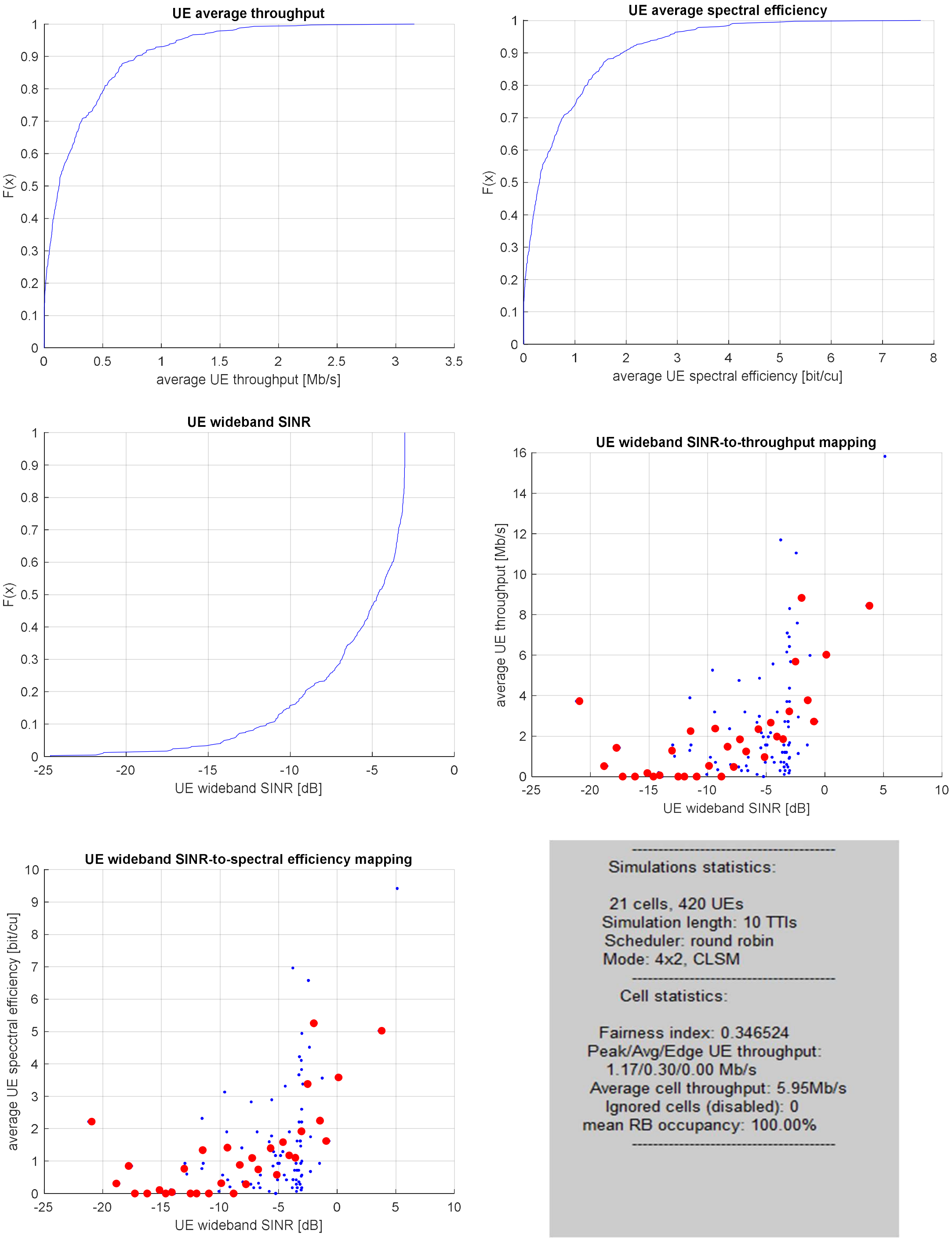


Figure 4.3 UE and eNodeB distribution in a specific geographic region



Simulations statistics:

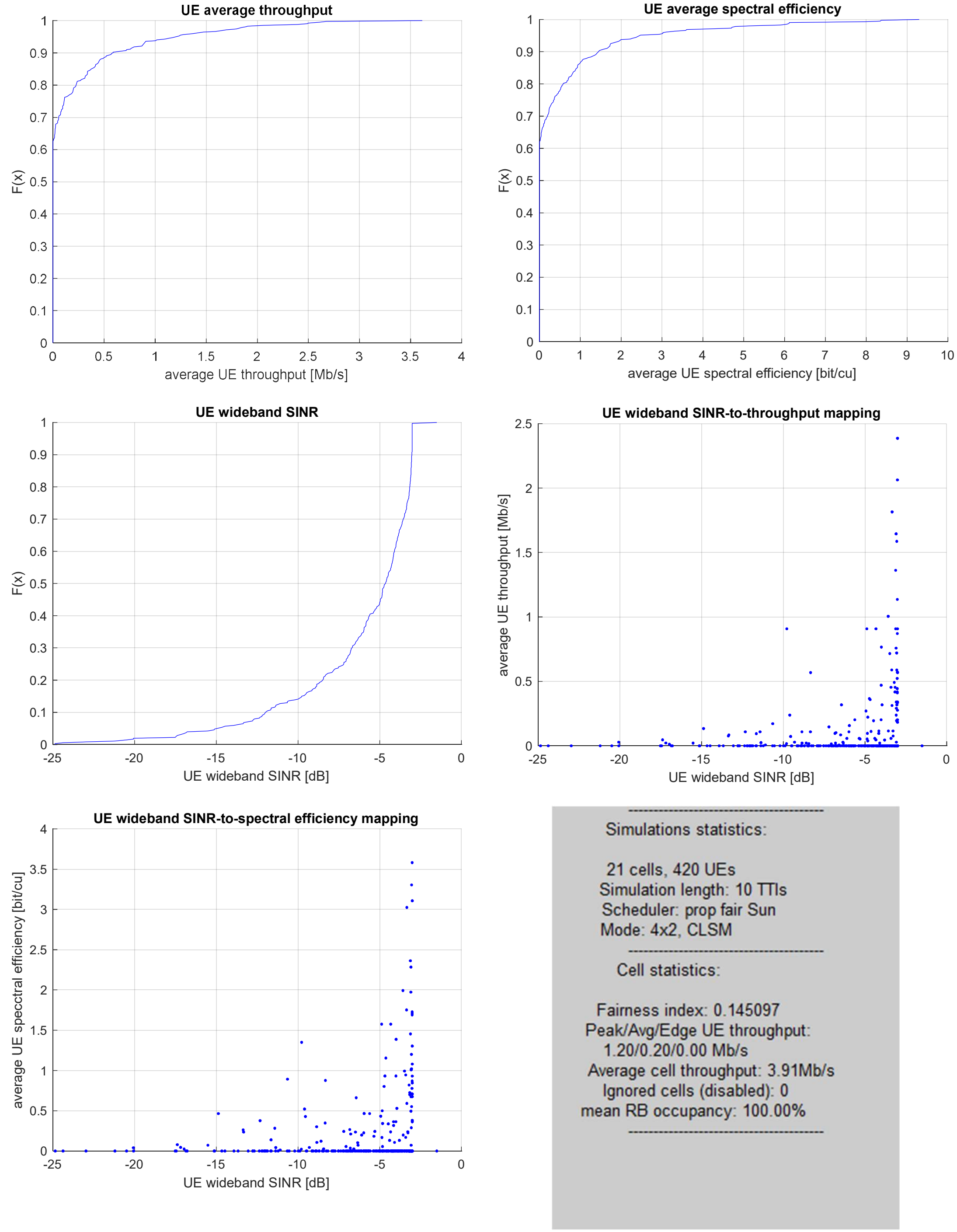
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.346524
Peak/Avg/Edge UE throughput:
1.17/0.30/0.00 Mb/s
Average cell throughput: 5.95Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.4: Simulation Statistics: UE still, frequency 2 GHz, bandwidth 10 MHz, Round Robin

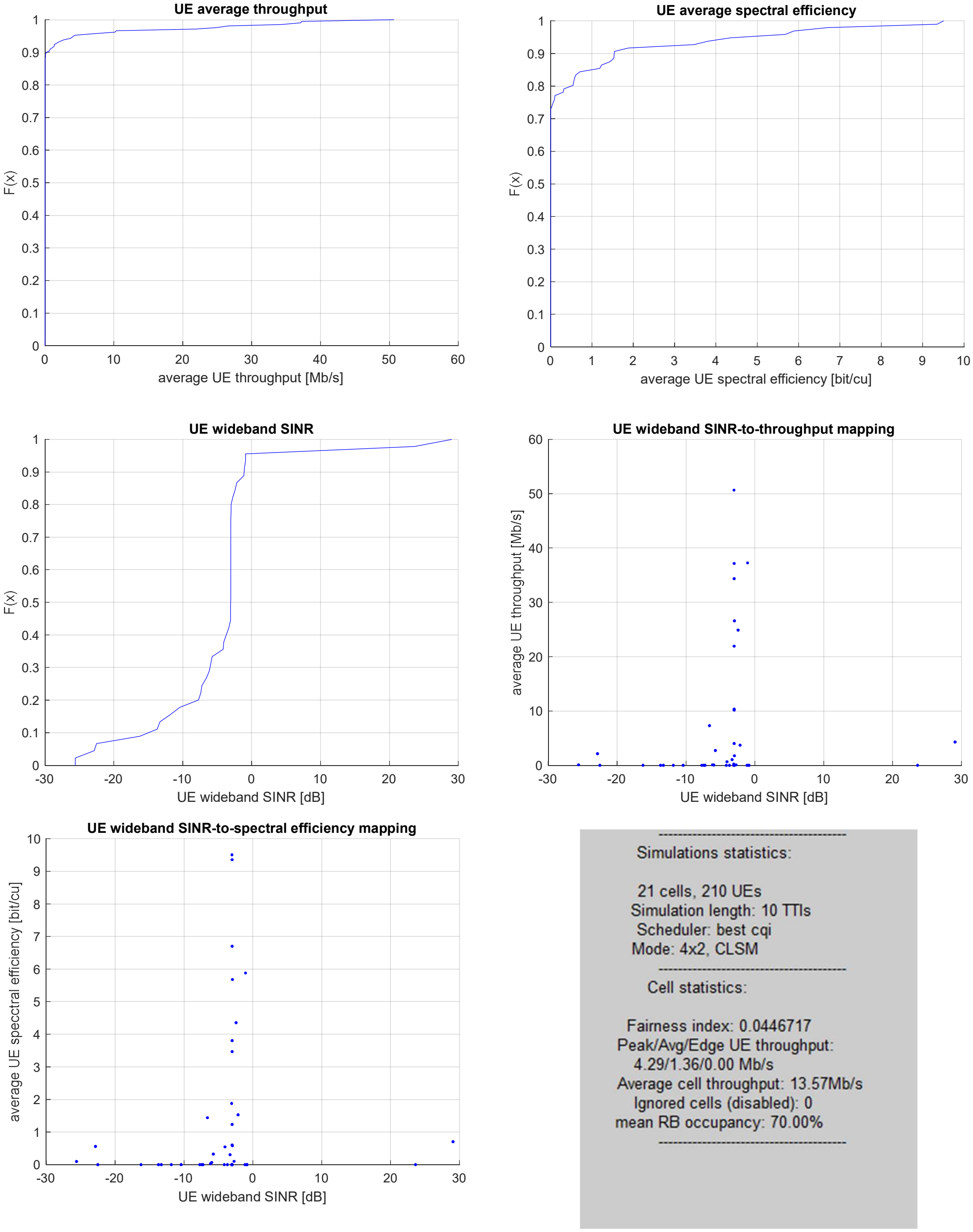
UE still, Frequency 2 GHz, Bandwidth 10 MHz, Prop Fair Sun



```
        ---------------------------------------
   Simulations statistics:

    21 cells, 420 UEs
  Simulation length: 10 TTIs
   Scheduler: prop fair Sun
  Mode: 4x2, CLSM
        ---------------------------------------
      Cell statistics:

  Fairness index: 0.145097
 Peak/Avg/Edge UE throughput:
   1.20/0.20/0.00 Mb/s
  Average cell throughput: 3.91Mb/s
   Ignored cells (disabled): 0
mean RB occupancy: 100.00%
        ---------------------------------------
```

Figure 4.5: UE still, Frequency 2 GHz, Bandwidth 10 MHz, Prop Fair Sun

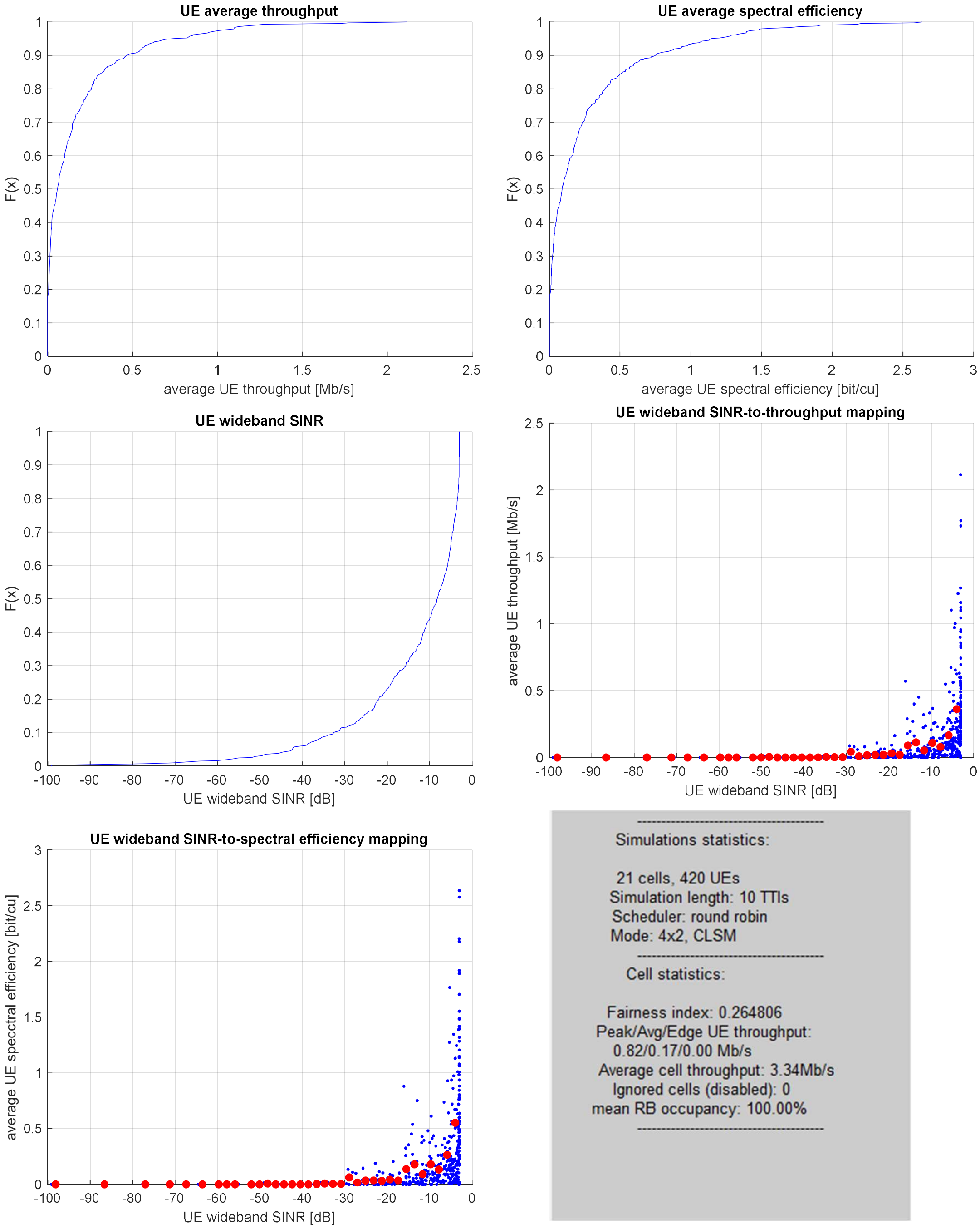
UE still, Frequency 2 GHz, Bandwidth 10 MHz, Best CQI



```
--------------------------------------
Simulations statistics:

 21 cells, 210 UEs
Simulation length: 10 TTIs
 Scheduler: best cqi
Mode: 4x2, CLSM
--------------------------------------
 Cell statistics:

 Fairness index: 0.0446717
Peak/Avg/Edge UE throughput:
 4.29/1.36/0.00 Mb/s
Average cell throughput: 13.57Mb/s
 Ignored cells (disabled): 0
mean RB occupancy: 70.00%
--------------------------------------
```

Figure 4.6: UE still, frequency 2 GHz, Bandwidth 10 MHz, Best CQI

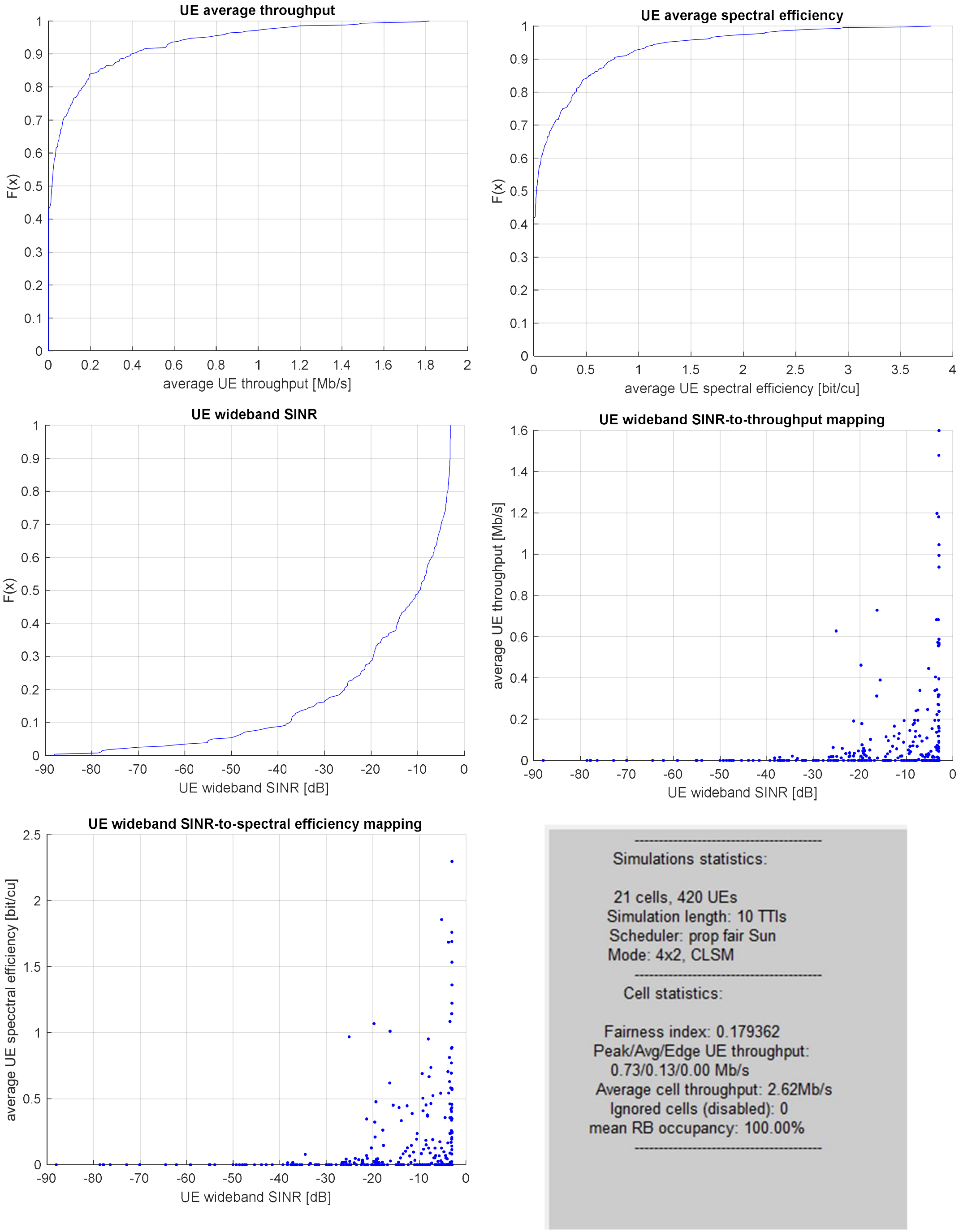
UE still, Frequency 5 GHz, Bandwidth 15 MHz, Round Robin



```
-----------------------------------------
Simulations statistics:

21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM
-----------------------------------------
Cell statistics:

Fairness index: 0.264806
Peak/Avg/Edge UE throughput:
0.82/0.17/0.00 Mb/s
Average cell throughput: 3.34Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%
-----------------------------------------
```

Figure 4.7: UE still, Frequency 5 GHz, Bandwidth 15 MHz, Round Robi

UE still, Frequency 5 GHz, Bandwidth 15 MHz, Prop Fair Sun



Simulations statistics:

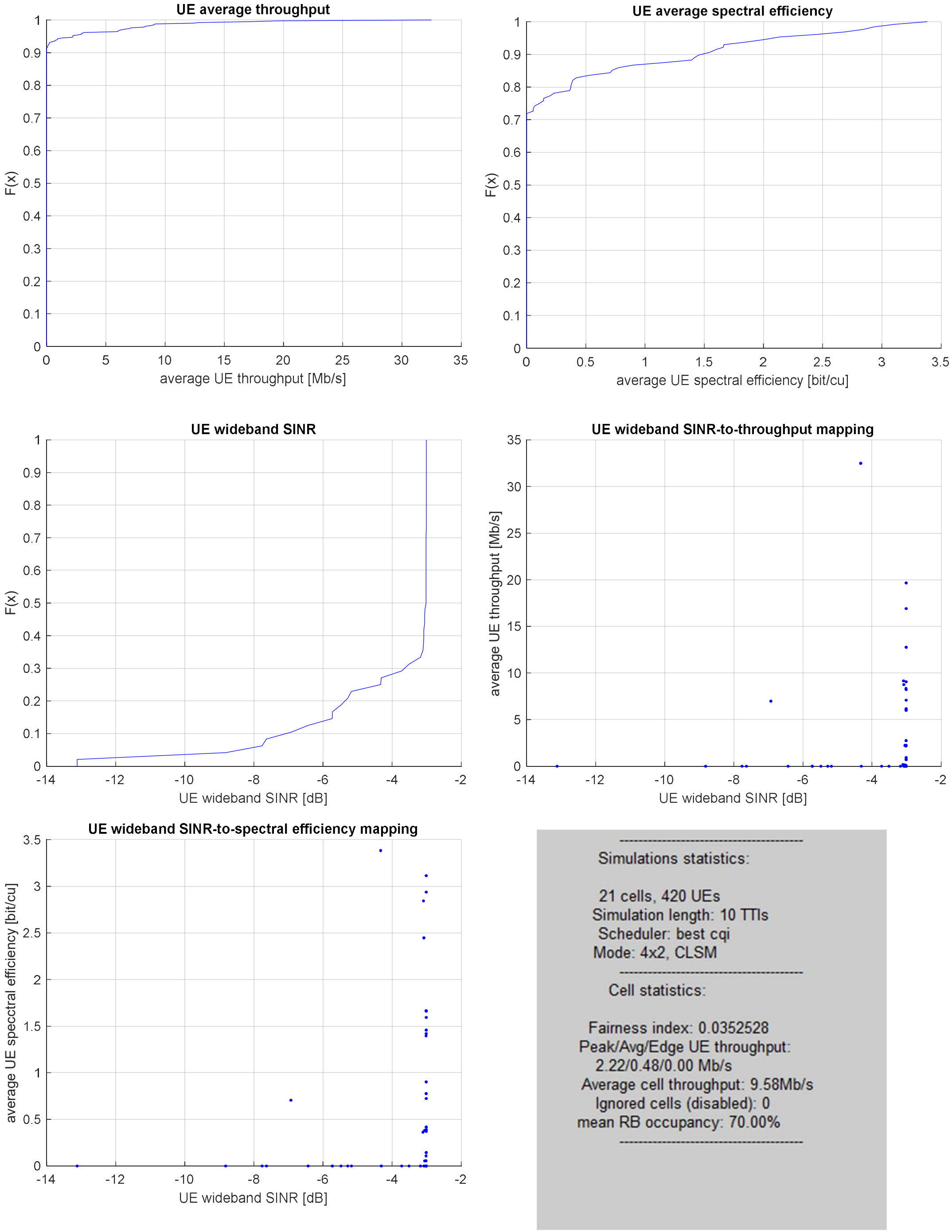
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.179362
Peak/Avg/Edge UE throughput:
0.73/0.13/0.00 Mb/s
Average cell throughput: 2.62Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.8: UE still, Frequency 5 GHz, Bandwidth 15 MHz, Prop Fair Sun

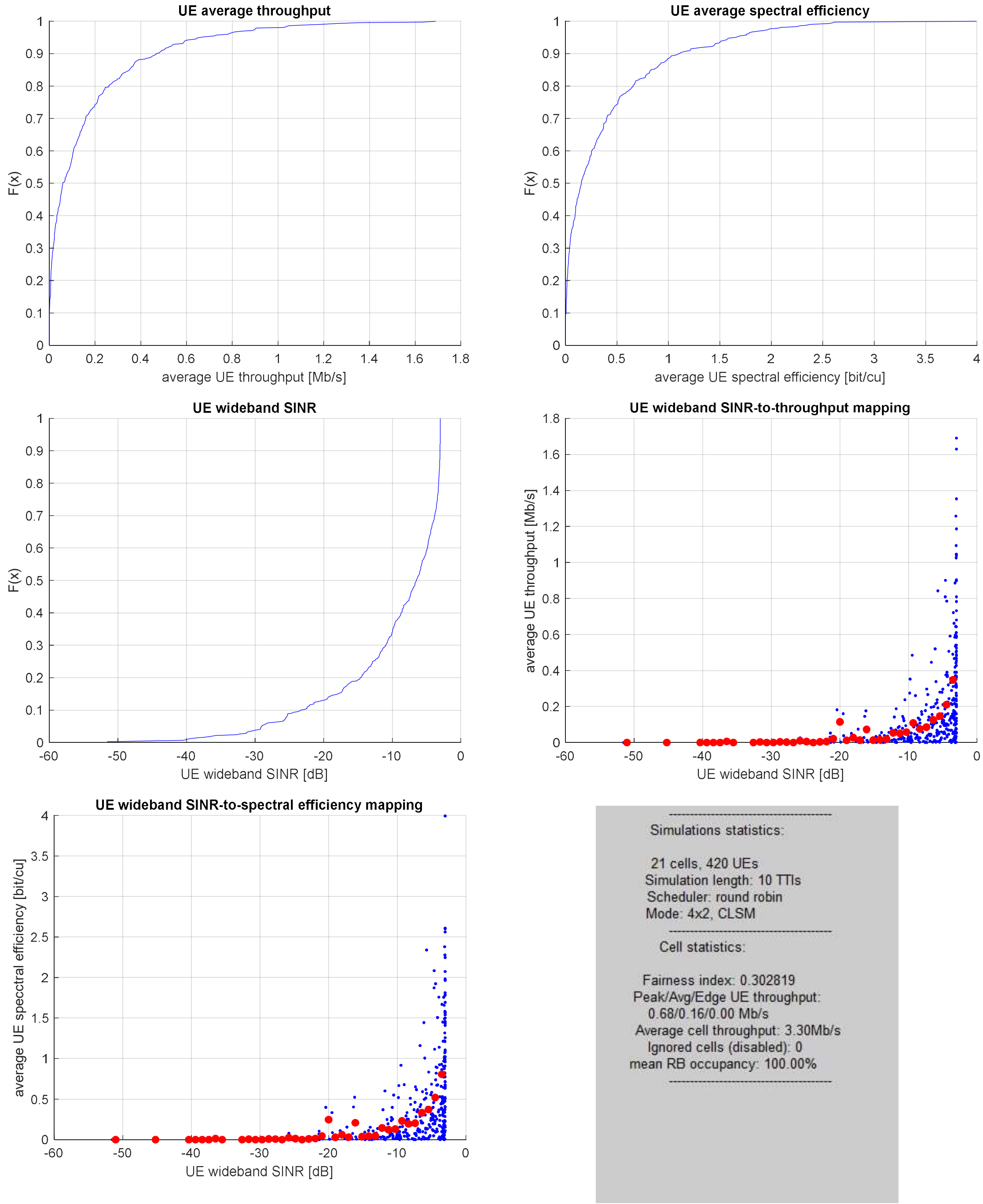
UE still, Frequency 5 GHz, Bandwidth 15 MHz, Best CQI



```
----------------------------------------
  Simulations statistics:

  21 cells, 420 UEs
 Simulation length: 10 TTIs
  Scheduler: best cqi
 Mode: 4x2, CLSM
----------------------------------------
    Cell statistics:

 Fairness index: 0.0352528
Peak/Avg/Edge UE throughput:
  2.22/0.48/0.00 Mb/s
 Average cell throughput: 9.58Mb/s
   Ignored cells (disabled): 0
mean RB occupancy: 70.00%
----------------------------------------
```

Figure 4.9: UE still, Frequency 5 GHz, Bandwidth 15 MHz, Best CQI

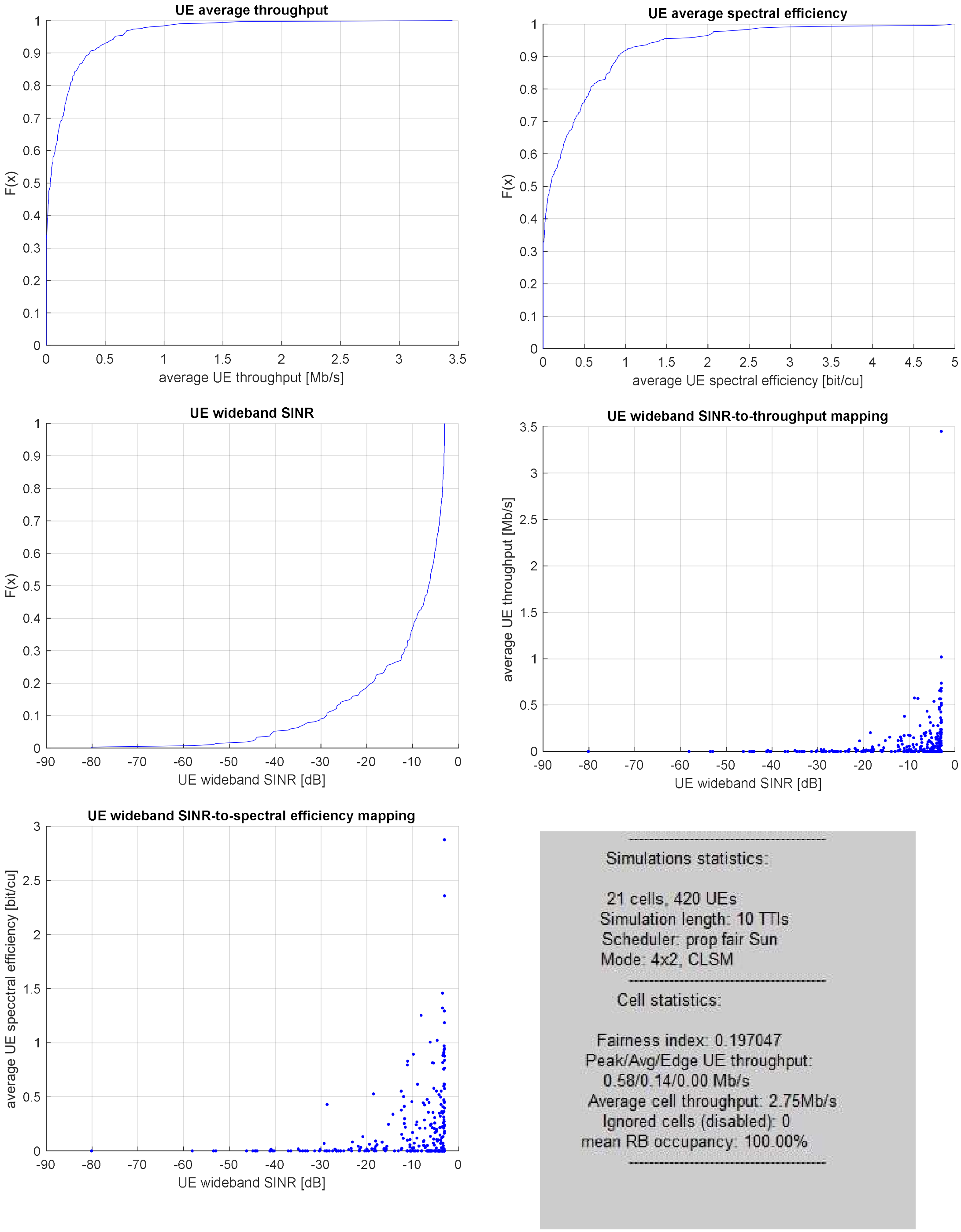
UE velocity= 5 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Round Robin



```
-----------------------------------------
Simulations statistics:

21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM
-----------------------------------------
Cell statistics:

Fairness index: 0.302819
Peak/Avg/Edge UE throughput:
0.68/0.16/0.00 Mb/s
Average cell throughput: 3.30Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%
-----------------------------------------
```

Figure 4.10: UE velocity= 5 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Round Robin

UE velocity= 5 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Prop Fair Sun



Simulations statistics:

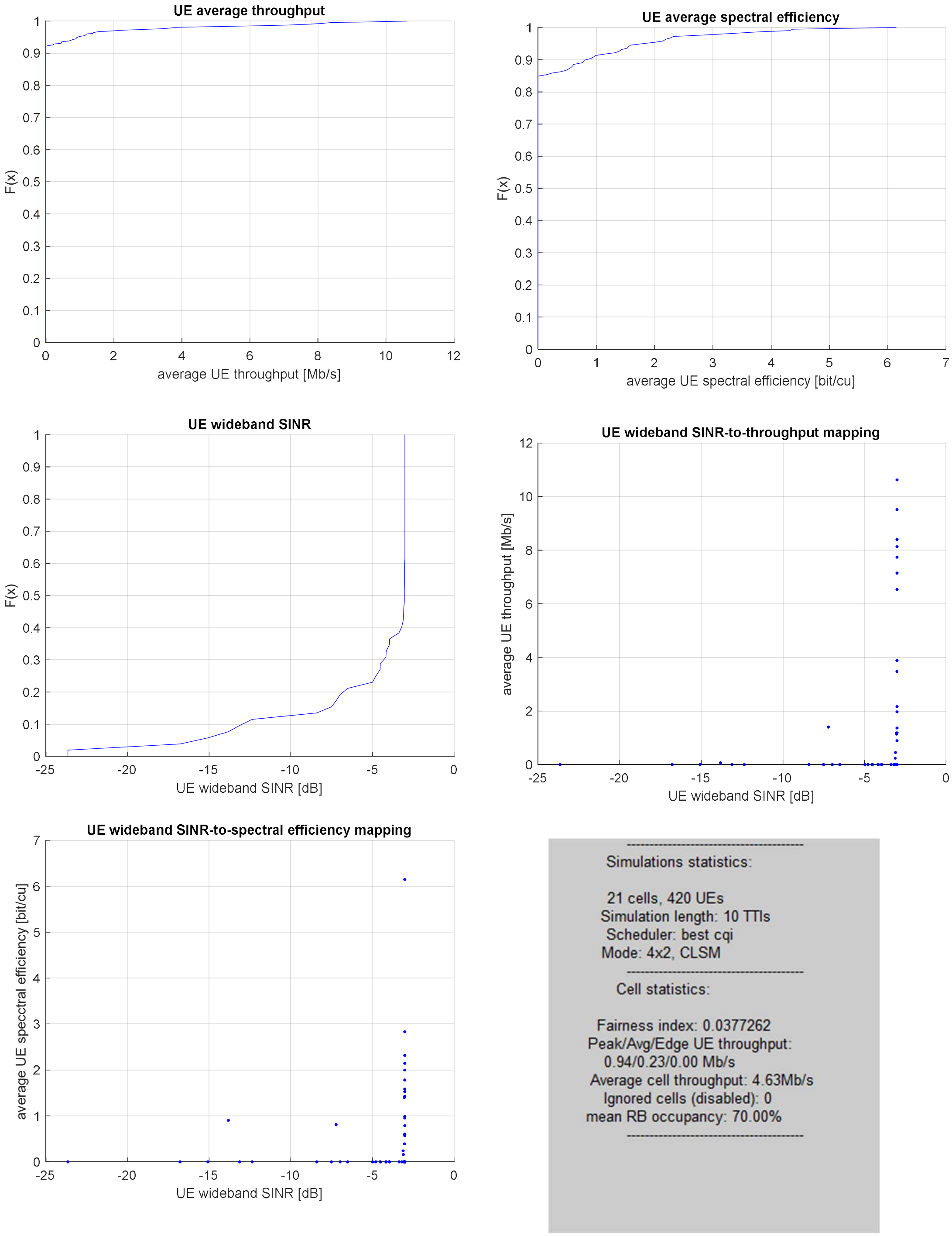
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.197047
Peak/Avg/Edge UE throughput:
0.58/0.14/0.00 Mb/s
Average cell throughput: 2.75Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.11: UE velocity= 5 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Prop Fair Sun

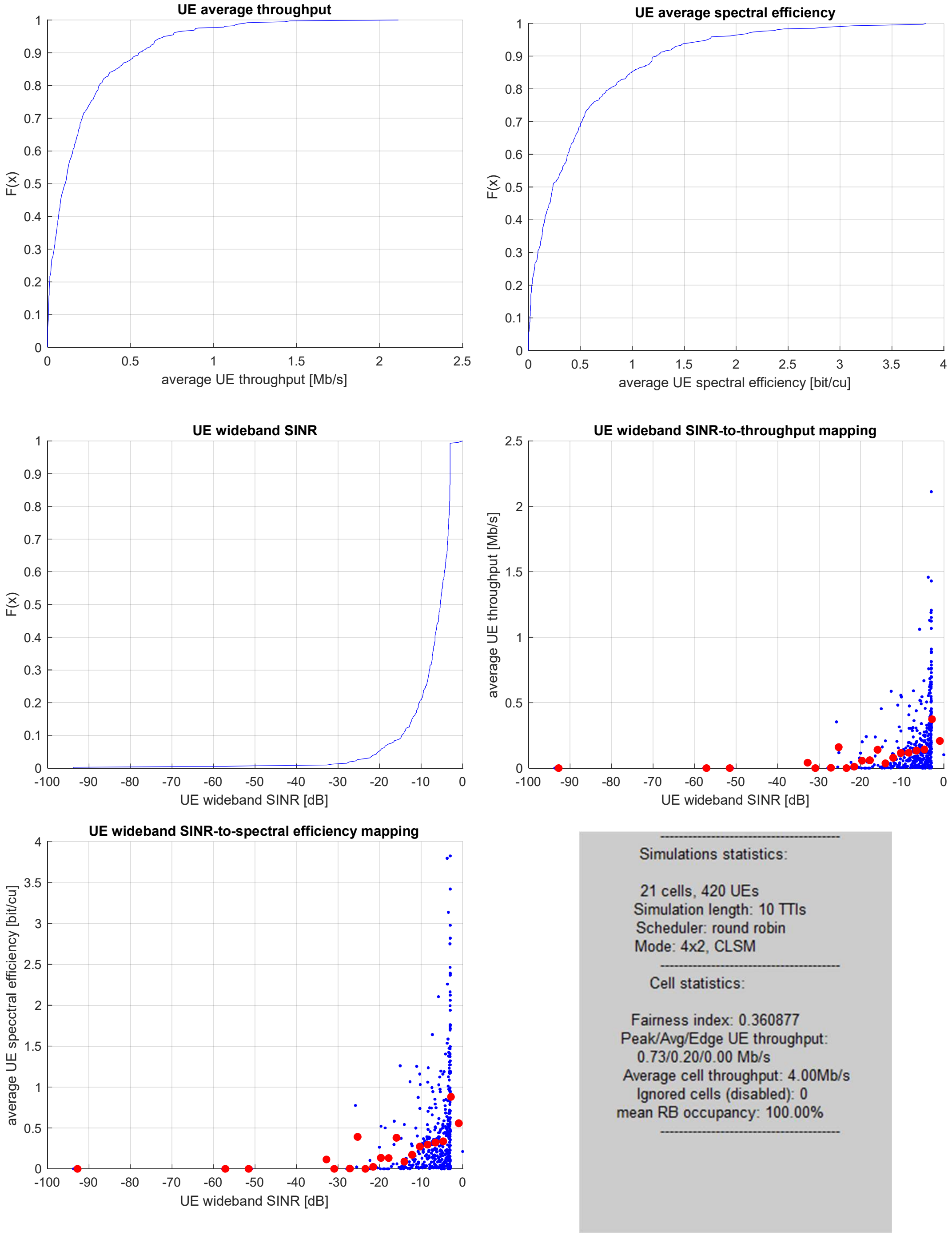
UE velocity= 5 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Best CQI



```
------------------------------------------
Simulations statistics:

21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 4x2, CLSM
------------------------------------------
Cell statistics:

Fairness index: 0.0377262
Peak/Avg/Edge UE throughput:
0.94/0.23/0.00 Mb/s
Average cell throughput: 4.63Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 70.00%
------------------------------------------
```

Figure 4.12: UE velocity= 5 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Best CQI

UE velocity= 40 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Round Robin



Simulations statistics:

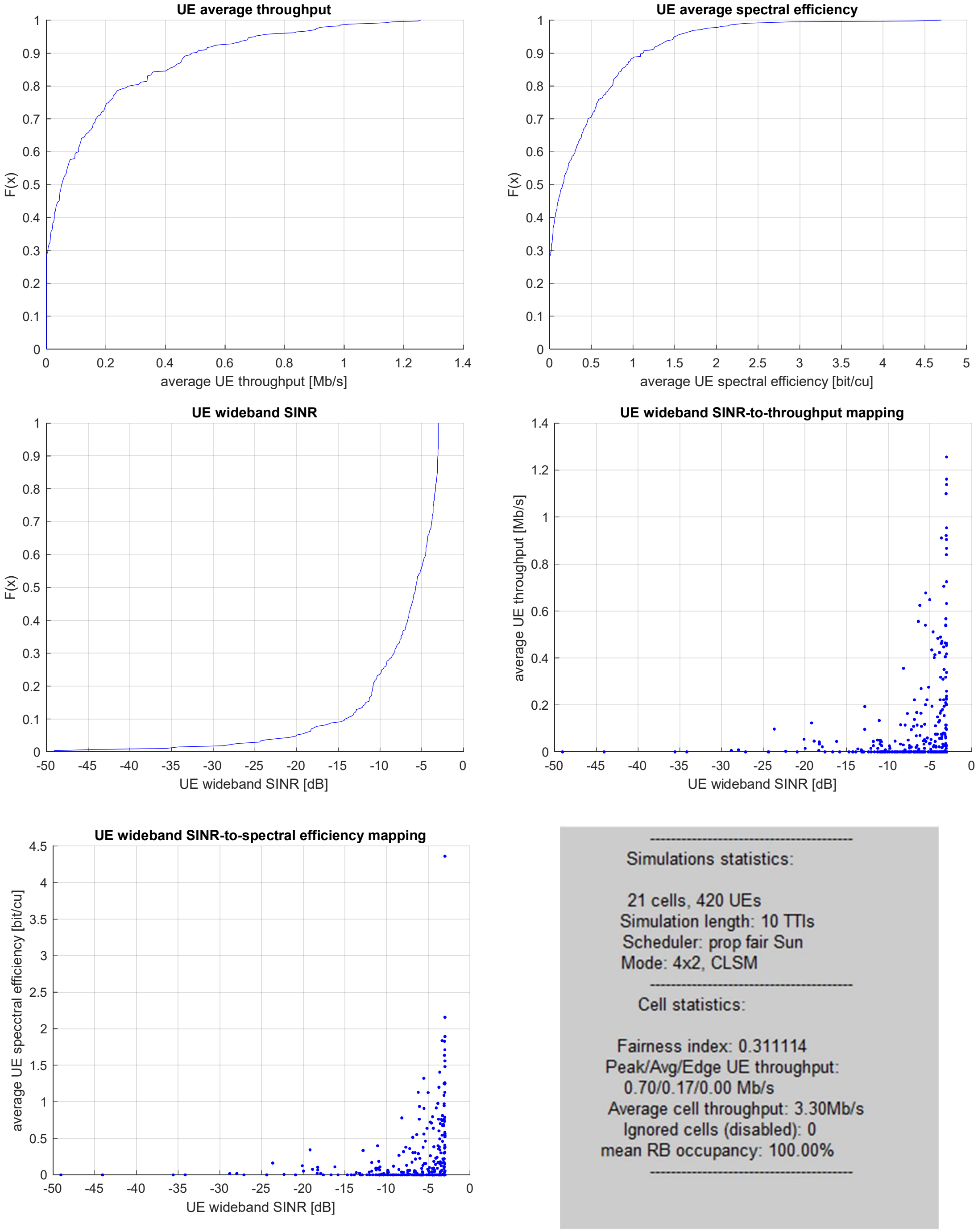
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.360877
Peak/Avg/Edge UE throughput:
0.73/0.20/0.00 Mb/s
Average cell throughput: 4.00Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.13: UE velocity= 40 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Round Robin

UE velocity= 40 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Prop Fair Sun



Simulations statistics:

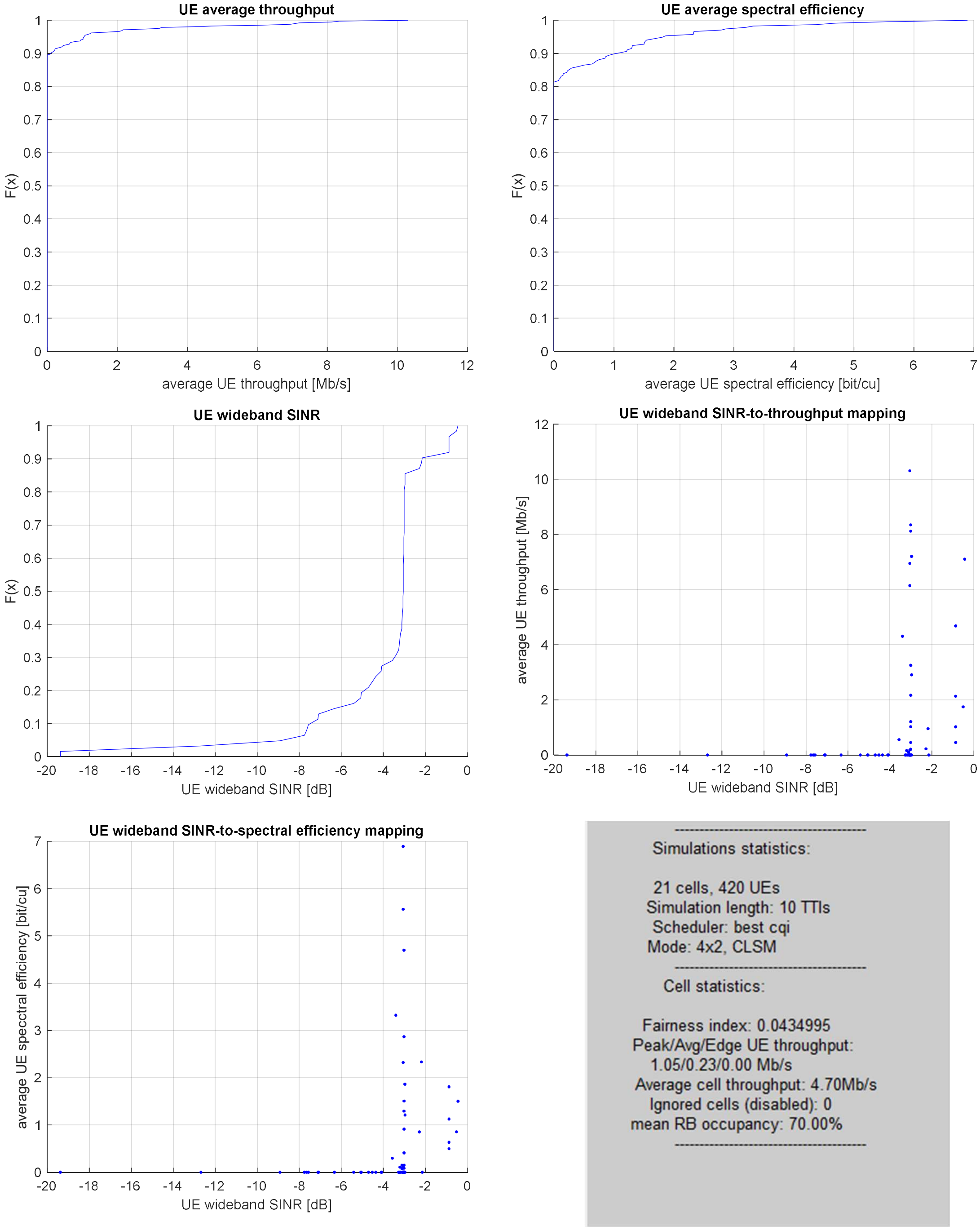
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.311114
Peak/Avg/Edge UE throughput:
0.70/0.17/0.00 Mb/s
Average cell throughput: 3.30Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.14: UE velocity= 40 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Prop Fair Sun

UE velocity= 40 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Best CQI



Simulations statistics:

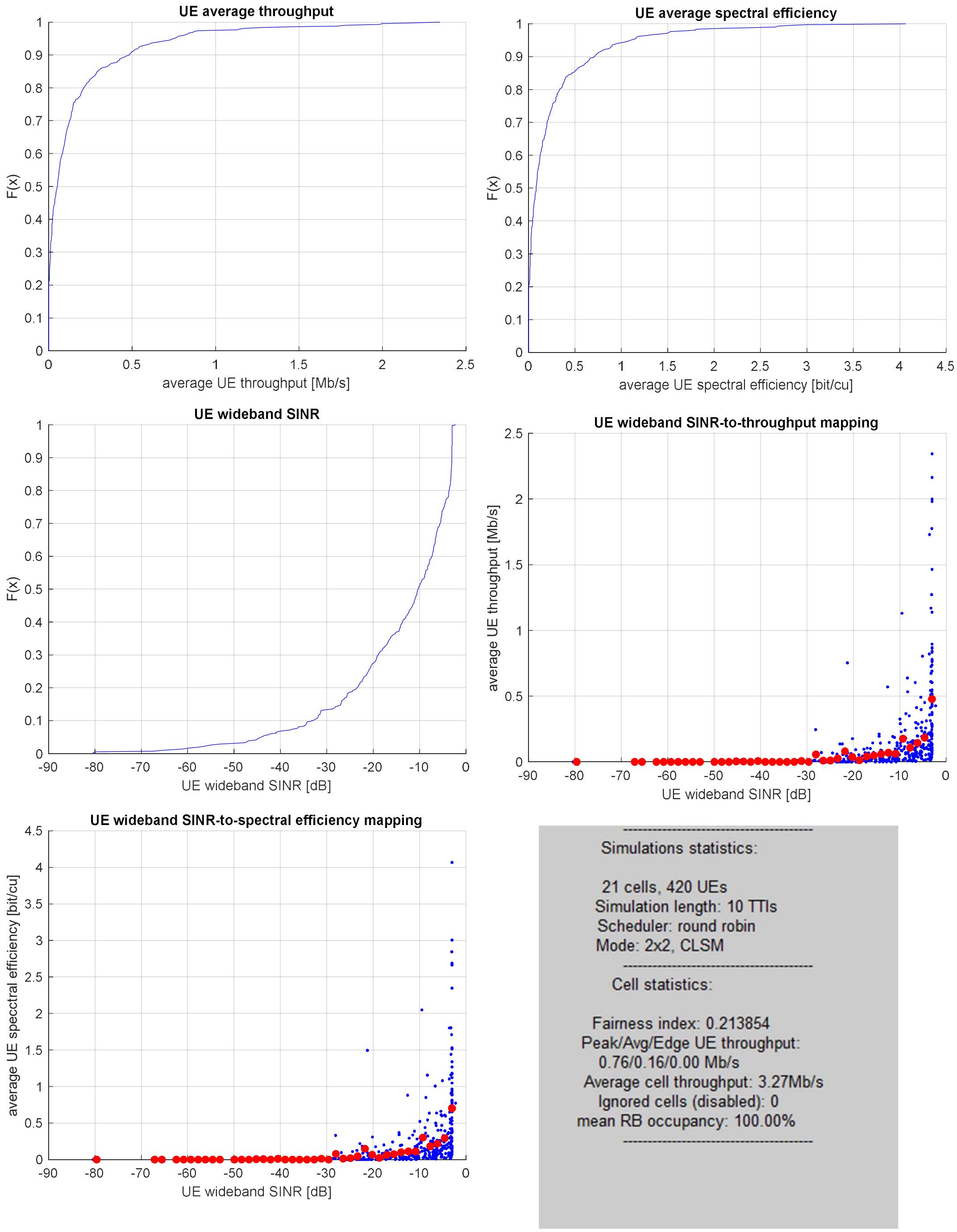
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.0434995
Peak/Avg/Edge UE throughput:
1.05/0.23/0.00 Mb/s
Average cell throughput: 4.70Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 70.00%

Figure 4.15: UE velocity= 40 km/h, Frequency 2 GHz, Bandwidth 10 MHz, Best CQI

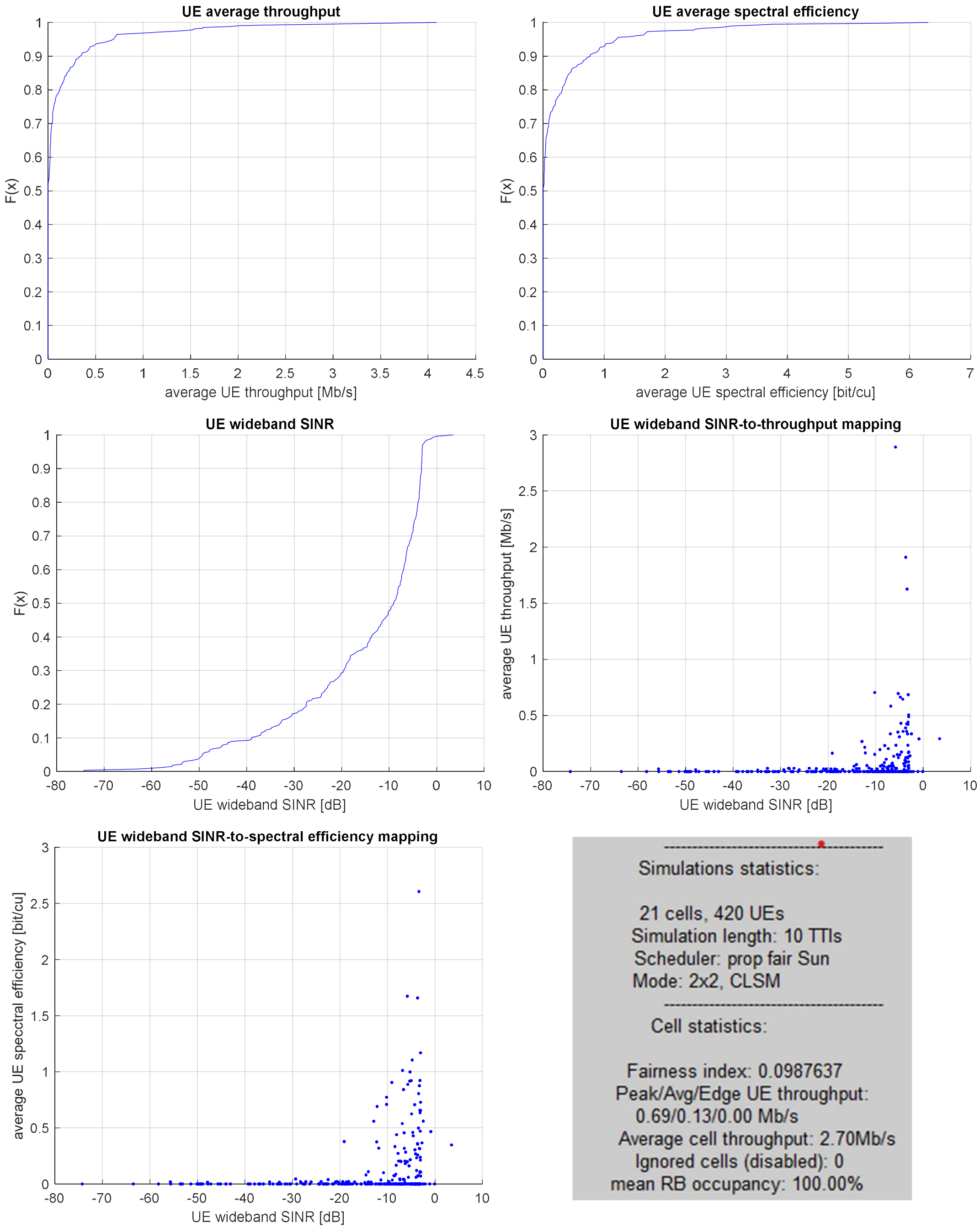
UE velocity= 5 km/h, Frequency 5 GHz, Bandwidth 15 MHz, Round Robin



```
---------------------------------------
  Simulations statistics:

   21 cells, 420 UEs
  Simulation length: 10 TTIs
  Scheduler: round robin
  Mode: 2x2, CLSM
---------------------------------------
    Cell statistics:

  Fairness index: 0.213854
 Peak/Avg/Edge UE throughput:
   0.76/0.16/0.00 Mb/s
  Average cell throughput: 3.27Mb/s
   Ignored cells (disabled): 0
 mean RB occupancy: 100.00%
---------------------------------------
```

Figure 4.16: UE velocity= 5 km/h, Frequency 5 GHz, Bandwidth 15 MHz, Round Robin

UE velocity= 5 km/h, Frequency 5 GHz, Bandwidth 15 MHz, Proportional Fair Sun



Simulations statistics:

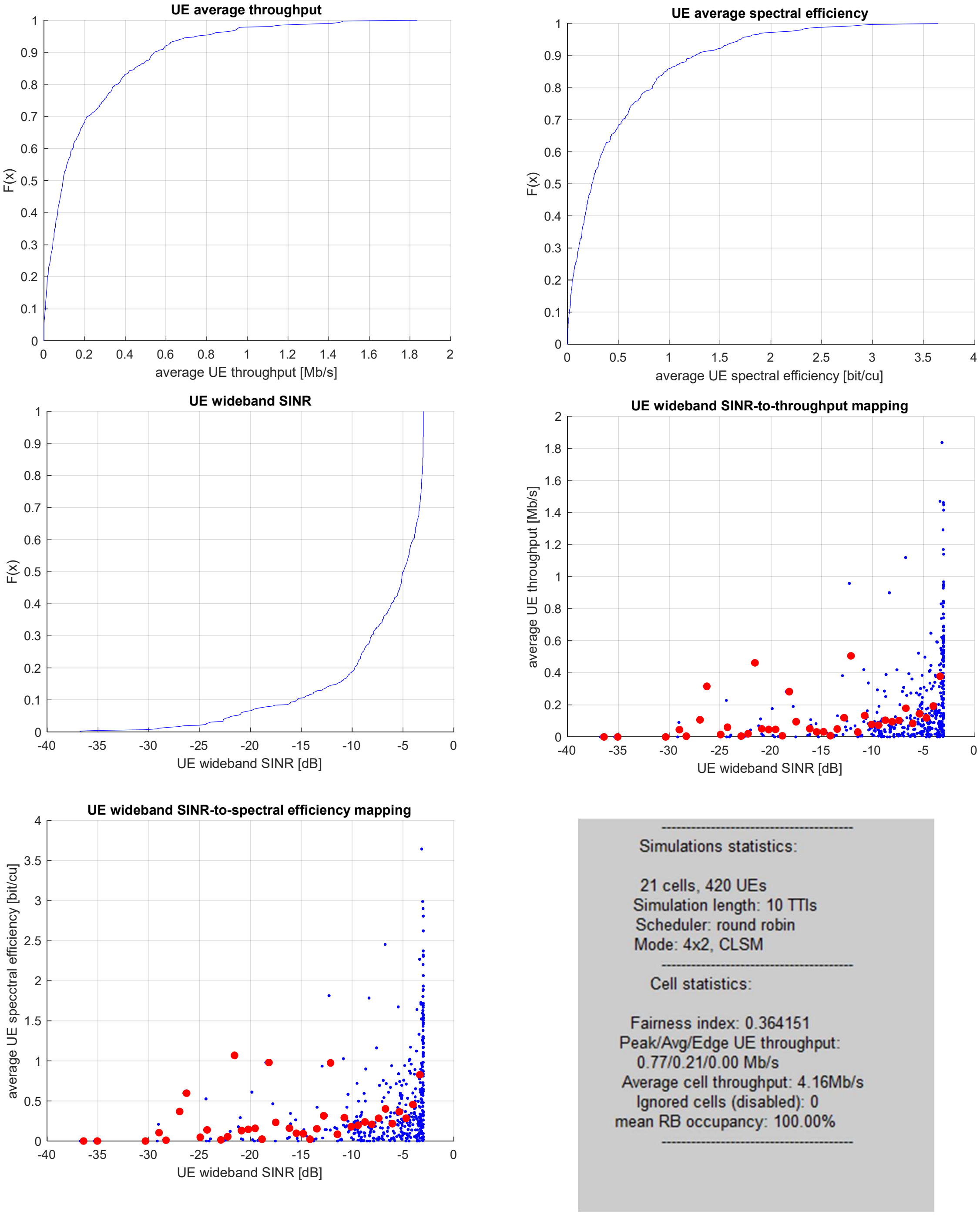
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 2x2, CLSM

Cell statistics:

Fairness index: 0.0987637
Peak/Avg/Edge UE throughput:
0.69/0.13/0.00 Mb/s
Average cell throughput: 2.70Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.17: UE velocity= 5 km/h, Frequency 5 GHz, Bandwidth 15 MHz, Proportional Fair Sun

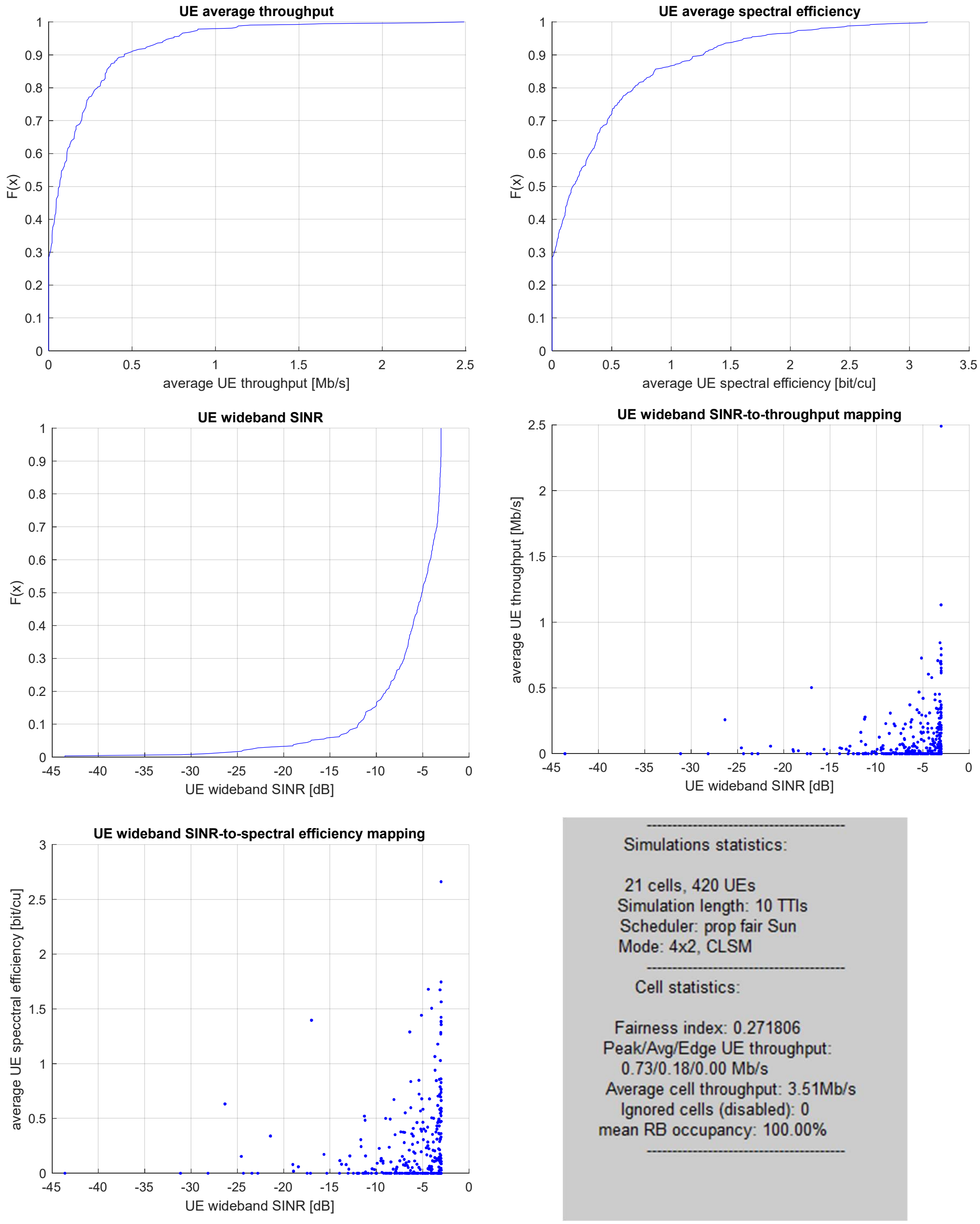
UE velocity= 120 km/h, Frequency 2GHz, Bandwidth 10 MHz, Round Robin



```
-----------------------------------------
Simulations statistics:

 21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM
-----------------------------------------
    Cell statistics:

Fairness index: 0.364151
Peak/Avg/Edge UE throughput:
  0.77/0.21/0.00 Mb/s
Average cell throughput: 4.16Mb/s
  Ignored cells (disabled): 0
mean RB occupancy: 100.00%
-----------------------------------------
```

Figure 4.18: UE velocity= 120 km/h, Frequency 2GHz, Bandwidth 10 MHz, Round Robin

UE velocity= 120 km/h, Frequency 2GHz, Bandwidth 10 MHz, Prop Fair Sun



Simulations statistics:

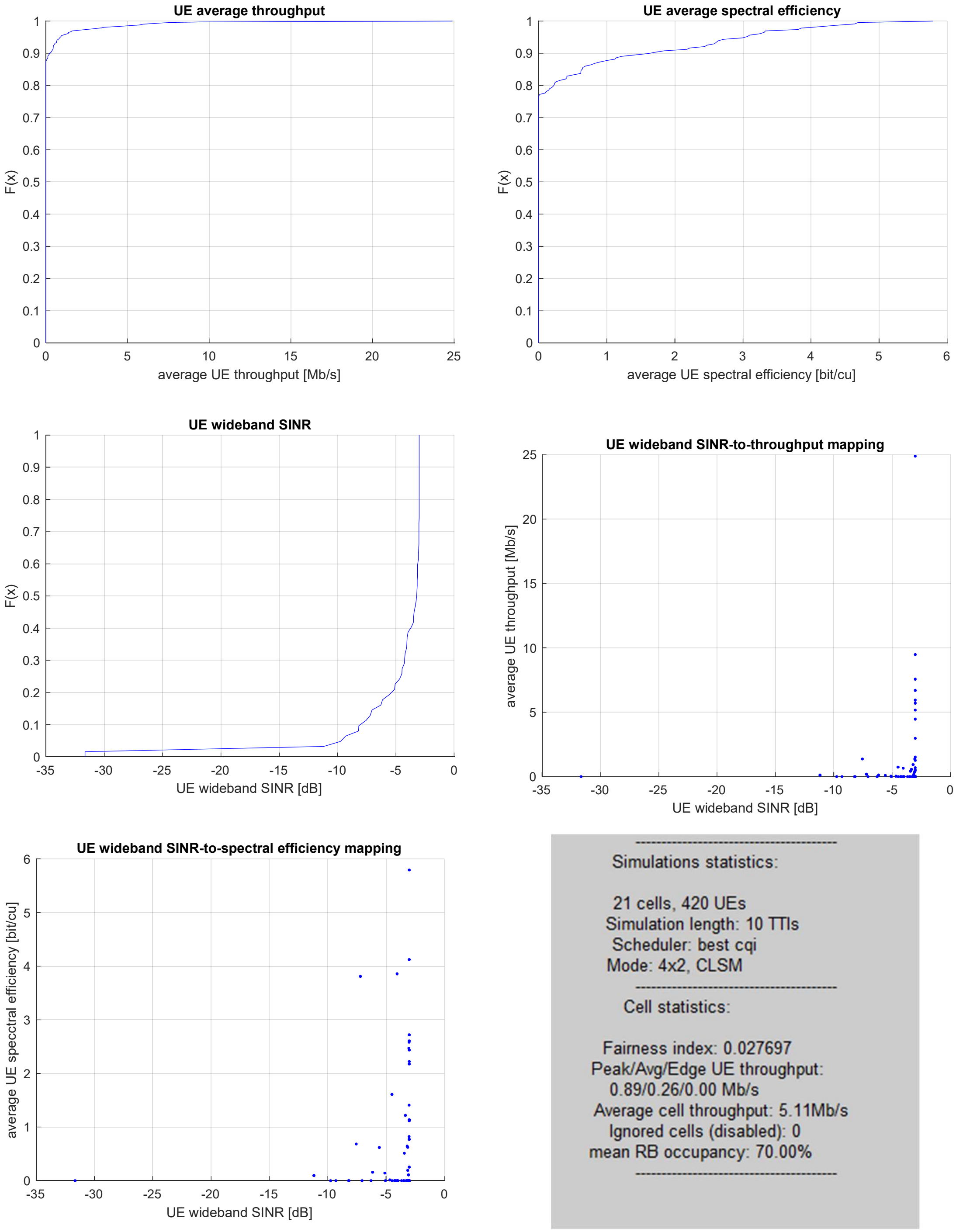
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.271806
Peak/Avg/Edge UE throughput:
0.73/0.18/0.00 Mb/s
Average cell throughput: 3.51Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.19: UE velocity= 120 km/h, Frequency 2GHz, Bandwidth 10 MHz, Prop Fair Sun

UE velocity= 120 km/h, Frequency 2GHz, Bandwidth 10 MHz, Best CQI



```
----------------------------------------
    Simulations statistics:

     21 cells, 420 UEs
   Simulation length: 10 TTIs
     Scheduler: best cqi
   Mode: 4x2, CLSM
----------------------------------------
        Cell statistics:

   Fairness index: 0.027697
  Peak/Avg/Edge UE throughput:
     0.89/0.26/0.00 Mb/s
   Average cell throughput: 5.11Mb/s
     Ignored cells (disabled): 0
  mean RB occupancy: 70.00%
----------------------------------------
```

Figure 4.20: UE velocity= 120 km/h, Frequency 2GHz, Bandwidth 10 MHz, Best CQI

Next, we have the CoMP scheduler, in which, basically a UE is connected to multiple eNBs, and receives data from multiple eNBs which enhances the throughput. We compared this scheduler on basis of multiple velocities and different number UE per cell (only for static case). Then, an extension was made for the CoMP scheduler, which is the runtime precoding. Runtime precoding reduces complexity which is incurred due to coherent transmission, at the cost of some throughput. Here for the static and 5 km/h case, ITU Pedestrian-A channel was used and for the 40 km/h case, ITU Pedestrian-B channel was used.

UE still, Coordinated Multi Point, Round Robin, 20 UE/cell

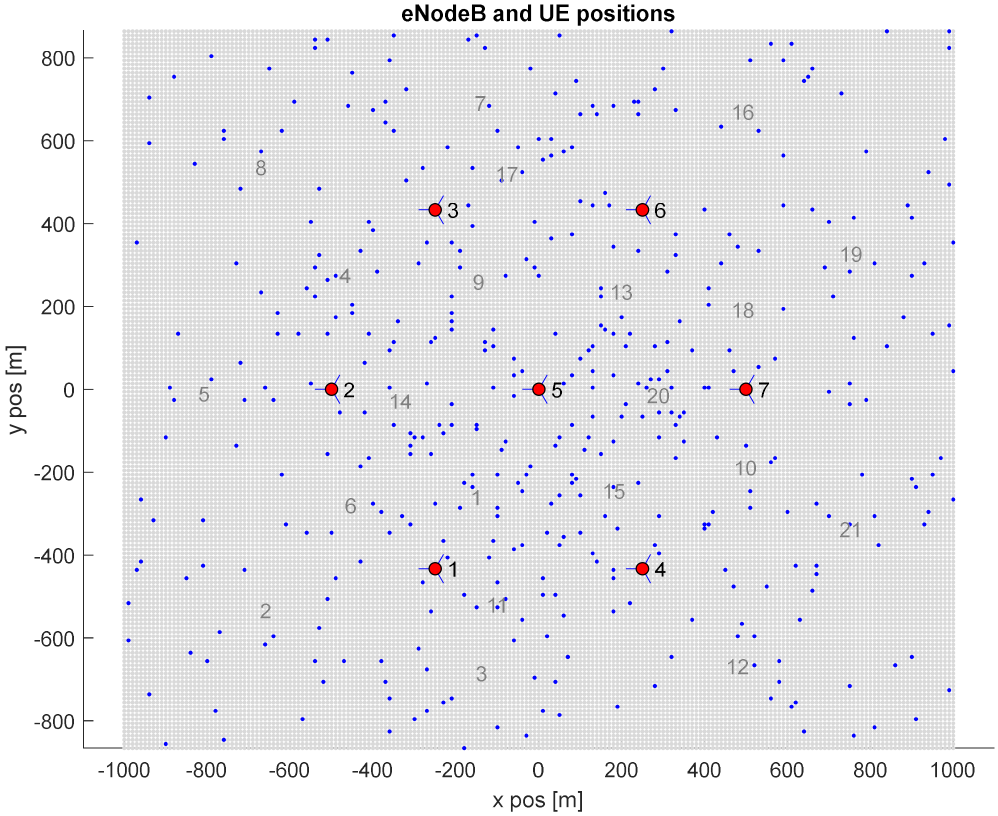
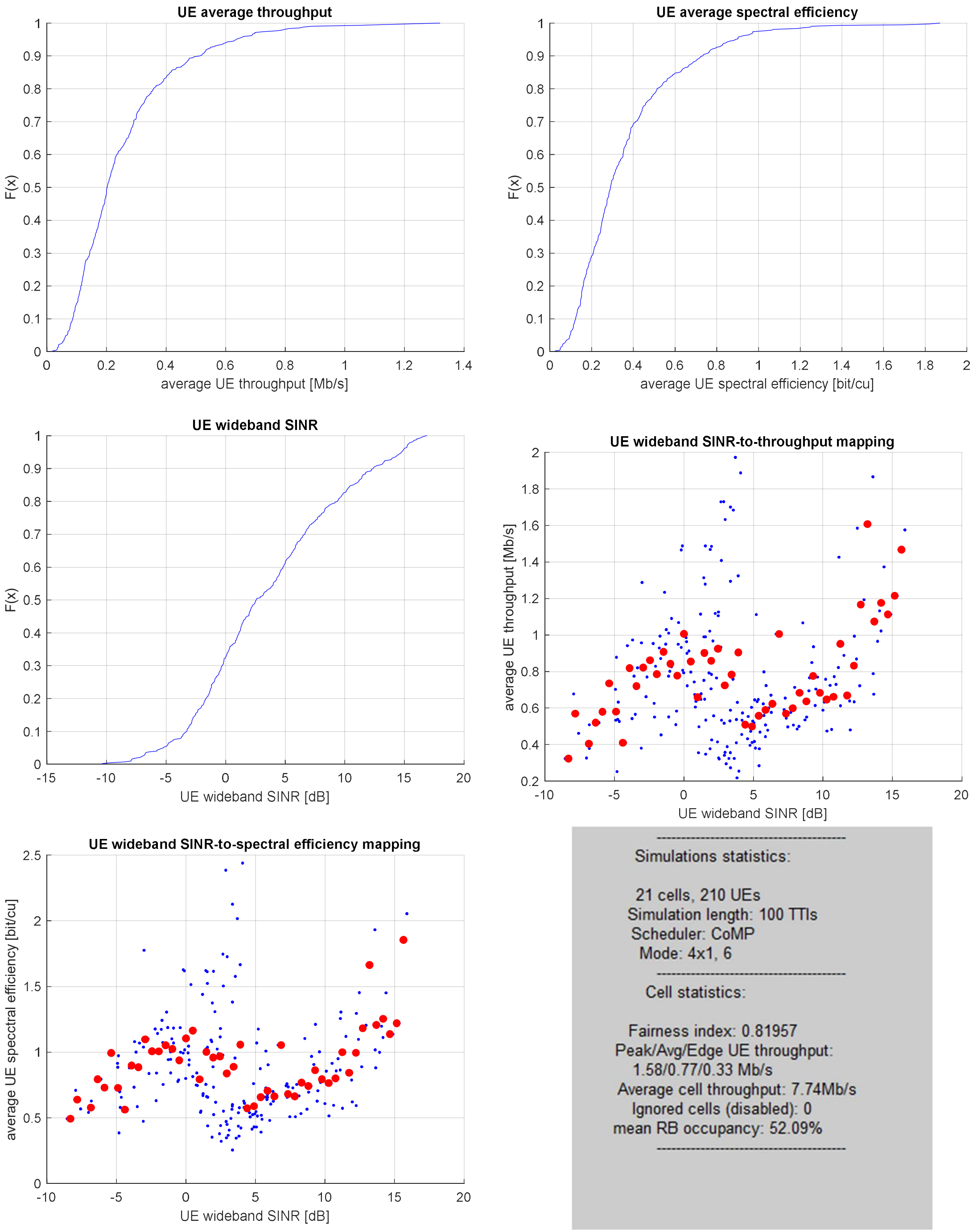


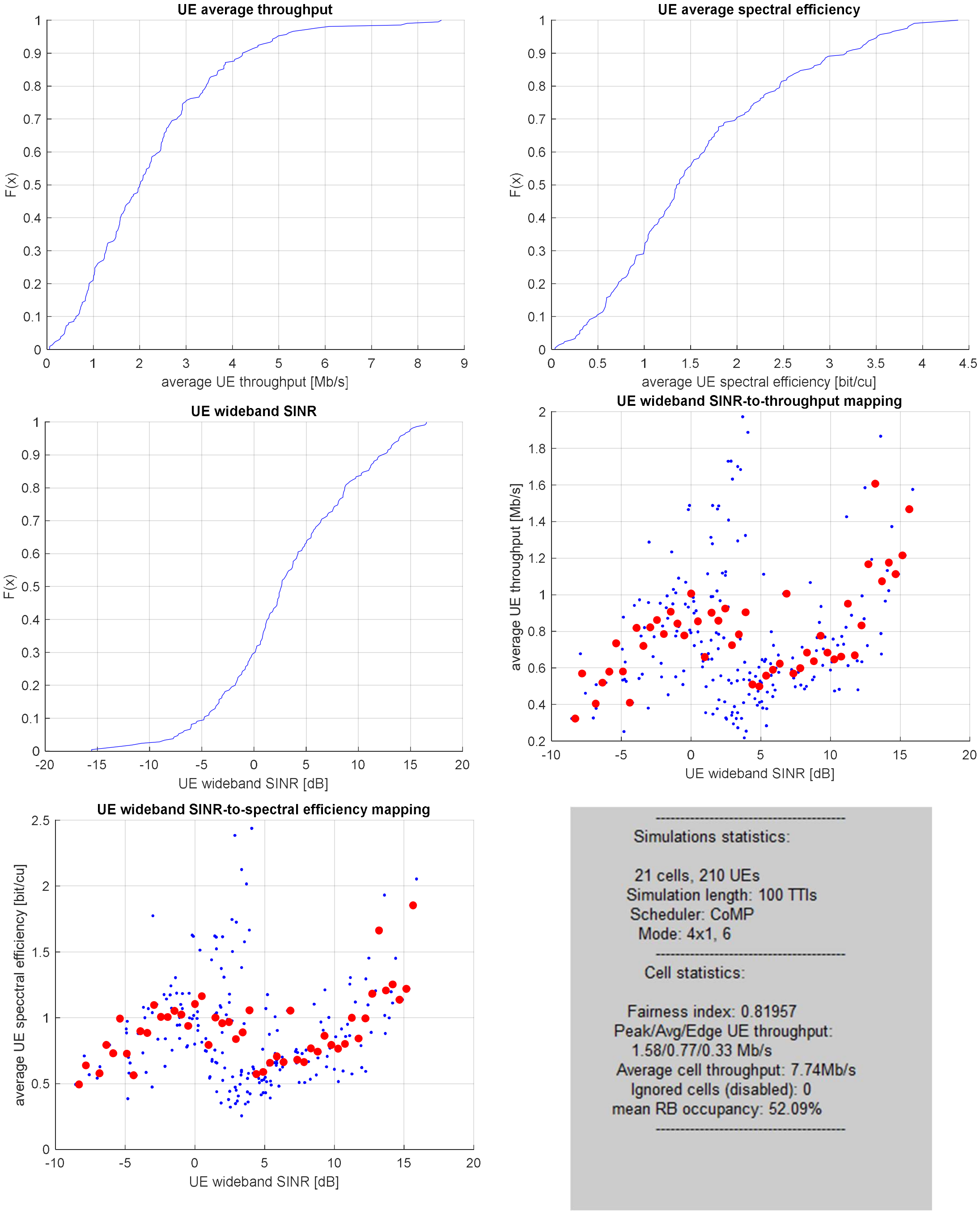
Figure 4.21: UE and eNodeB distribution in a geographical area



```
------------------------------------
Simulations statistics:

 21 cells, 210 UEs
Simulation length: 100 TTIs
Scheduler: CoMP
  Mode: 4x1, 6
------------------------------------
   Cell statistics:

 Fairness index: 0.81957
Peak/Avg/Edge UE throughput:
   1.58/0.77/0.33 Mb/s
 Average cell throughput: 7.74Mb/s
   Ignored cells (disabled): 0
mean RB occupancy: 52.09%
------------------------------------
```

Figure 4.22: UE still, Coordinated Multi Point, Round Robin, 20 UE/cell

UE still, Coordinated Multi Point, Round Robin, 10 UE/cell



Simulations statistics:

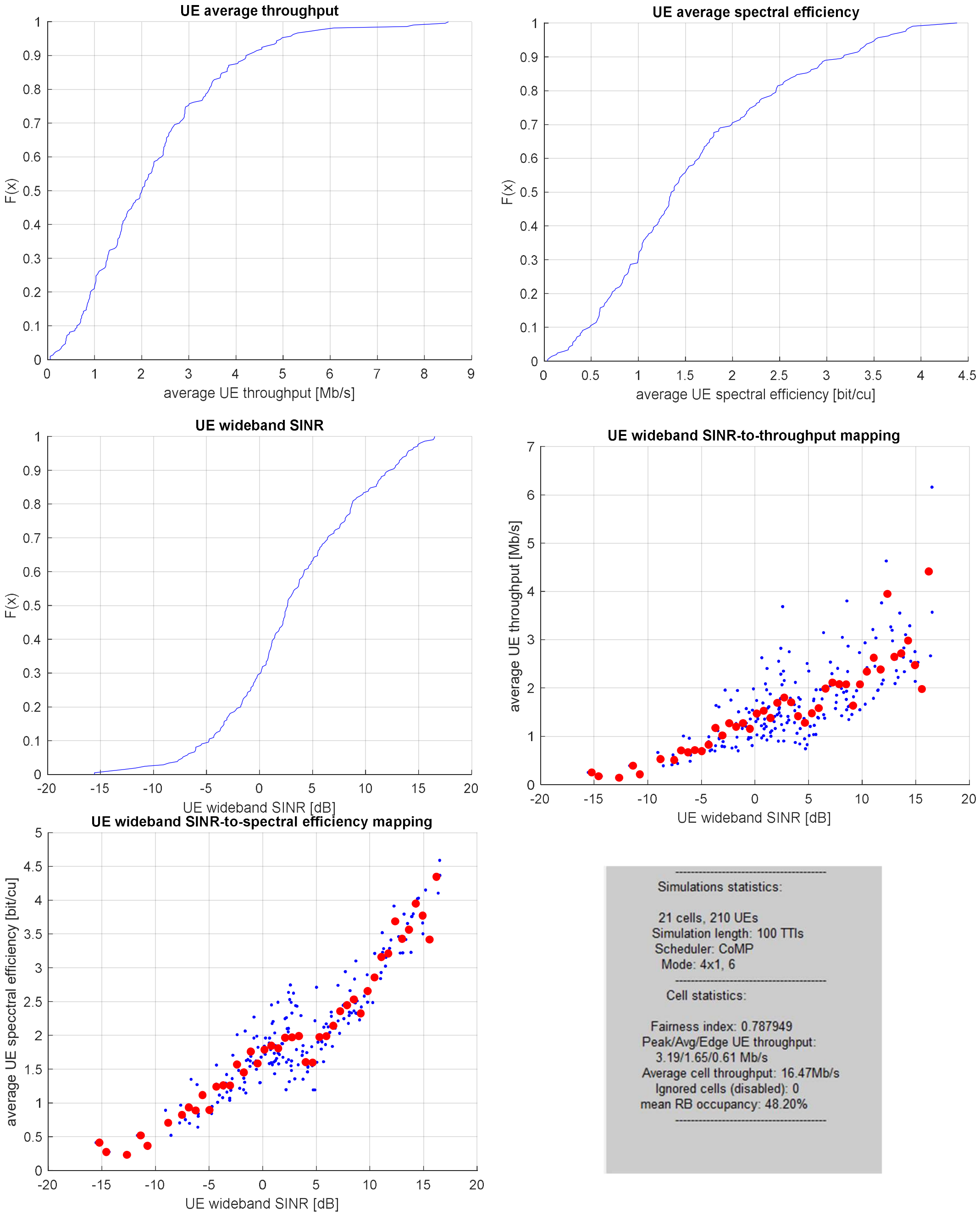
21 cells, 210 UEs
Simulation length: 100 TTIs
Scheduler: CoMP
Mode: 4x1, 6

Cell statistics:

Fairness index: 0.81957
Peak/Avg/Edge UE throughput:
1.58/0.77/0.33 Mb/s
Average cell throughput: 7.74Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 52.09%

Figure 4.23: UE still, Coordinated Multi Point, Round Robin, 10 UE/cell

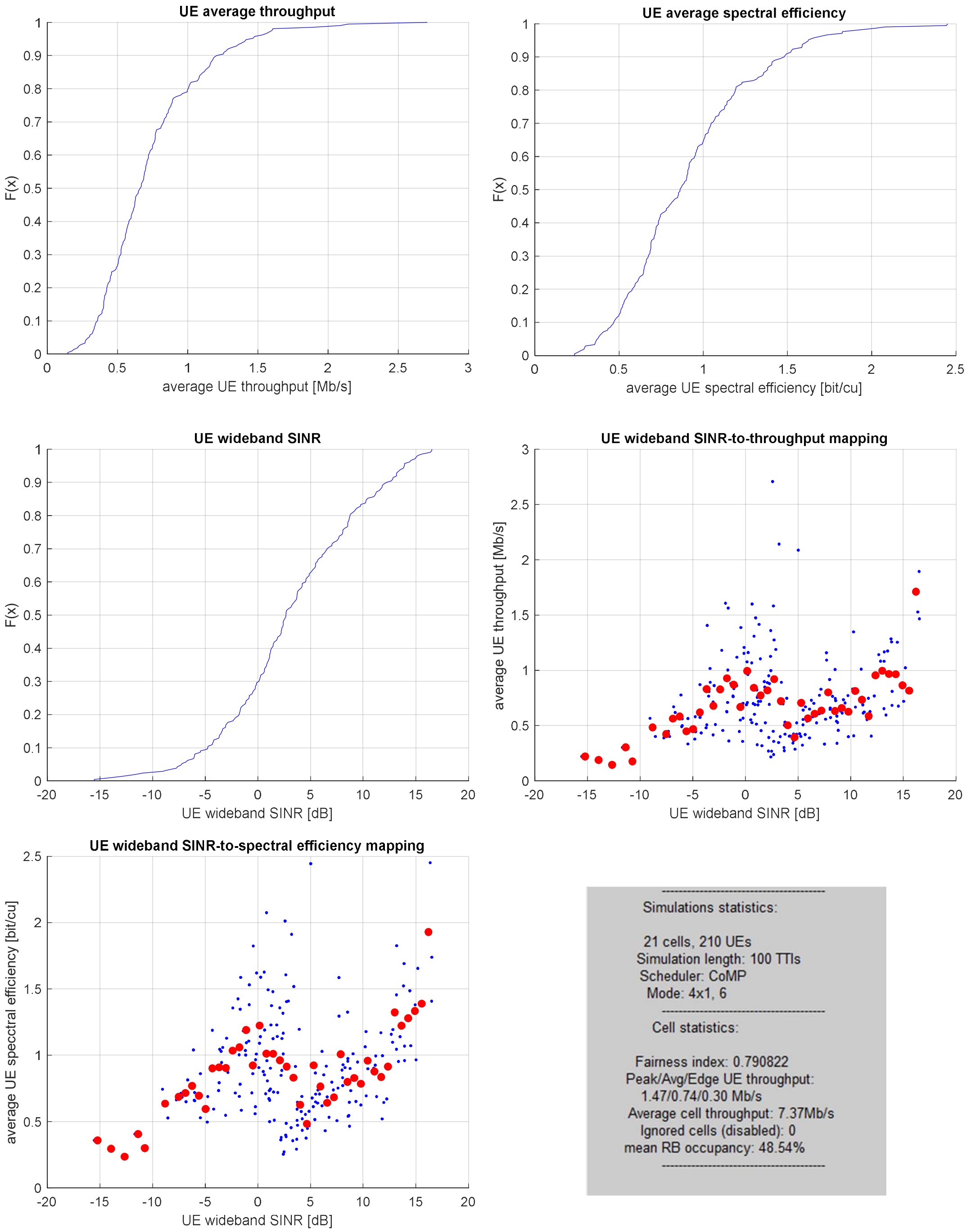
UE= 5 km/h, Coordinated Multi Point, Round Robin, 10 UE/cell



```
----------------------------------------
Simulations statistics:

 21 cells, 210 UEs
Simulation length: 100 TTIs
Scheduler: CoMP
 Mode: 4x1, 6
----------------------------------------
Cell statistics:

Fairness index: 0.787949
Peak/Avg/Edge UE throughput:
3.19/1.65/0.61 Mb/s
Average cell throughput: 16.47Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 48.20%
----------------------------------------
```

Figure 4.24: UE= 5 km/h, Coordinated Multi Point, Round Robin, 10 UE/cell

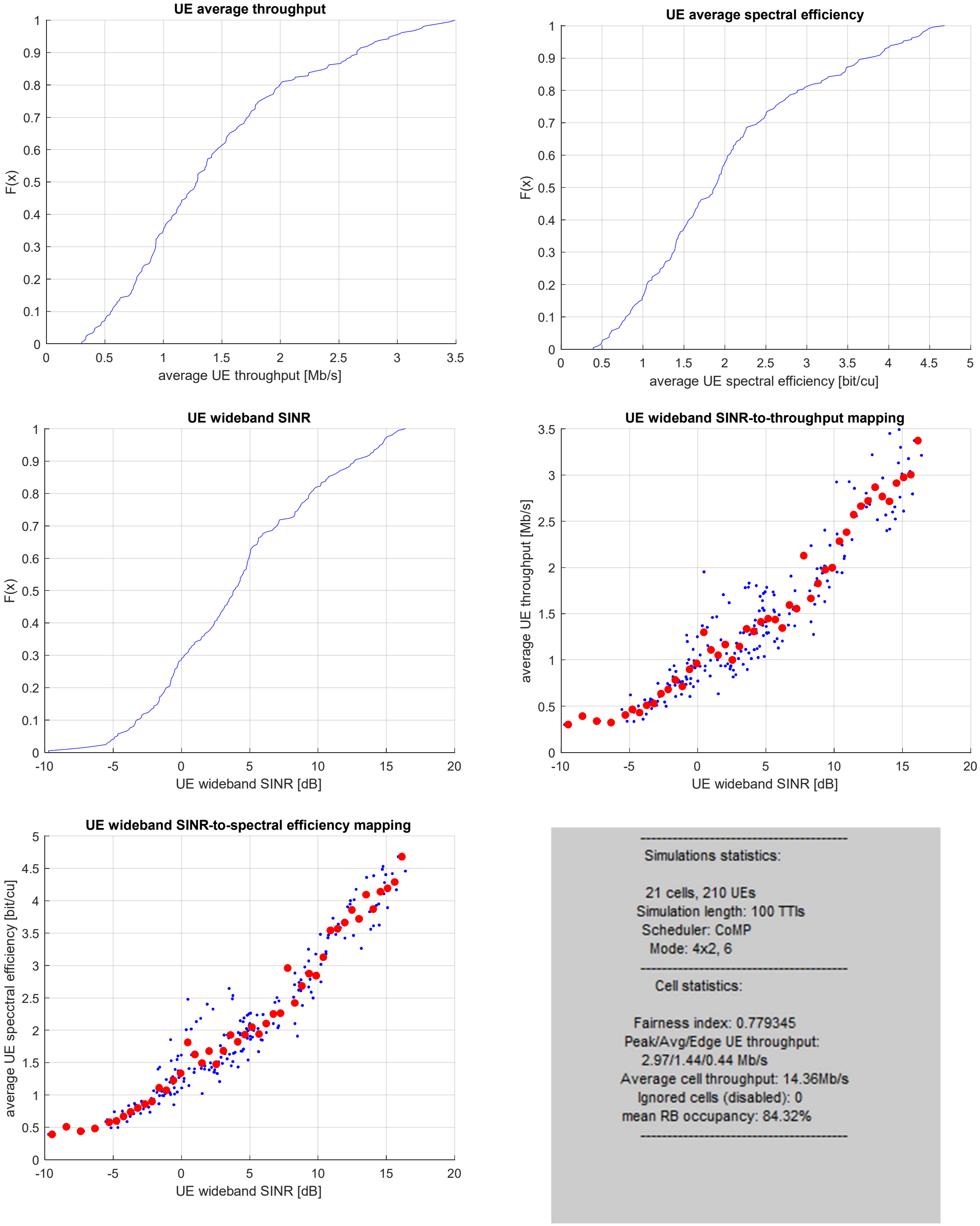
UE= 40 km/h, Coordinated Multi Point, Round Robin, 10 UE/cell



```
-----------------------------------------
Simulations statistics:

 21 cells, 210 UEs
Simulation length: 100 TTIs
 Scheduler: CoMP
  Mode: 4x1, 6
-----------------------------------------
  Cell statistics:

Fairness index: 0.790822
Peak/Avg/Edge UE throughput:
    1.47/0.74/0.30 Mb/s
Average cell throughput: 7.37Mb/s
  Ignored cells (disabled): 0
mean RB occupancy: 48.54%
-----------------------------------------
```

Figure 4.25: UE= 40 km/h, Coordinated Multi Point, Round Robin, 10 UE/cell

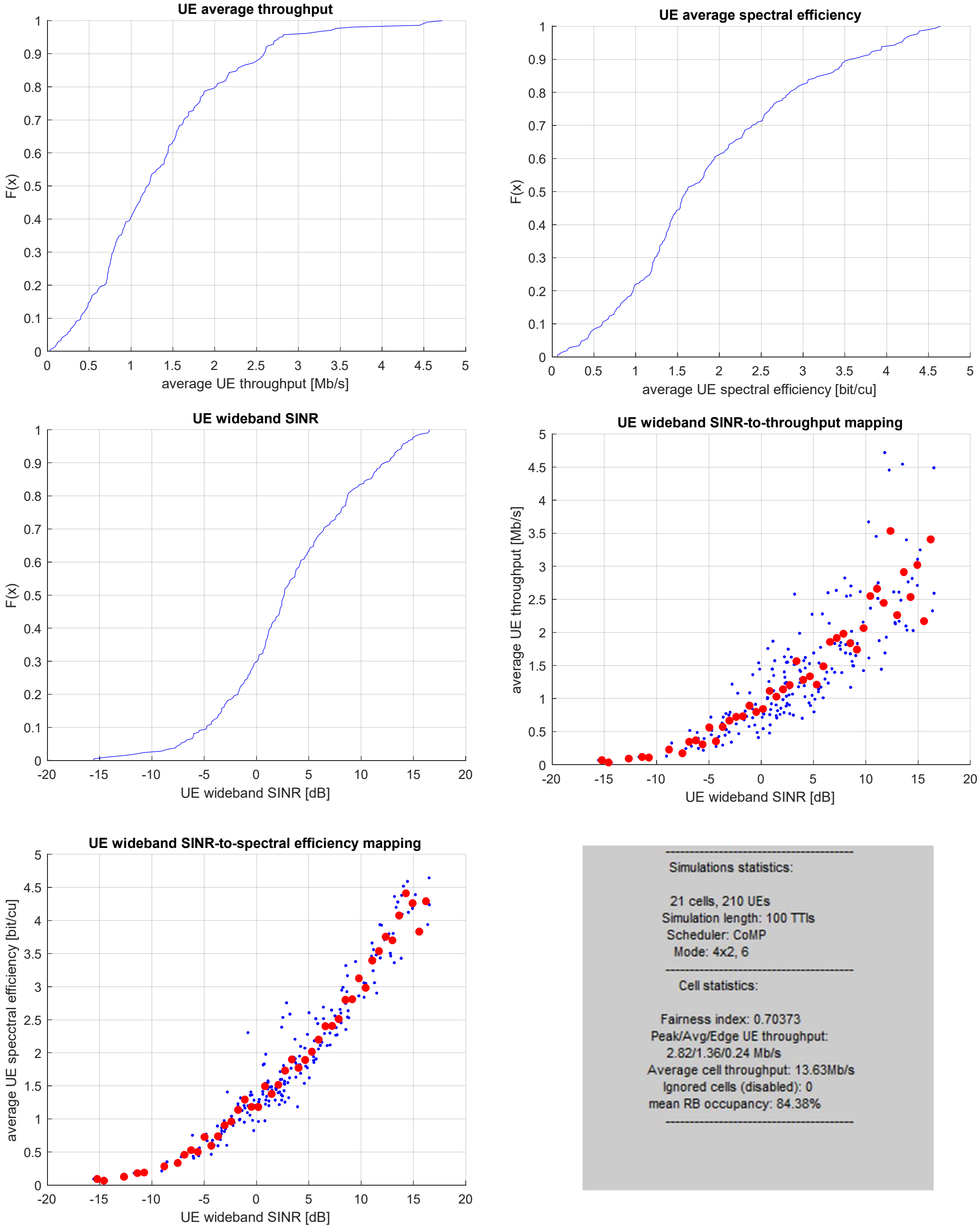
UE still, Runtime Precoding, 10 UE/cell



```
-----------------------------------------
Simulations statistics:

21 cells, 210 UEs
Simulation length: 100 TTIs
Scheduler: CoMP
Mode: 4x2, 6
-----------------------------------------
Cell statistics:

Fairness index: 0.779345
Peak/Avg/Edge UE throughput:
2.97/1.44/0.44 Mb/s
Average cell throughput: 14.36Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 84.32%
-----------------------------------------
```

Figure 4.26: UE still, Runtime Precoding, 10 UE/cell

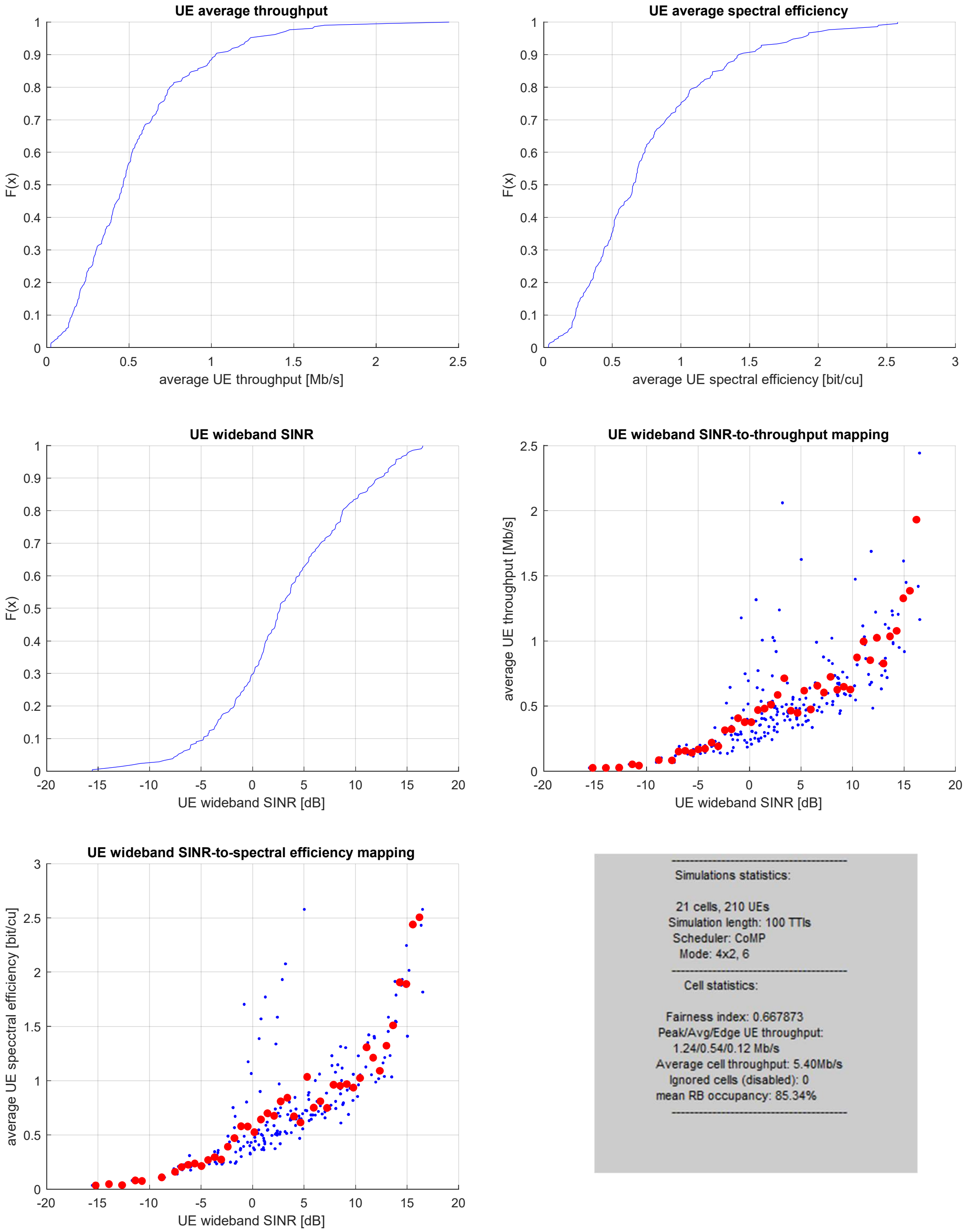
UE velocity= 5 km/h, Runtime Precoding, 10 UE/cell



```
----------------------------------------
 Simulations statistics:

  21 cells, 210 UEs
 Simulation length: 100 TTIs
  Scheduler: CoMP
   Mode: 4x2, 6
----------------------------------------
   Cell statistics:

 Fairness index: 0.70373
 Peak/Avg/Edge UE throughput:
  2.82/1.36/0.24 Mb/s
 Average cell throughput: 13.63Mb/s
  Ignored cells (disabled): 0
 mean RB occupancy: 84.38%
----------------------------------------
```

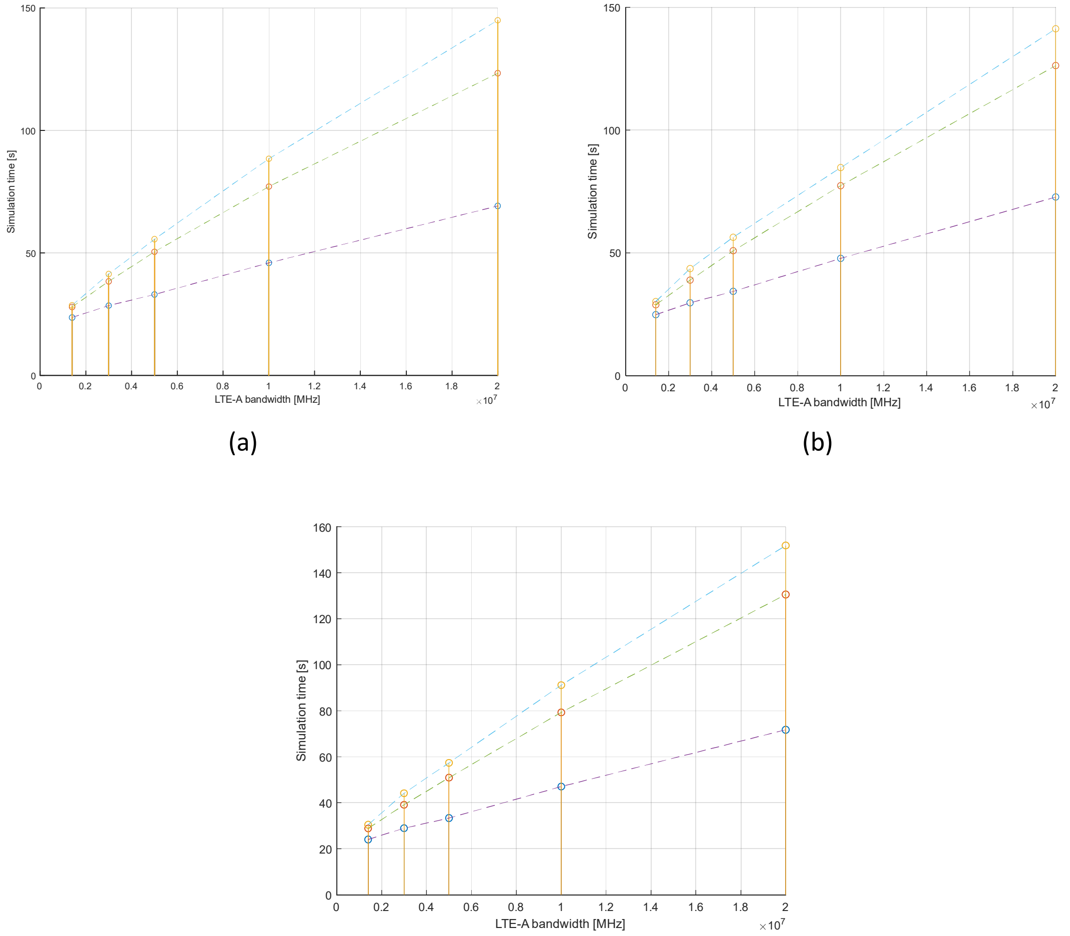
Figure 4.27: UE velocity= 5 km/h, Runtime Precoding, 10 UE/cell

UE velocity= 40 km/h, Runtime Precoding, 10 UE/cell



```
---------------------------------------
 Simulations statistics:

 21 cells, 210 UEs
Simulation length: 100 TTIs
Scheduler: CoMP
 Mode: 4x2, 6
---------------------------------------
 Cell statistics:

 Fairness index: 0.667873
Peak/Avg/Edge UE throughput:
 1.24/0.54/0.12 Mb/s
Average cell throughput: 5.40Mb/s
 Ignored cells (disabled): 0
mean RB occupancy: 85.34%
---------------------------------------
```

Figure 4.28: UE velocity= 40 km/h, Runtime Precoding, 10 UE/cell



(a)

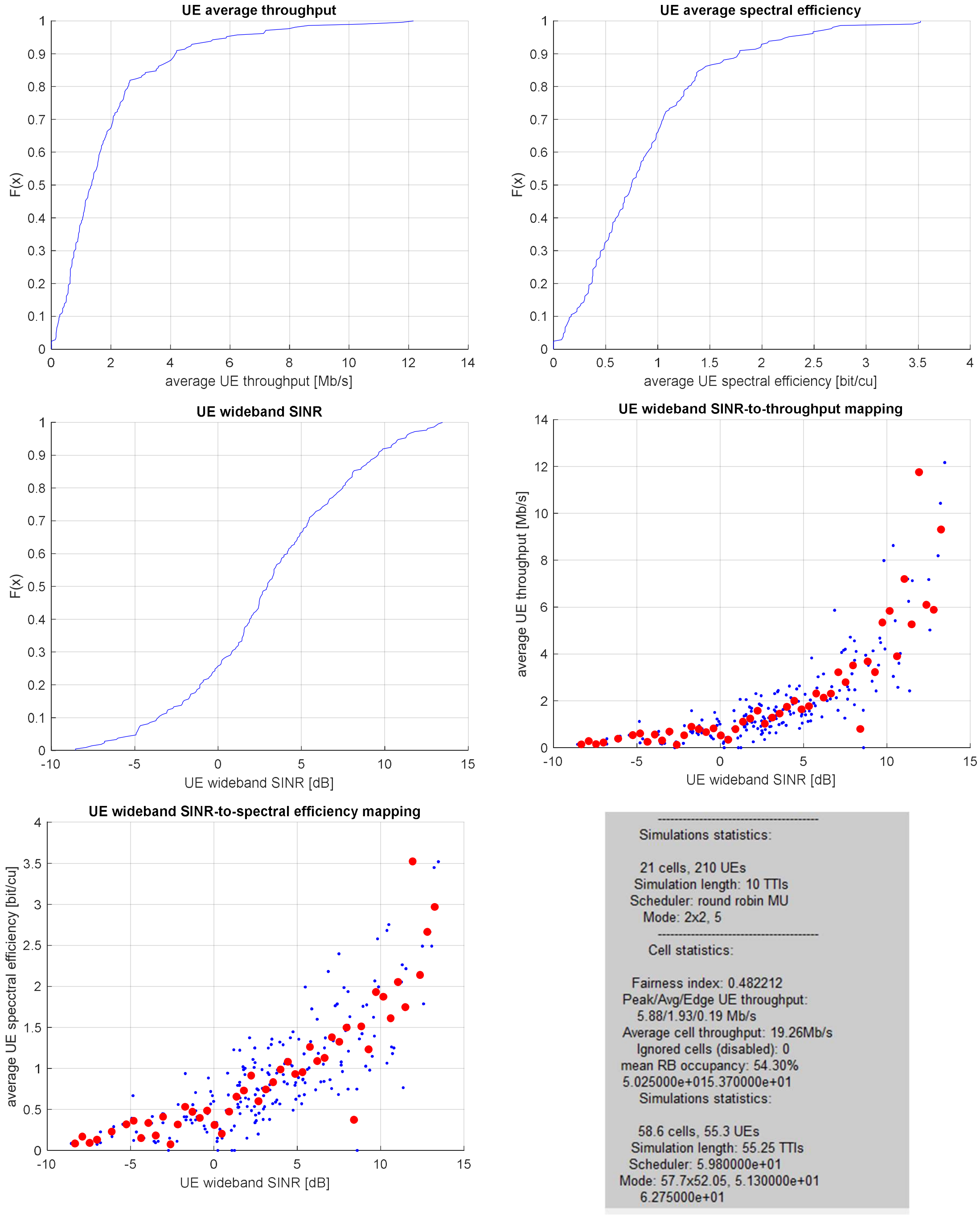
(b)

(c)

Figure 4.29: Performance for (a) still UE (b) UE with velocity 5 km/h (c) UE with velocity 40 km/h

Next is the transmission mode MIMO case, where we use antennas, which enable us to have MU-MIMO rather than MC-MIMO as in the previous cases. We compared this for different velocities also. There is also a transmission mode, MU-MIMO with eight-layer spatial multiplexing, but for the complexity regarding its physical layer model and lower throughput, it was avoided.

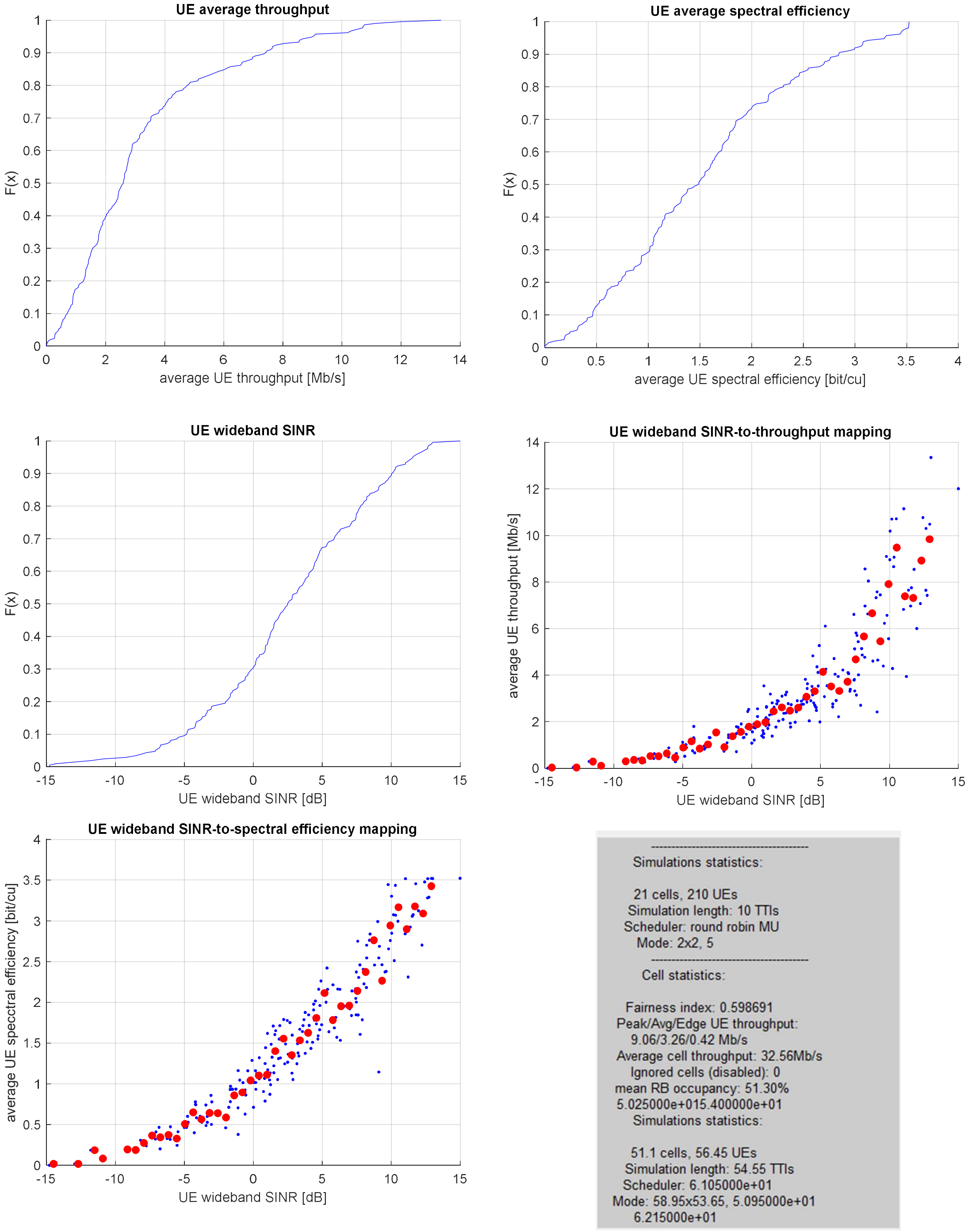
UE still, MIMO, 10 UE/cell



```
         ----------------------------------------
      Simulations statistics:

      21 cells, 210 UEs
     Simulation length: 10 TTIs
    Scheduler: round robin MU
       Mode: 2x2, 5
         ----------------------------------------
        Cell statistics:

    Fairness index: 0.482212
   Peak/Avg/Edge UE throughput:
      5.88/1.93/0.19 Mb/s
   Average cell throughput: 19.26Mb/s
      Ignored cells (disabled): 0
   mean RB occupancy: 54.30%
   5.025000e+015.370000e+01
      Simulations statistics:

      58.6 cells, 55.3 UEs
     Simulation length: 55.25 TTIs
    Scheduler: 5.980000e+01
   Mode: 57.7x52.05, 5.130000e+01
      6.275000e+01
```

Figure 4.30: UE still, MIMO, 10 UE/cell

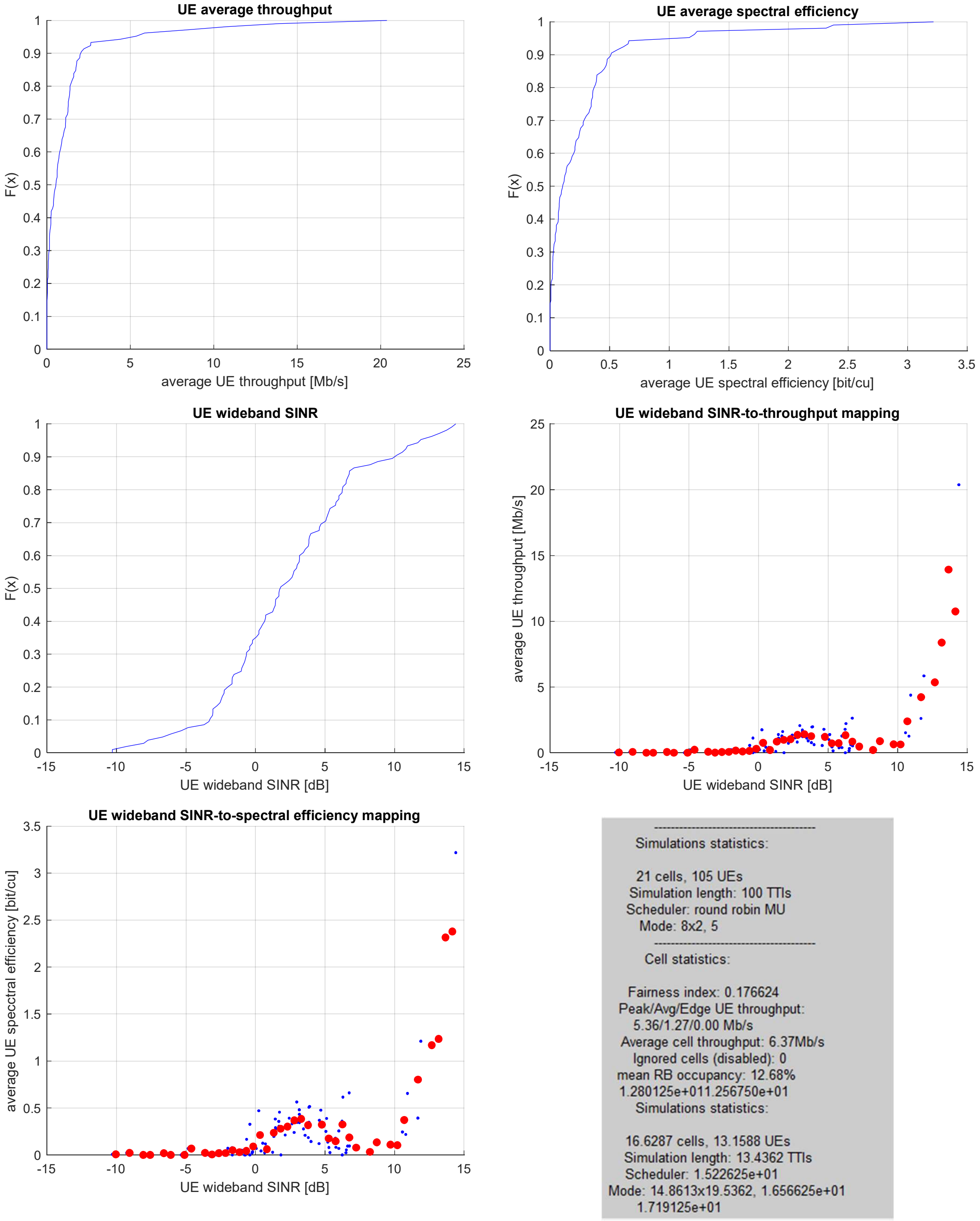
UE velocity= 5 km/h, MIMO, 10 UE/cell



```
 ----------------------------------------
  Simulations statistics:

  21 cells, 210 UEs
 Simulation length: 10 TTIs
 Scheduler: round robin MU
   Mode: 2x2, 5
 ----------------------------------------
   Cell statistics:

  Fairness index: 0.598691
 Peak/Avg/Edge UE throughput:
   9.06/3.26/0.42 Mb/s
 Average cell throughput: 32.56Mb/s
   Ignored cells (disabled): 0
mean RB occupancy: 51.30%
 5.025000e+015.400000e+01
  Simulations statistics:

   51.1 cells, 56.45 UEs
  Simulation length: 54.55 TTIs
  Scheduler: 6.105000e+01
Mode: 58.95x53.65, 5.095000e+01
   6.215000e+01
```

Figure 4.31: UE velocity= 5 km/h, MIMO, 10 UE/cell

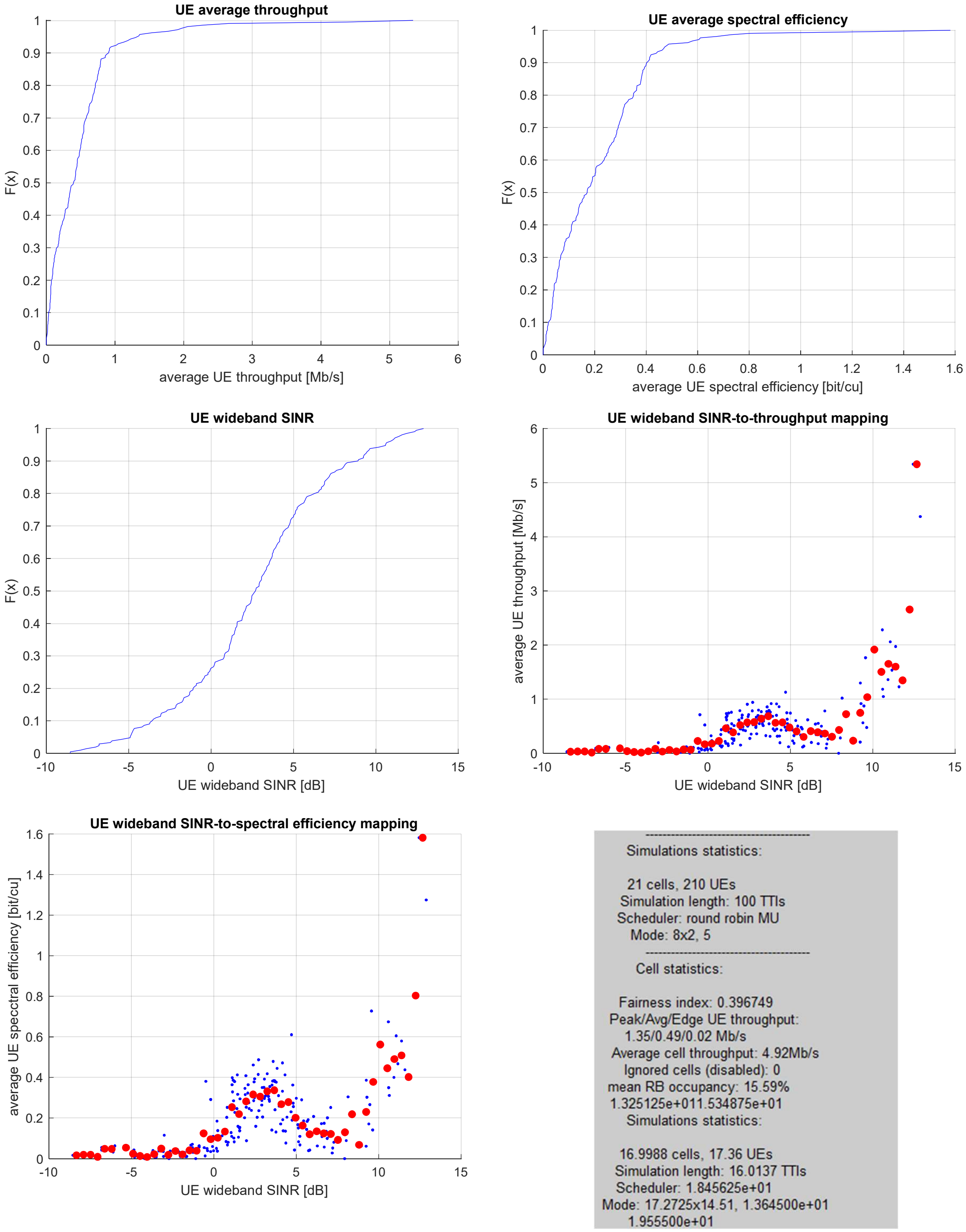
UE still, MIMO with Eight Layer Spatial Multiplexing, 5 UE/cell



```
-----------------------------------------
   Simulations statistics:

    21 cells, 105 UEs
  Simulation length: 100 TTIs
 Scheduler: round robin MU
     Mode: 8x2, 5
-----------------------------------------
      Cell statistics:

  Fairness index: 0.176624
Peak/Avg/Edge UE throughput:
    5.36/1.27/0.00 Mb/s
 Average cell throughput: 6.37Mb/s
    Ignored cells (disabled): 0
mean RB occupancy: 12.68%
1.280125e+011.256750e+01
   Simulations statistics:

  16.6287 cells, 13.1588 UEs
 Simulation length: 13.4362 TTIs
 Scheduler: 1.522625e+01
Mode: 14.8613x19.5362, 1.656625e+01
       1.719125e+01
```

Figure 4.32: UE still, MIMO with Eight Layer Spatial Multiplexing, 5 UE/cell

UE still, MIMO with Eight Layer Spatial Multiplexing, 10 UE/cell



```
            ----------------------------------------
        Simulations statistics:

         21 cells, 210 UEs
       Simulation length: 100 TTIs
      Scheduler: round robin MU
         Mode: 8x2, 5
            ----------------------------------------
           Cell statistics:

       Fairness index: 0.396749
     Peak/Avg/Edge UE throughput:
         1.35/0.49/0.02 Mb/s
      Average cell throughput: 4.92Mb/s
         Ignored cells (disabled): 0
     mean RB occupancy: 15.59%
      1.325125e+011.534875e+01
        Simulations statistics:

       16.9988 cells, 17.36 UEs
      Simulation length: 16.0137 TTIs
      Scheduler: 1.845625e+01
    Mode: 17.2725x14.51, 1.364500e+01
         1.955500e+01
```

Figure 4.33: UE still, MIMO with Eight Layer Spatial Multiplexing, 10 UE/cell

It is eminent from the studies so far that, we have been using a hexagonal grid structures so far for deployment of eNBs in a site. So, we are not able to increase the eNB number separately, considering the geometry of the hexagonal grid will be hampered, so instead we increase the number of rings.

UE still, 2 eNodeB rings, Round Robin, 5 UE/cell

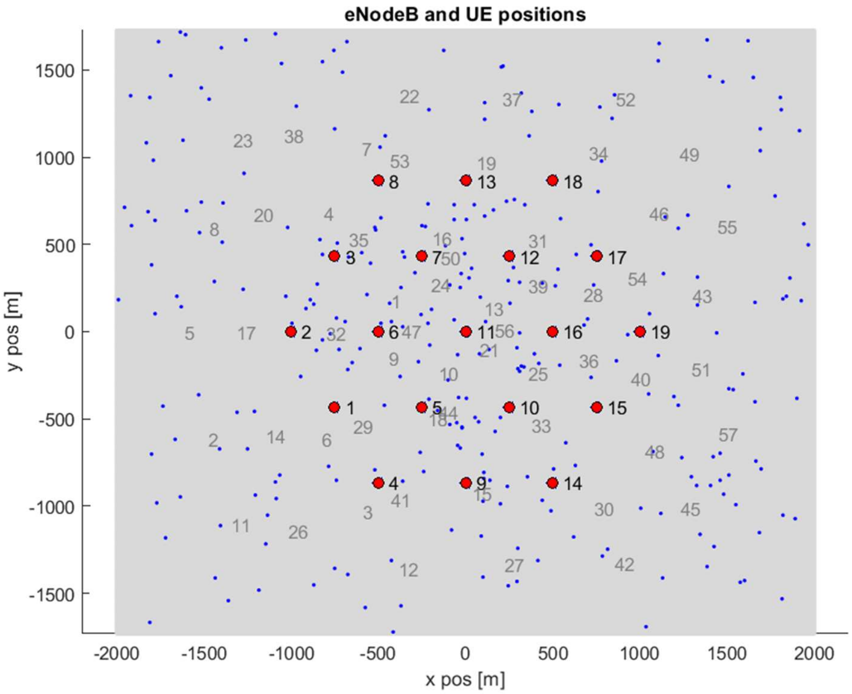
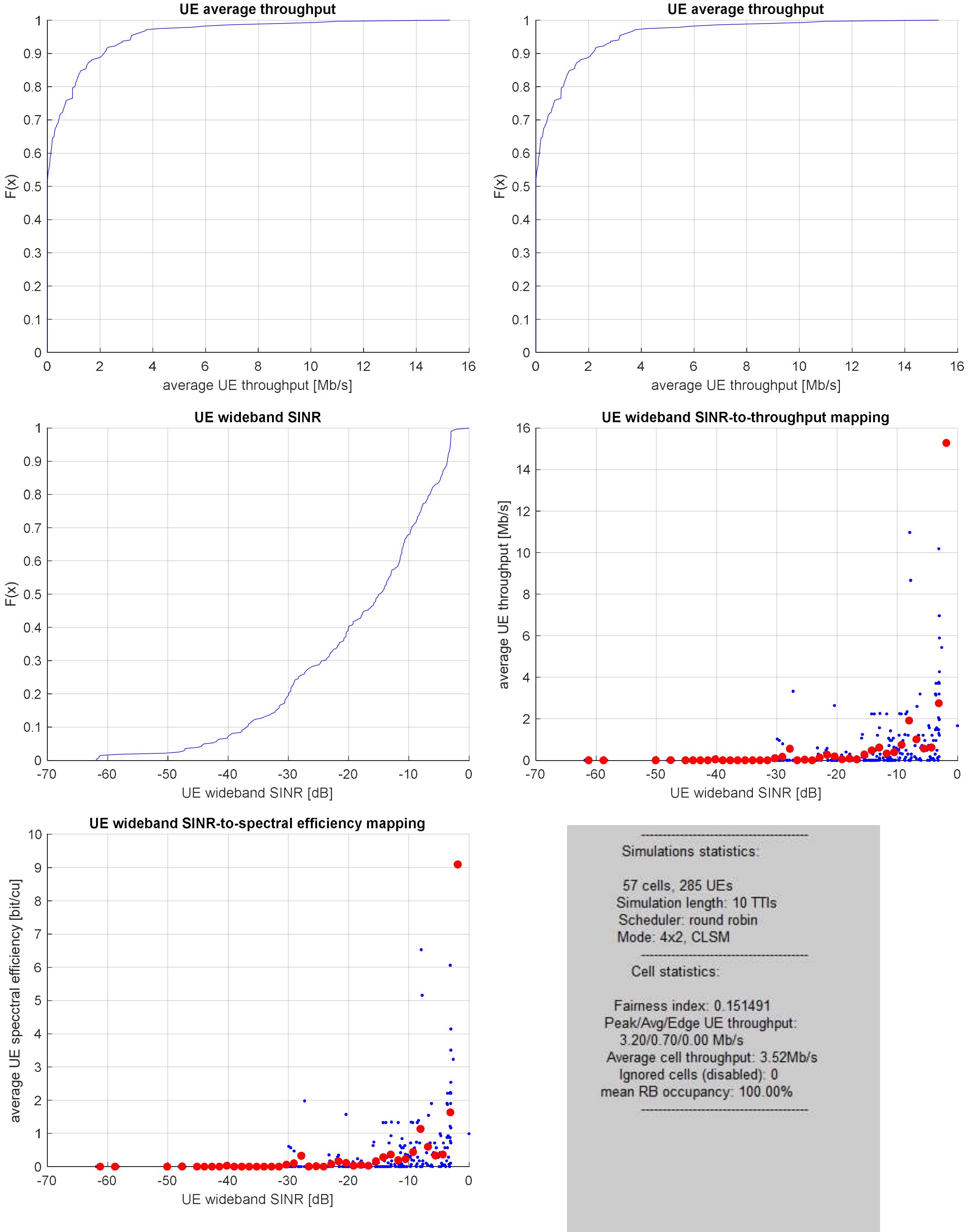


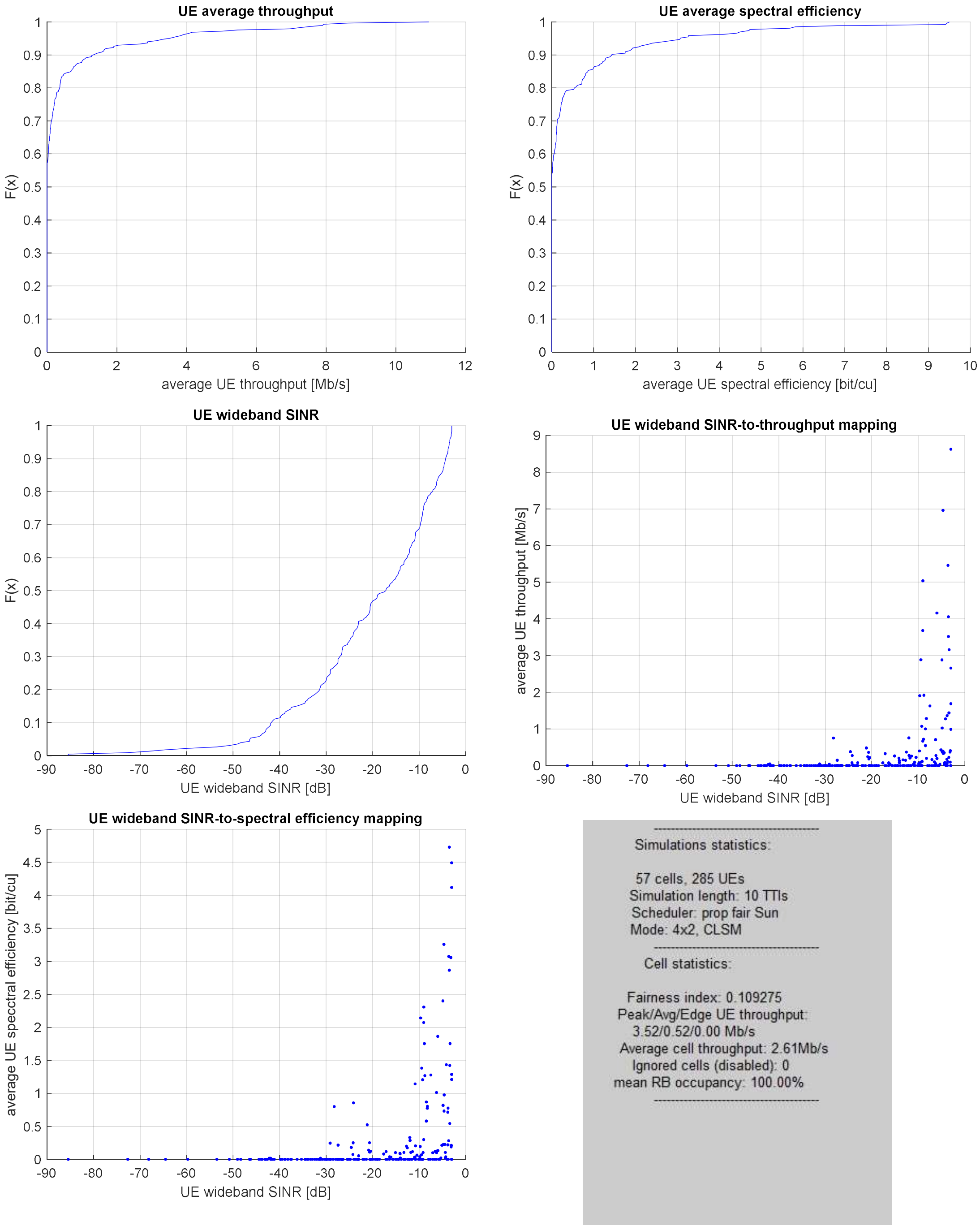
Figure 4.34: UE and eNodeB distribution



```
--------------------------------------------
Simulations statistics:

 57 cells, 285 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM
--------------------------------------------
Cell statistics:

Fairness index: 0.151491
Peak/Avg/Edge UE throughput:
 3.20/0.70/0.00 Mb/s
Average cell throughput: 3.52Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%
--------------------------------------------
```

Figure 4.35: UE still, 2 eNodeB rings, Round Robin, 5 UE/cell

UE still, 2 eNodeB rings, Prop Fair Sun, 5 UE/cell



Simulations statistics:

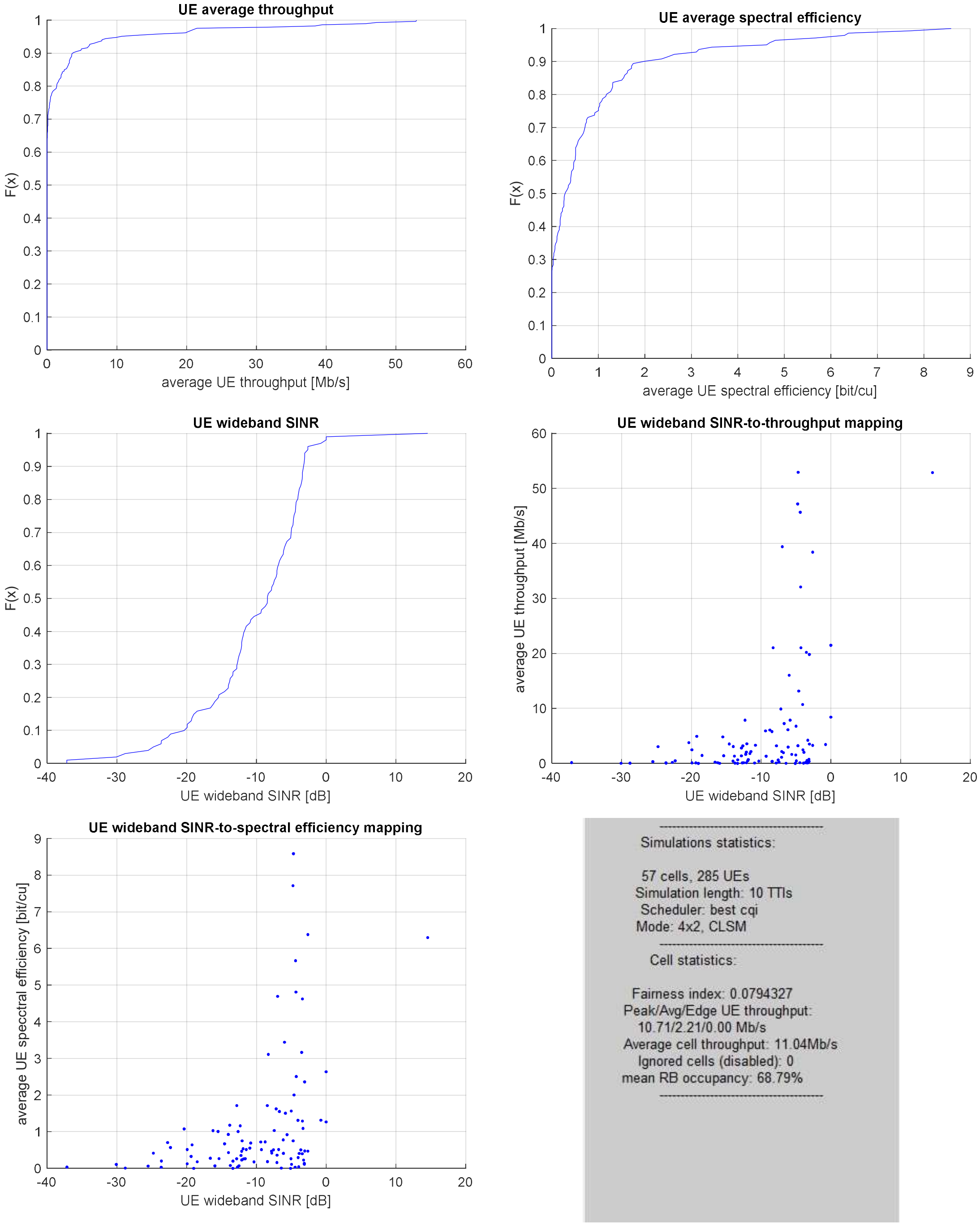
57 cells, 285 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.109275
Peak/Avg/Edge UE throughput:
3.52/0.52/0.00 Mb/s
Average cell throughput: 2.61Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.36: UE still, 2 eNodeB rings, Prop Fair Sun, 5 UE/cell

UE still, 2 eNodeB rings, Best CQI, 5 UE/cell



Simulations statistics:

57 cells, 285 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.0794327
Peak/Avg/Edge UE throughput:
10.71/2.21/0.00 Mb/s
Average cell throughput: 11.04Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 68.79%

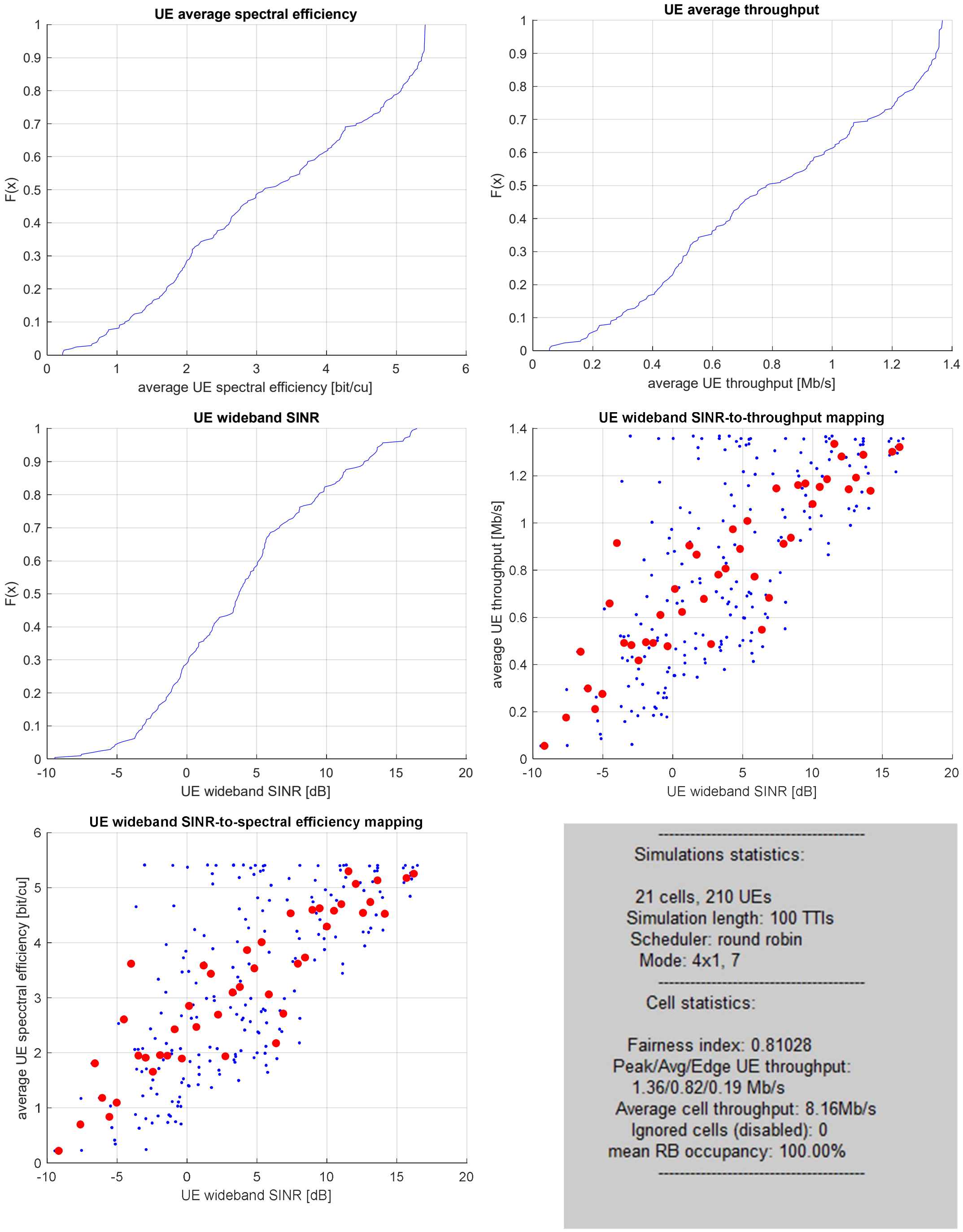
Figure 4.37: UE still, 2 eNodeB rings, Best CQI, 5 UE/cell

Now, we do our simulations for the transmission mode beamforming, where we use same signal phase in our multiple antenna elements, merge them to form a single signal, which provides us with more coverage area, good directivity and also strengthens the signal.

Another simulation was done using the MMW channels, where we use MMW antennas, i.e. eNBs for transmission. As its name suggests, very small antennas are required for transmission in this case. So, more antenna elements can be added in the eNB which will provide a better signal strength and directivity.

For our 5G technology, both MMW and beamforming are hot topic. The main drawback of MMW is that it has low penetration power due to its high frequency, whereas beamforming is somewhat costly since we are merging same signal components using multiple antennas. These two, can essentially be combined to remove each other's drawbacks to a considerable extent.

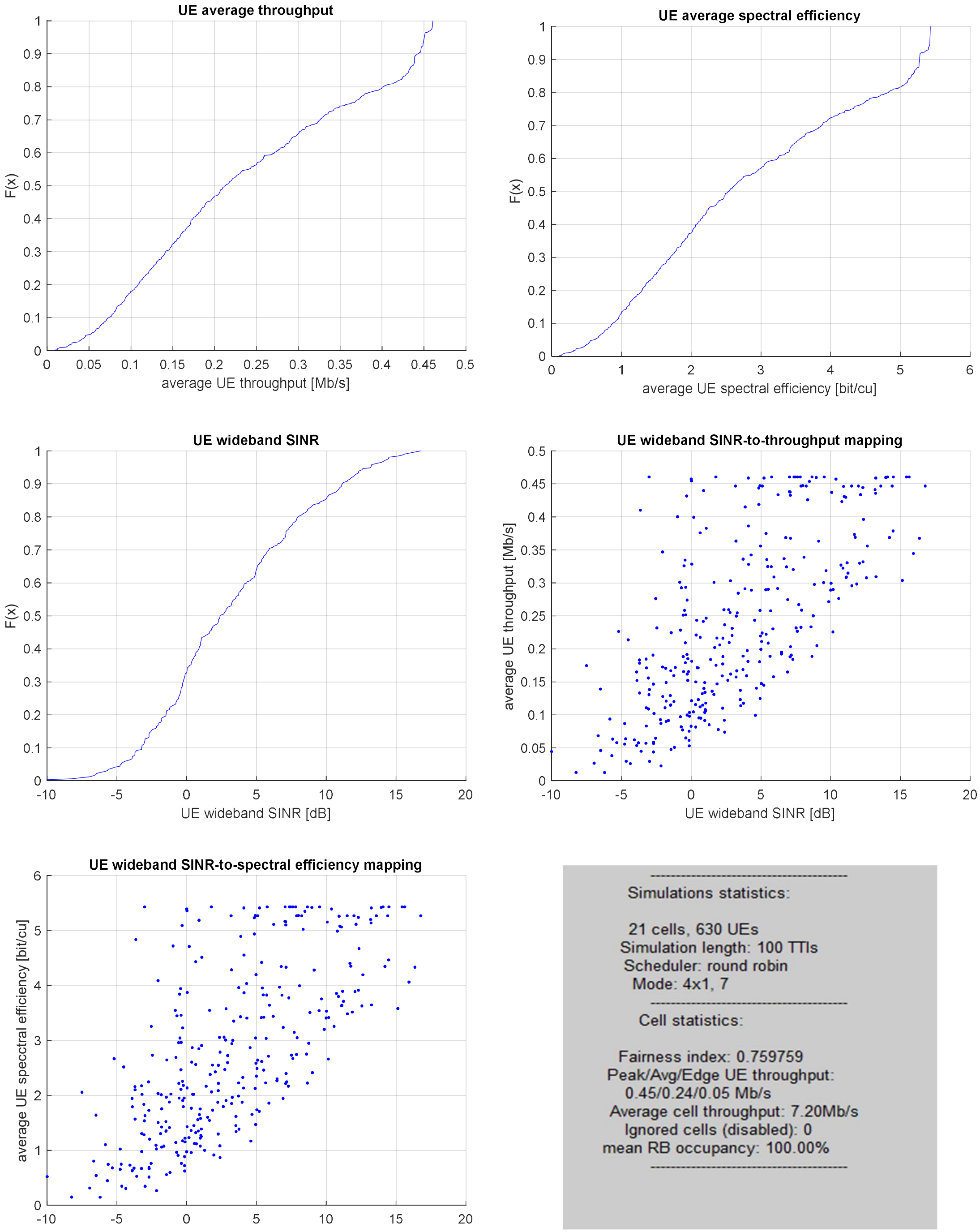
UE Still, Beamforming, Round Robin, 10 UE/cell



```
----------------------------------------
Simulations statistics:

 21 cells, 210 UEs
Simulation length: 100 TTIs
 Scheduler: round robin
   Mode: 4x1, 7
----------------------------------------
   Cell statistics:

 Fairness index: 0.81028
Peak/Avg/Edge UE throughput:
  1.36/0.82/0.19 Mb/s
 Average cell throughput: 8.16Mb/s
  Ignored cells (disabled): 0
mean RB occupancy: 100.00%
----------------------------------------
```

Figure 4.38: UE Still, Beamforming, Round Robin, 10 UE/cell

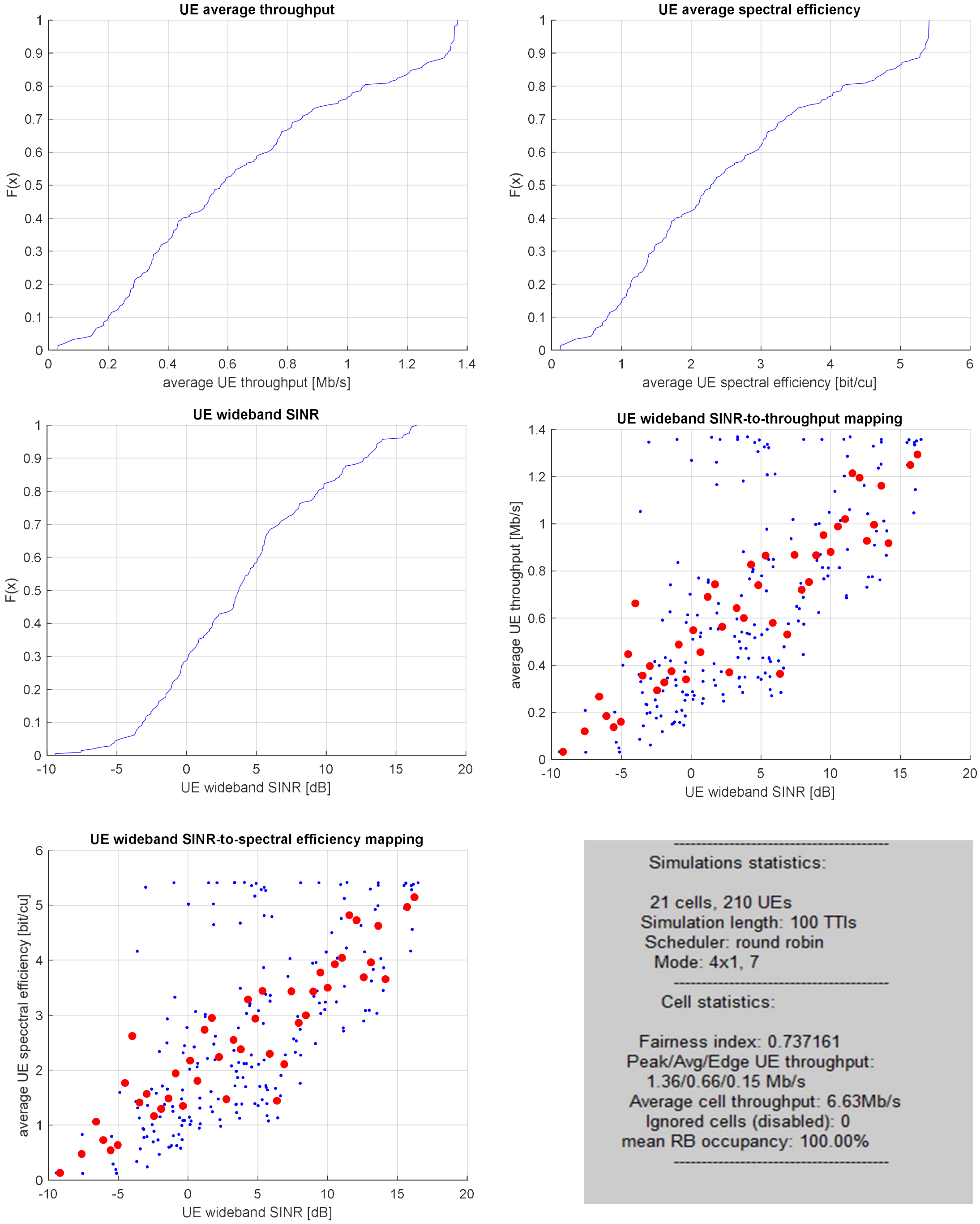
UE Still, Beamforming, Round Robin, 30 UE/cell



```
----------------------------------------
Simulations statistics:

 21 cells, 630 UEs
Simulation length: 100 TTIs
Scheduler: round robin
Mode: 4x1, 7
----------------------------------------
Cell statistics:

Fairness index: 0.759759
Peak/Avg/Edge UE throughput:
0.45/0.24/0.05 Mb/s
Average cell throughput: 7.20Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%
----------------------------------------
```

Figure 4.39: UE Still, Beamforming, Round Robin, 30 UE/cell

UE velocity= 40 km/h, Beamforming, Round Robin, 10 UE/cell



Simulations statistics:

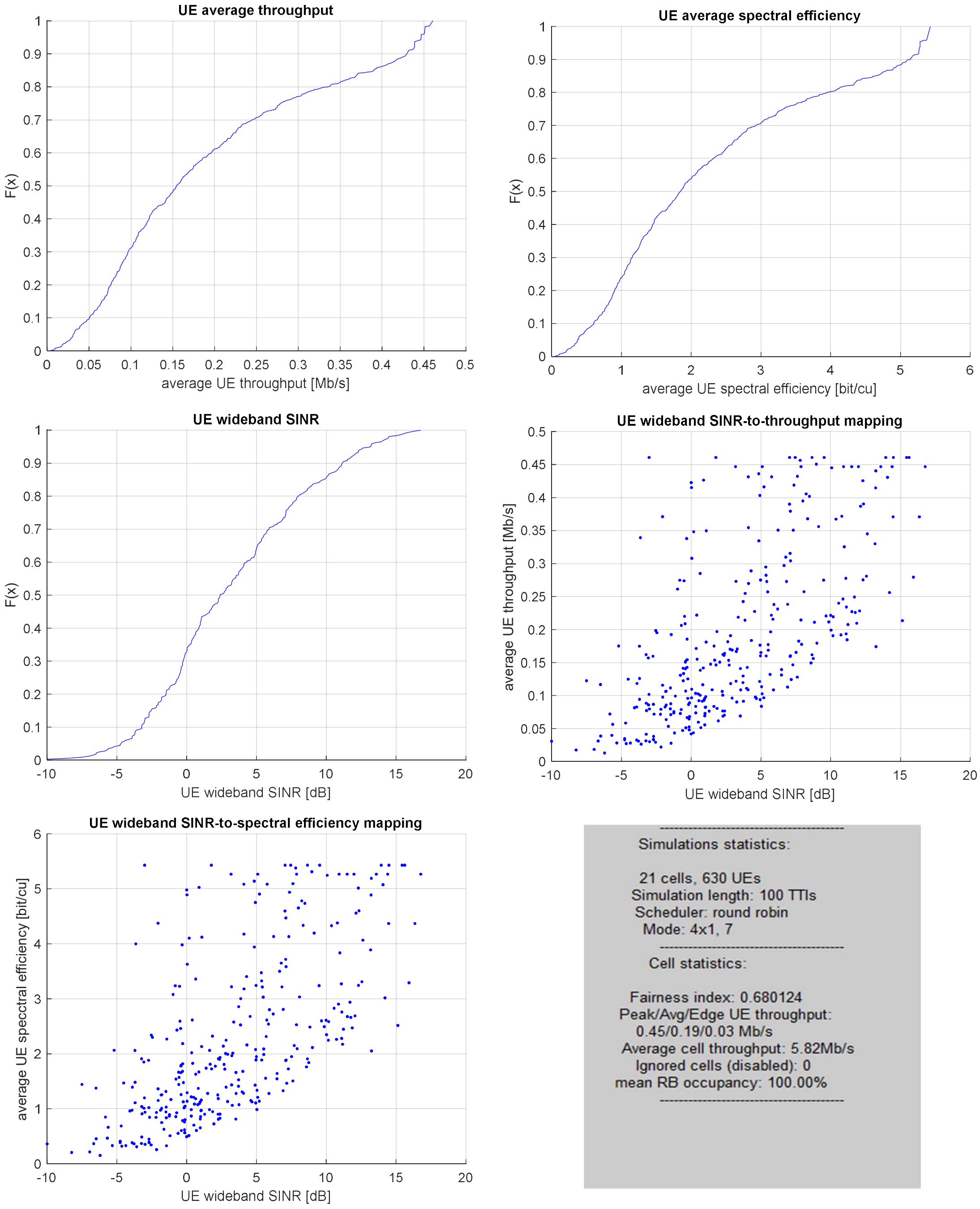
21 cells, 210 UEs
Simulation length: 100 TTIs
Scheduler: round robin
Mode: 4x1, 7

Cell statistics:

Fairness index: 0.737161
Peak/Avg/Edge UE throughput:
1.36/0.66/0.15 Mb/s
Average cell throughput: 6.63Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.40: UE velocity= 40 km/h, Beamforming, Round Robin, 10 UE/cell

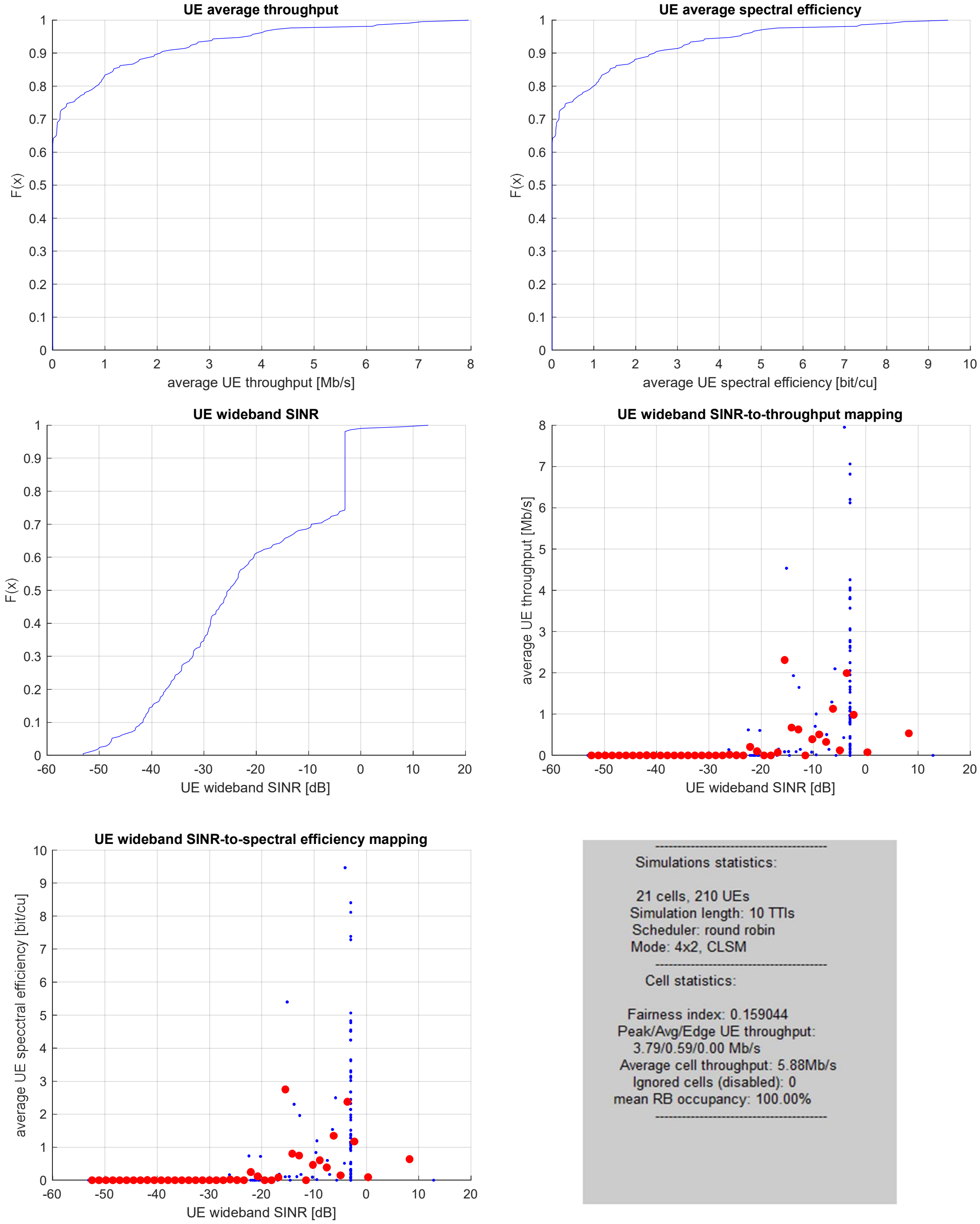
UE velocity= 40 km/h, Beamforming, Round Robin, 30 UE/cell



```
-----------------------------------------
Simulations statistics:

 21 cells, 630 UEs
Simulation length: 100 TTIs
 Scheduler: round robin
   Mode: 4x1, 7
-----------------------------------------
Cell statistics:

Fairness index: 0.680124
Peak/Avg/Edge UE throughput:
  0.45/0.19/0.03 Mb/s
Average cell throughput: 5.82Mb/s
  Ignored cells (disabled): 0
mean RB occupancy: 100.00%
-----------------------------------------
```

Figure 4.41: UE velocity= 40 km/h, Beamforming, Round Robin, 30 UE/cell

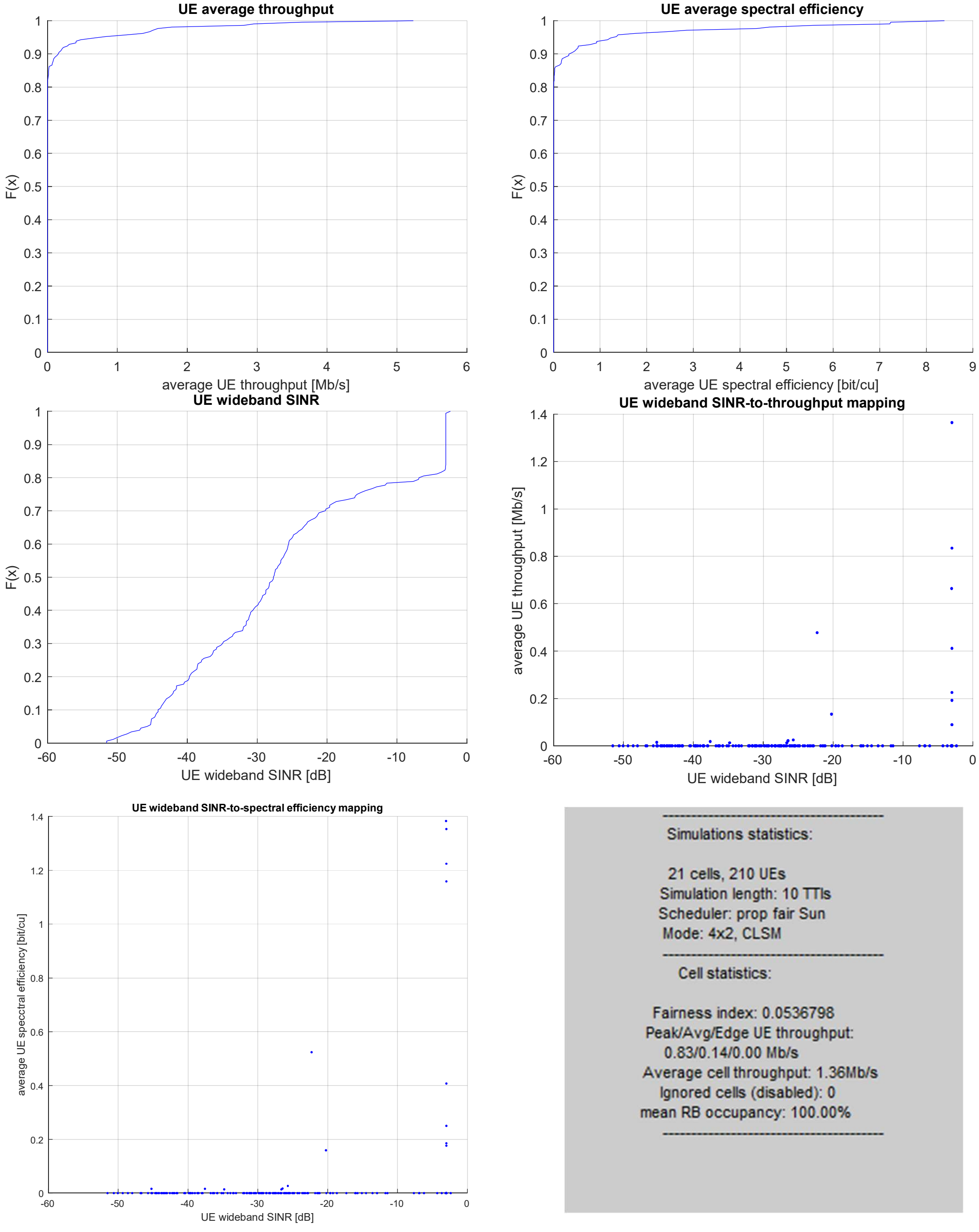
UE still, MMW Channels, Round Robin, 10 UE/cell



```
----------------------------------------
  Simulations statistics:

   21 cells, 210 UEs
  Simulation length: 10 TTIs
  Scheduler: round robin
  Mode: 4x2, CLSM
----------------------------------------
    Cell statistics:

  Fairness index: 0.159044
 Peak/Avg/Edge UE throughput:
  3.79/0.59/0.00 Mb/s
 Average cell throughput: 5.88Mb/s
  Ignored cells (disabled): 0
mean RB occupancy: 100.00%
----------------------------------------
```

Figure 4.42: UE still, MMW Channels, Round Robin, 10 UE/cell

UE still, MMW Channels, Prop Fair Sun, 10 UE/cell



Simulations statistics:

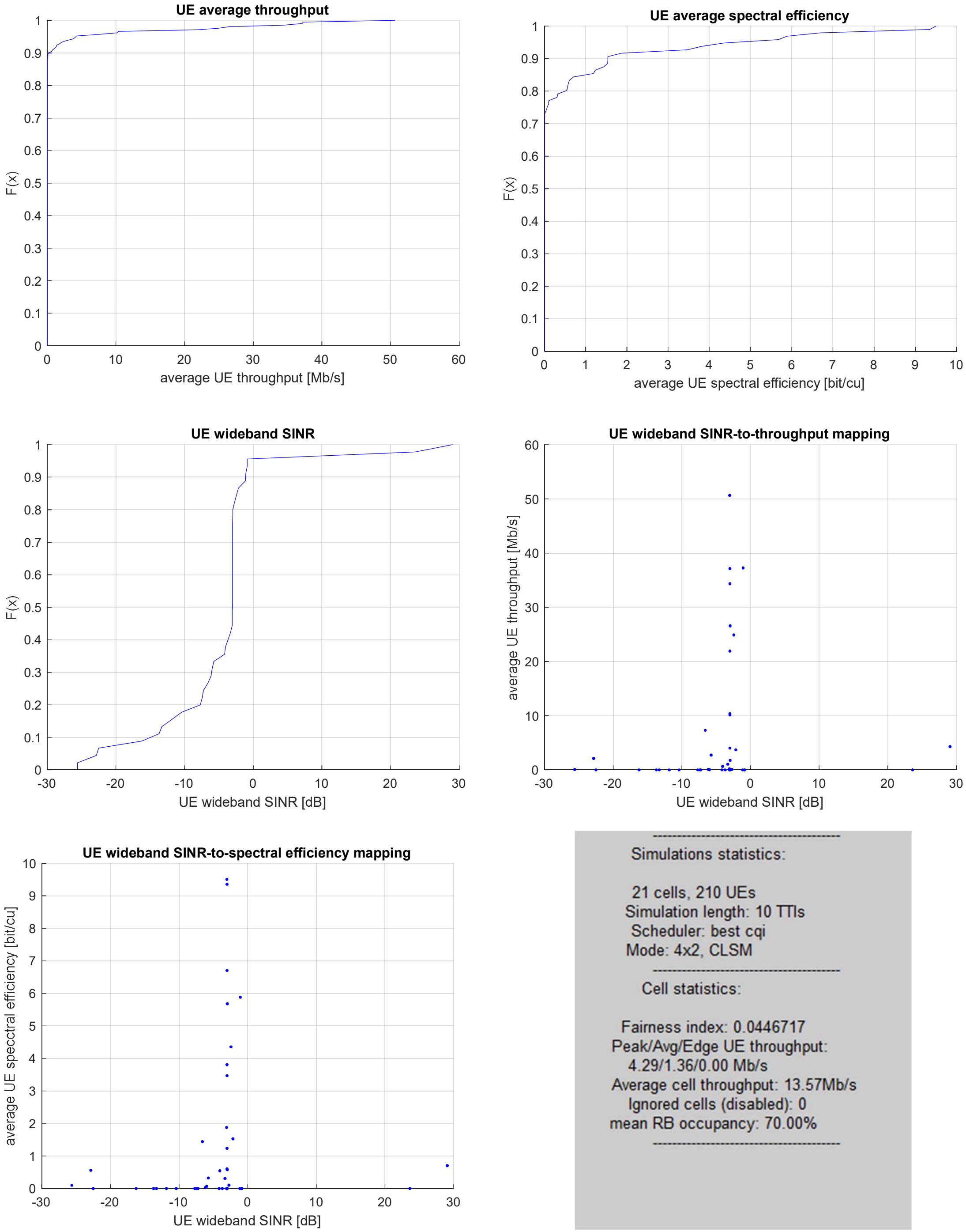
21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.0536798
Peak/Avg/Edge UE throughput:
0.83/0.14/0.00 Mb/s
Average cell throughput: 1.36Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.43: UE still, MMW Channels, Prop Fair Sun, 10 UE/cell

UE still, MMW Channels, Best CQI, 10 UE/cell



Simulations statistics:

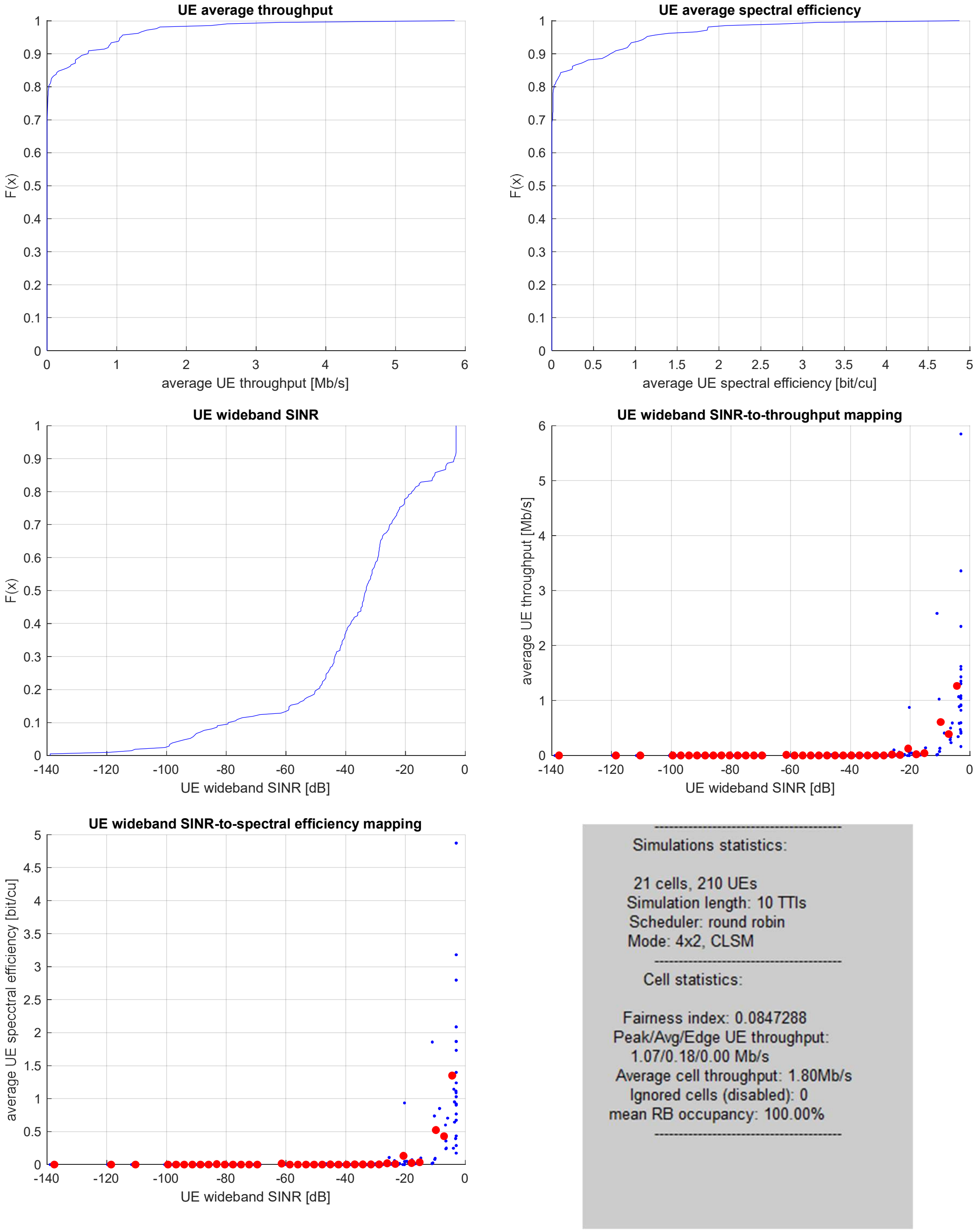
21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.0446717
Peak/Avg/Edge UE throughput:
4.29/1.36/0.00 Mb/s
Average cell throughput: 13.57Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 70.00%

Figure 4.44: UE still, MMW Channels, Best CQI, 10 UE/cell

UE velocity= 5 km/h, MMW Channels, Round Robin, 10 UE/cell



Simulations statistics:

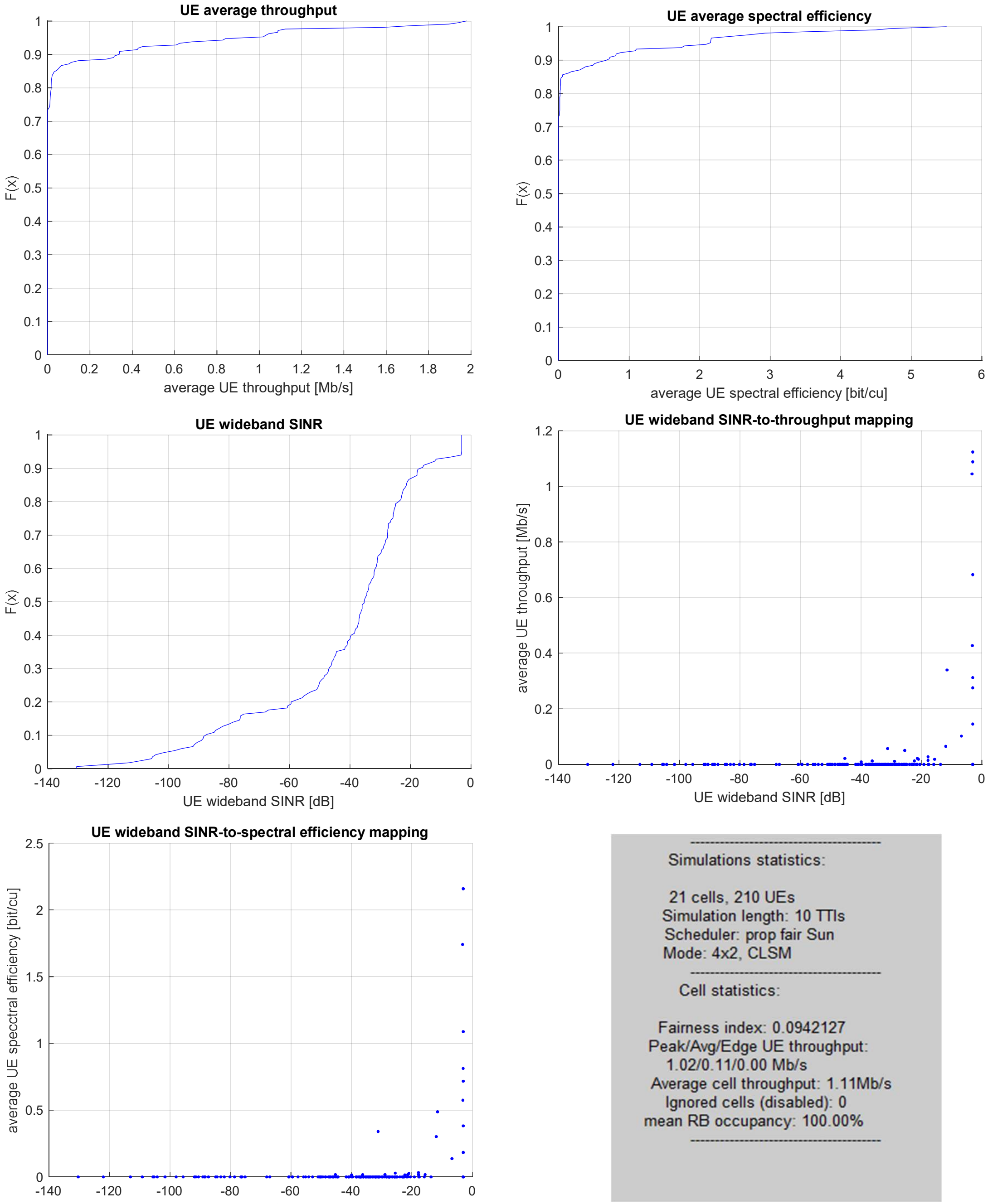
21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.0847288
Peak/Avg/Edge UE throughput:
1.07/0.18/0.00 Mb/s
Average cell throughput: 1.80Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.45: UE velocity= 5 km/h, MMW Channels, Round Robin, 10 UE/cell

UE velocity= 5 km/h, MMW Channels, Prop Fair Sun, 10 UE/cell



Simulations statistics:

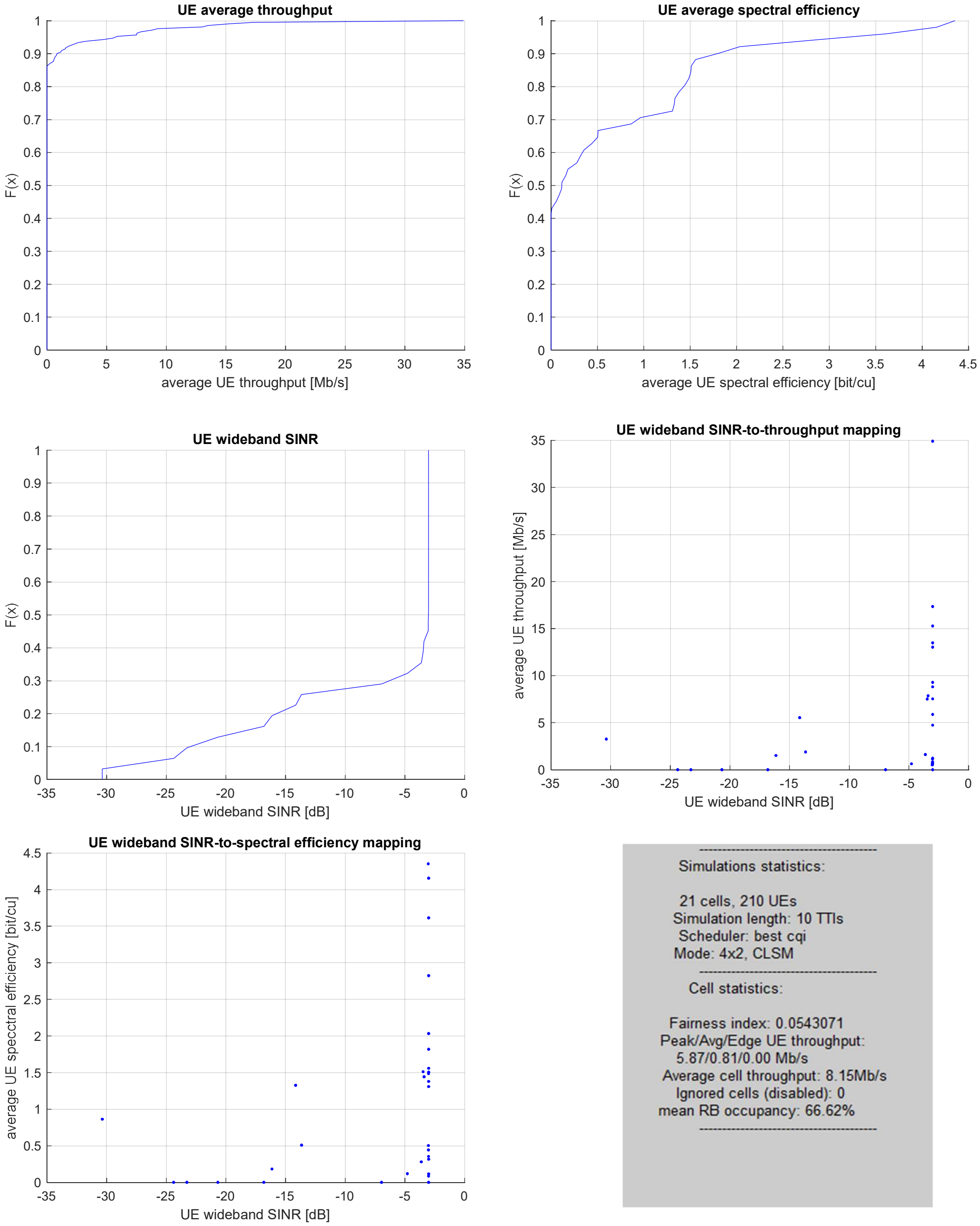
21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.0942127
Peak/Avg/Edge UE throughput:
1.02/0.11/0.00 Mb/s
Average cell throughput: 1.11Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.46: UE velocity= 5 km/h, MMW Channels, Prop Fair Sun, 10 UE/cell

UE velocity= 5 km/h, MMW Channels, Best CQI, 10 UE/cell



Simulations statistics:

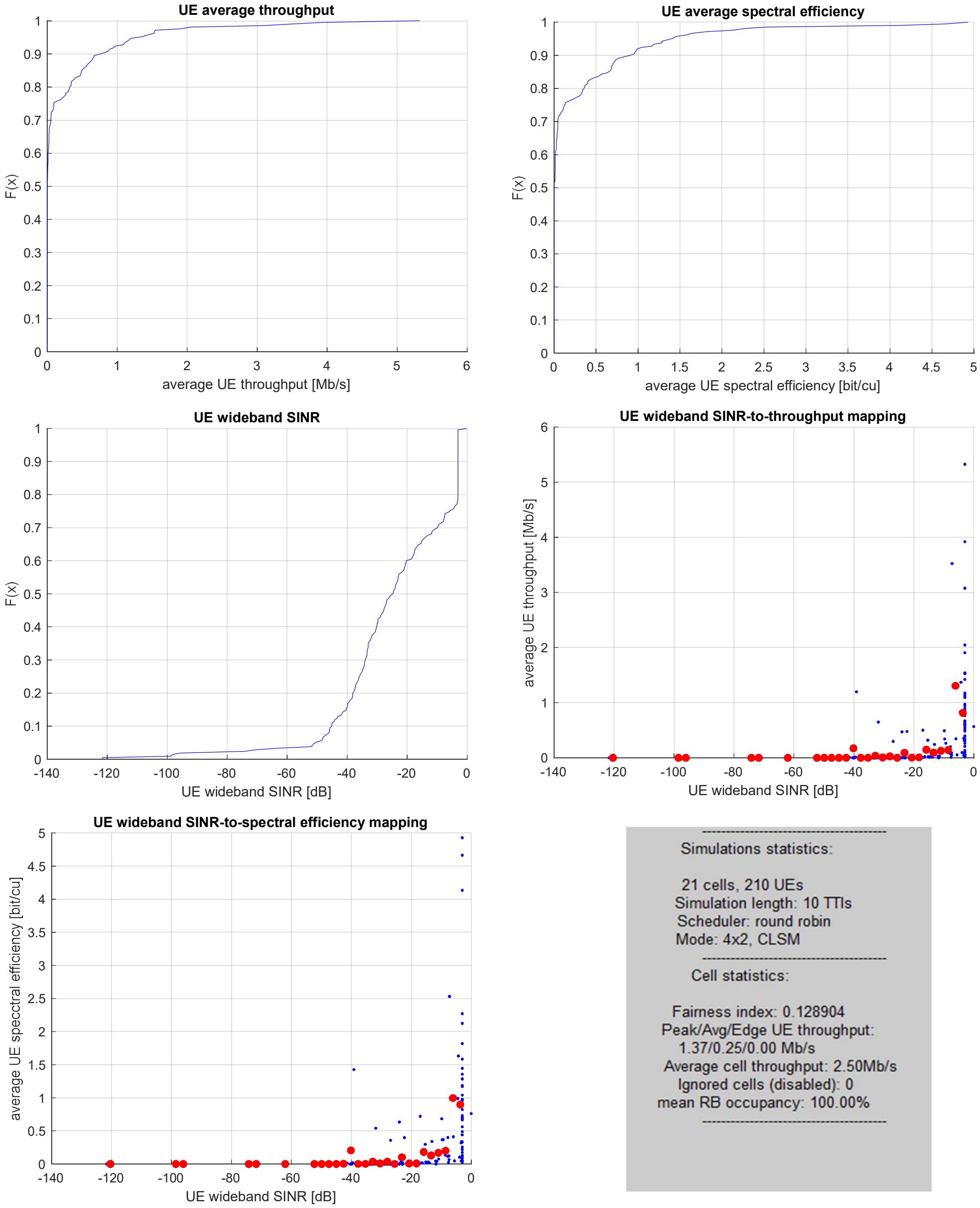
21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.0543071
Peak/Avg/Edge UE throughput:
5.87/0.81/0.00 Mb/s
Average cell throughput: 8.15Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 66.62%

Figure 4.47: UE velocity= 5 km/h, MMW Channels, Best CQI, 10 UE/cell

UE velocity= 40 km/h, MMW Channels, Round Robin, 10 UE/cell



Simulations statistics:

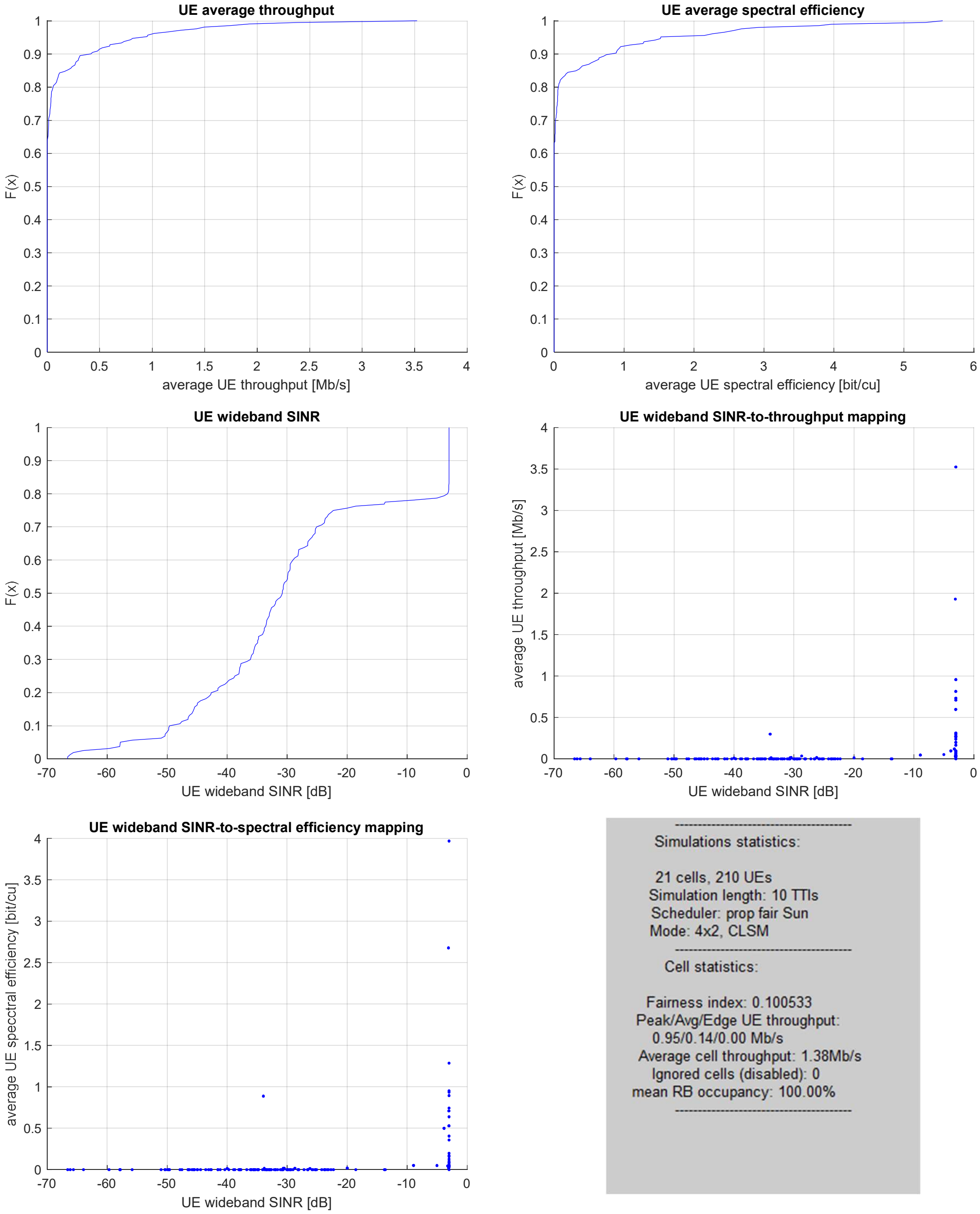
21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x2, CLSM

Cell statistics:

Fairness index: 0.128904
Peak/Avg/Edge UE throughput:
1.37/0.25/0.00 Mb/s
Average cell throughput: 2.50Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.48: UE velocity= 40 km/h, MMW Channels, Round Robin, 10 UE/cell

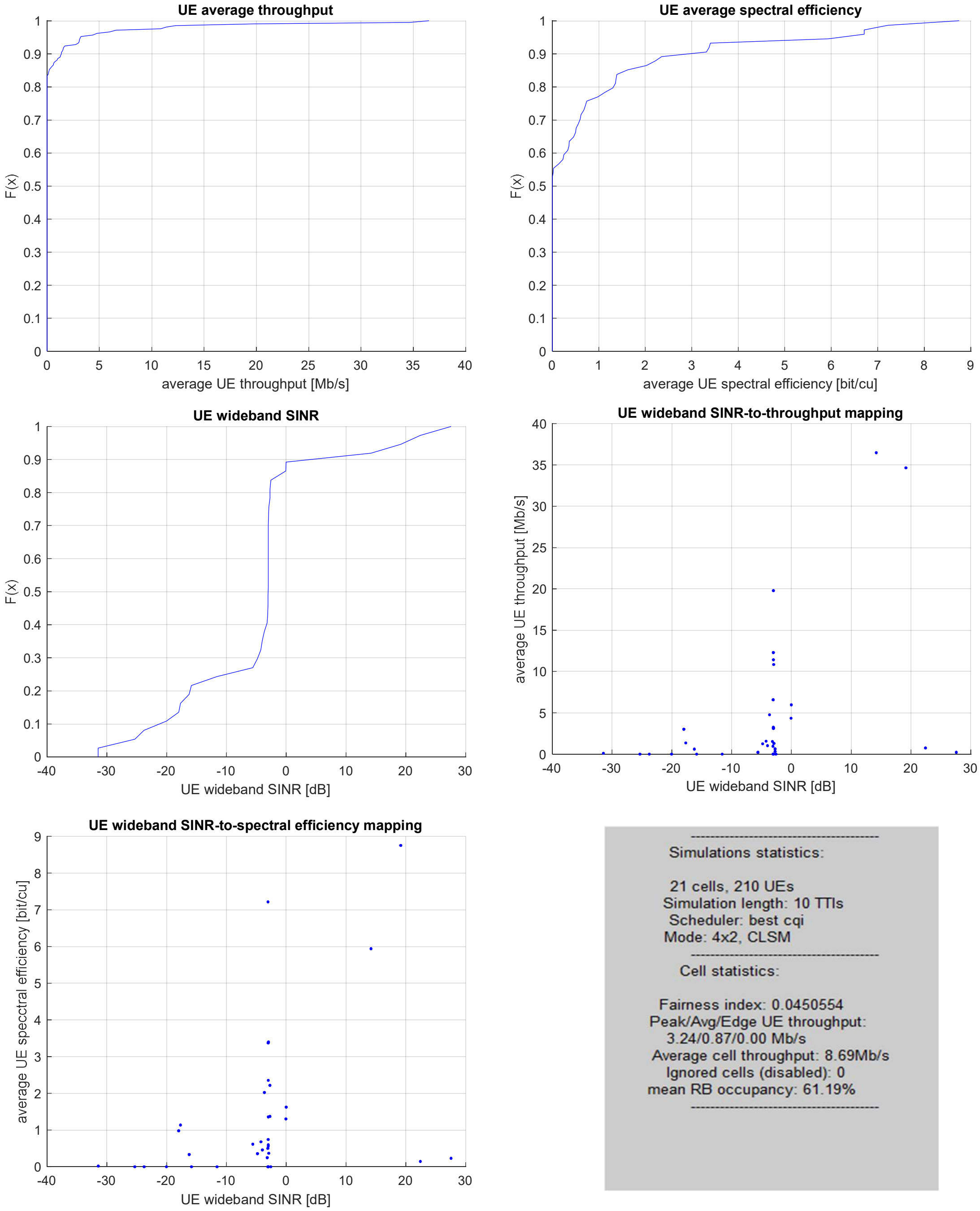
UE velocity= 40 km/h, MMW Channels, Prop Fair Sun, 10 UE/cell



```
-------------------------------------
Simulations statistics:

21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x2, CLSM
-------------------------------------
Cell statistics:

Fairness index: 0.100533
Peak/Avg/Edge UE throughput:
0.95/0.14/0.00 Mb/s
Average cell throughput: 1.38Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%
-------------------------------------
```

Figure 4.49: UE velocity= 40 km/h, MMW Channels, Prop Fair Sun, 10 UE/cell

UE velocity= 40 km/h, MMW Channels, Best CQI, 10 UE/cell



```
----------------------------------------
Simulations statistics:

21 cells, 210 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 4x2, CLSM
----------------------------------------
Cell statistics:

Fairness index: 0.0450554
Peak/Avg/Edge UE throughput:
3.24/0.87/0.00 Mb/s
Average cell throughput: 8.69Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 61.19%
----------------------------------------
```

Figure 4.50: UE velocity= 40 km/h, MMW Channels, Best CQI, 10 UE/cell

The main significance of RRH and femto-cells are described in the chapter 3, section 3.1, and what makes it so important as a network parameter. So here, we included both cases in our simulation. Since in case of RRH, 2 eNB rings are used, the UEs were considered static, because it requires a high-powered processor to run the simulation.

Remote Radio Head

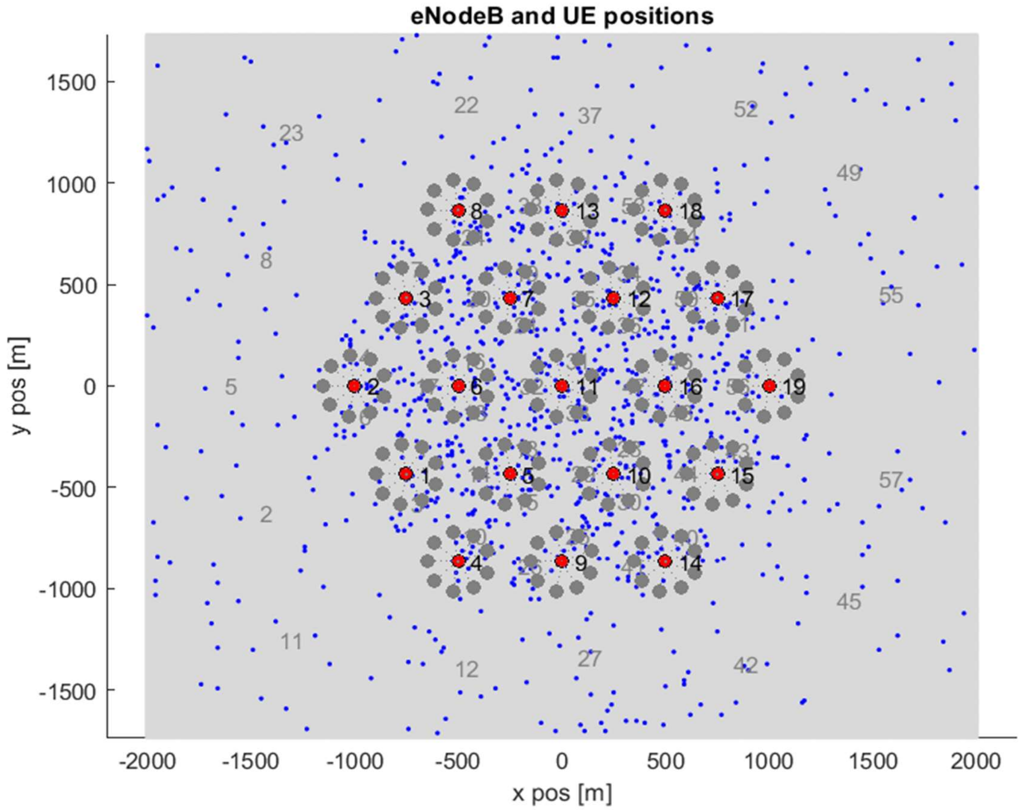
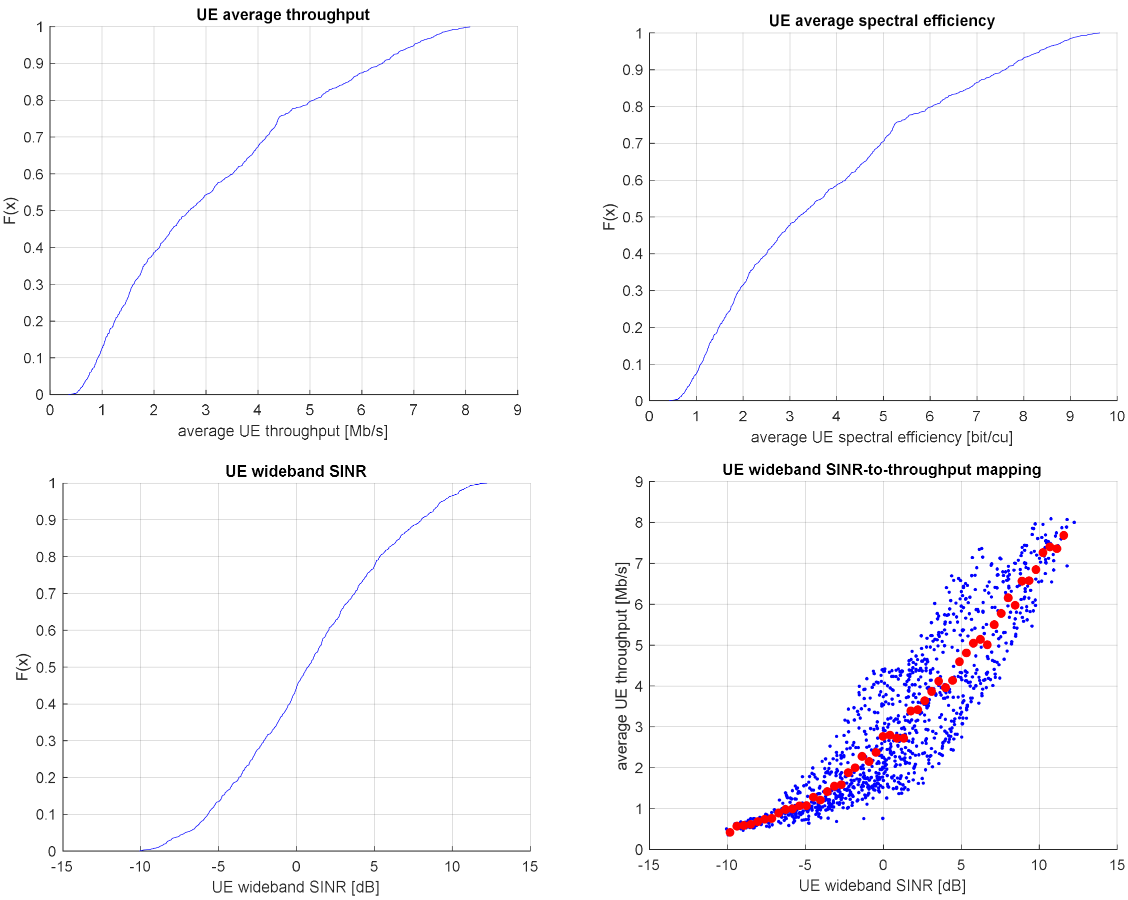
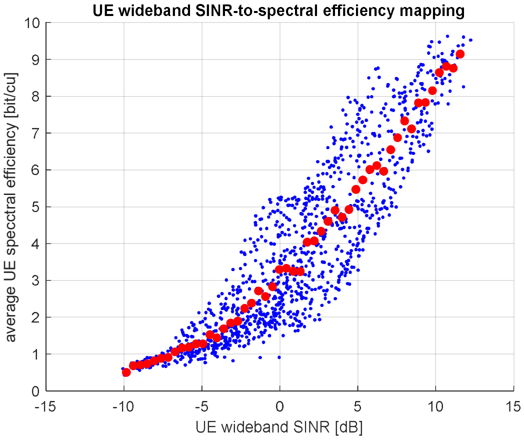


Figure 4.51: UE and eNodeB distribution

Remote Radio Head, Round Robin





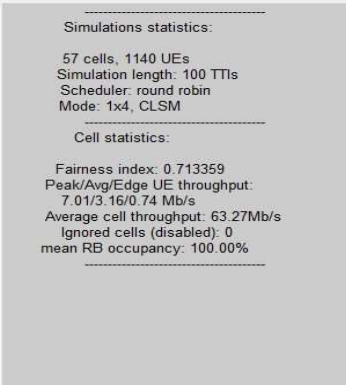
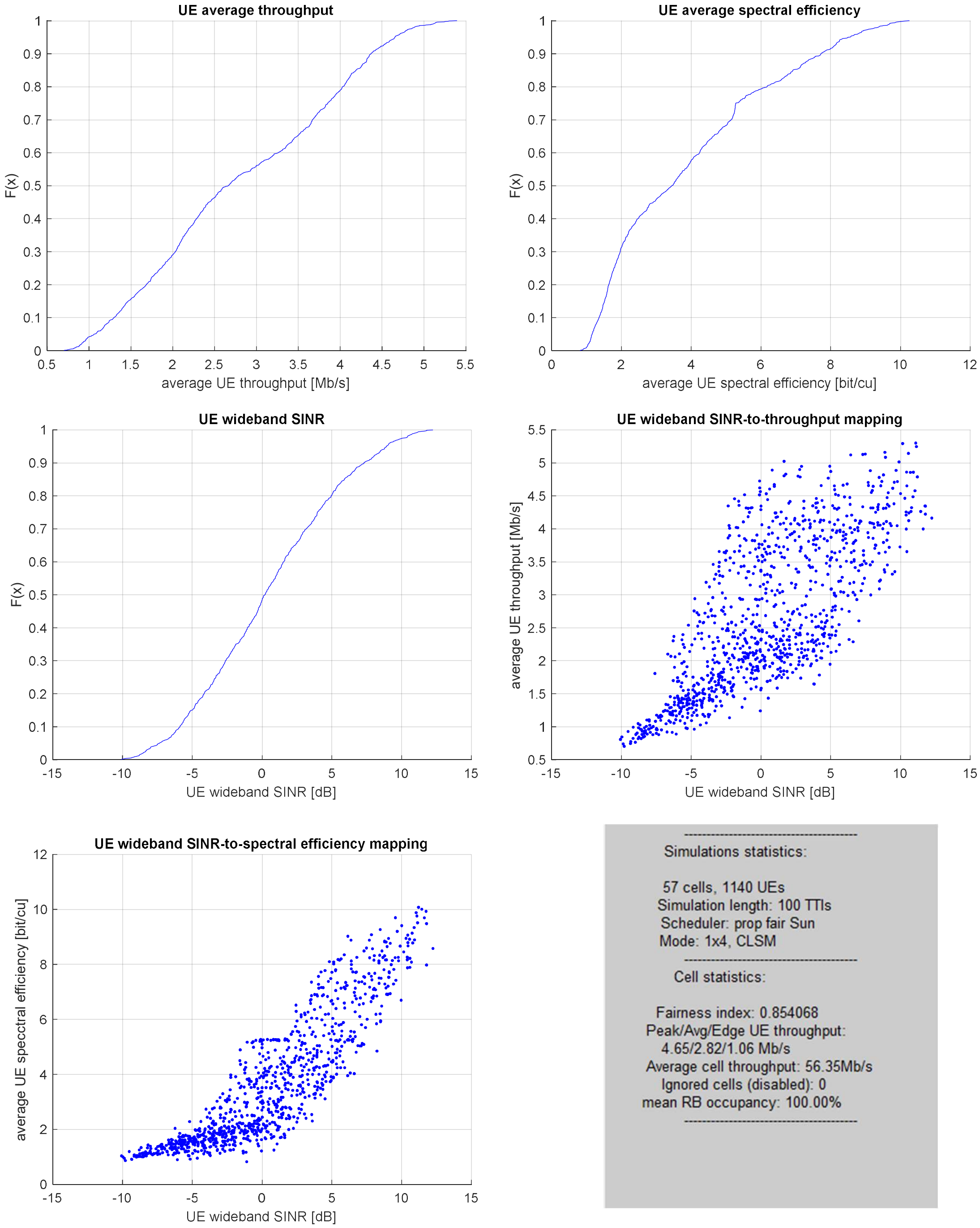

```
---------------------------------------
Simulations statistics:

57 cells, 1140 UEs
Simulation length: 100 TTIs
Scheduler: round robin
Mode: 1x4, CLSM
---------------------------------------
Cell statistics:

Fairness index: 0.713359
Peak/Avg/Edge UE throughput:
7.01/3.16/0.74 Mb/s
Average cell throughput: 63.27Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%
---------------------------------------
```

Figure 4.52: Remote Radio Head, Round Robin

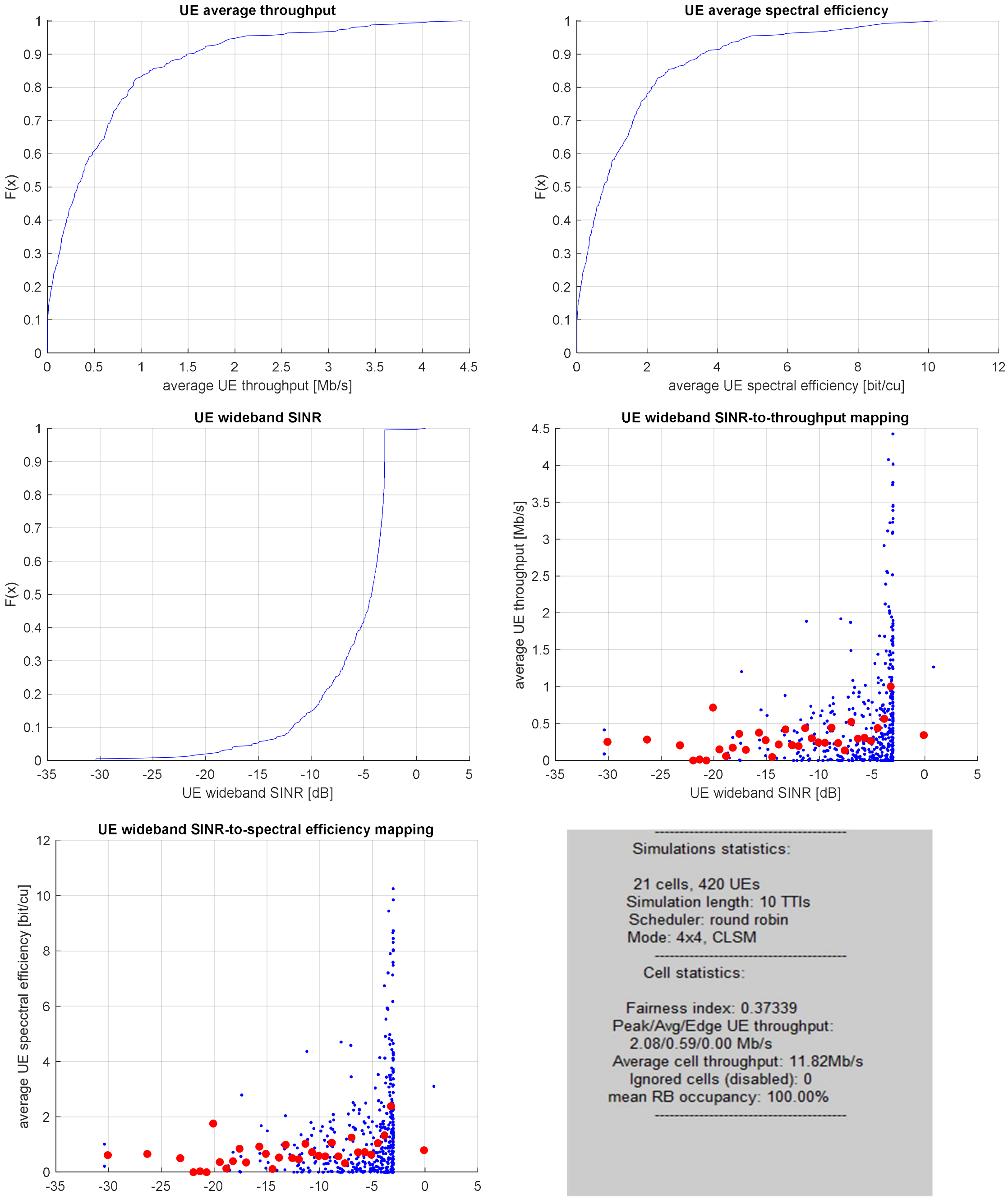
Remote Radio Head, Prop Fair Sun



```
----------------------------------------
Simulations statistics:

57 cells, 1140 UEs
Simulation length: 100 TTIs
Scheduler: prop fair Sun
Mode: 1x4, CLSM
----------------------------------------
Cell statistics:

Fairness index: 0.854068
Peak/Avg/Edge UE throughput:
4.65/2.82/1.06 Mb/s
Average cell throughput: 56.35Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%
----------------------------------------
```

Figure 4.53: Remote Radio Head, Prop Fair Sun

nTx=4 and nRx= 4, Round Robin



Simulations statistics:

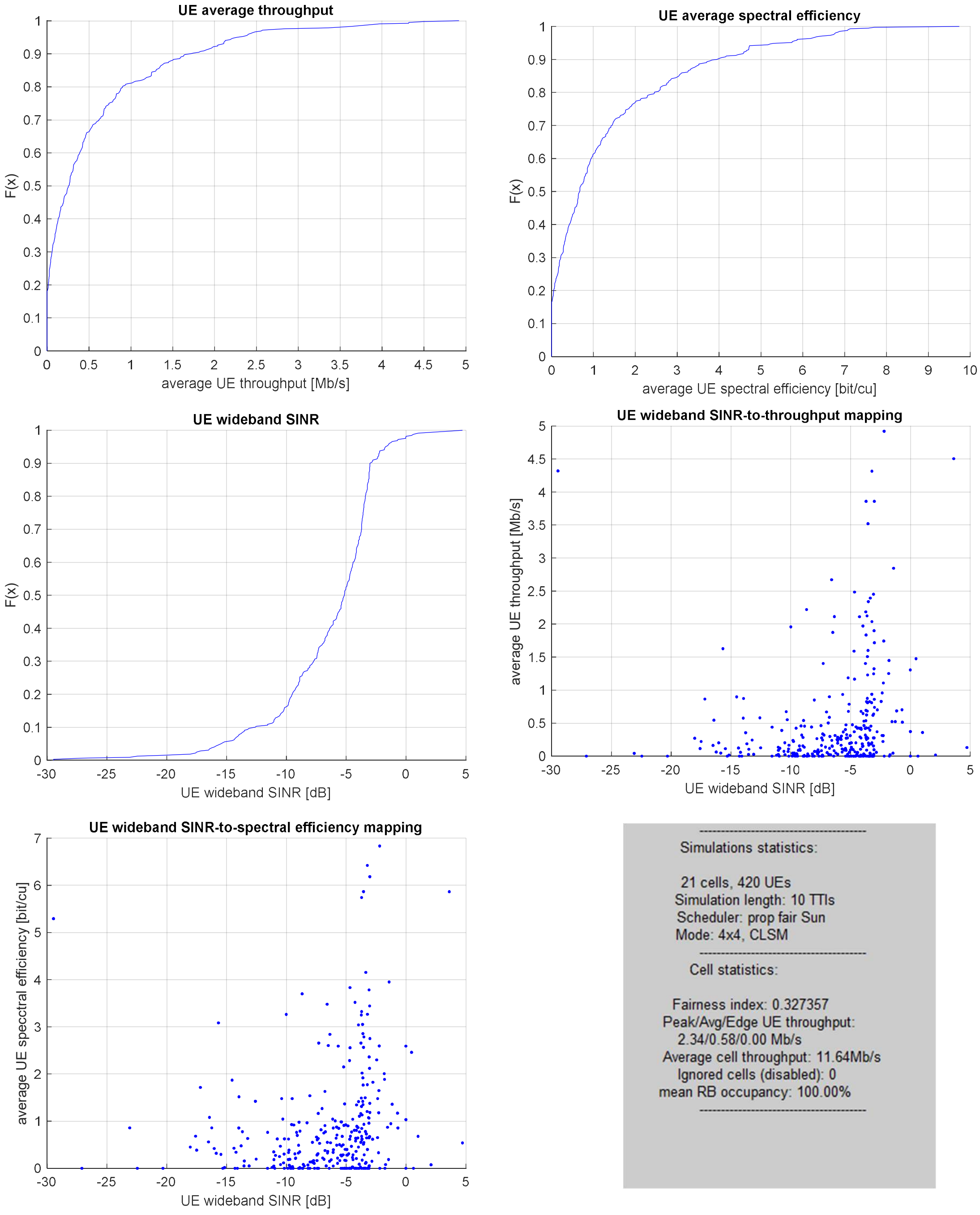
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 4x4, CLSM

Cell statistics:

Fairness index: 0.37339
Peak/Avg/Edge UE throughput:
2.08/0.59/0.00 Mb/s
Average cell throughput: 11.82Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.54: nTx=4 and nRx= 4, Round Robin

nTx= 4 and nRx= 5, Prop Fair Sun



Simulations statistics:

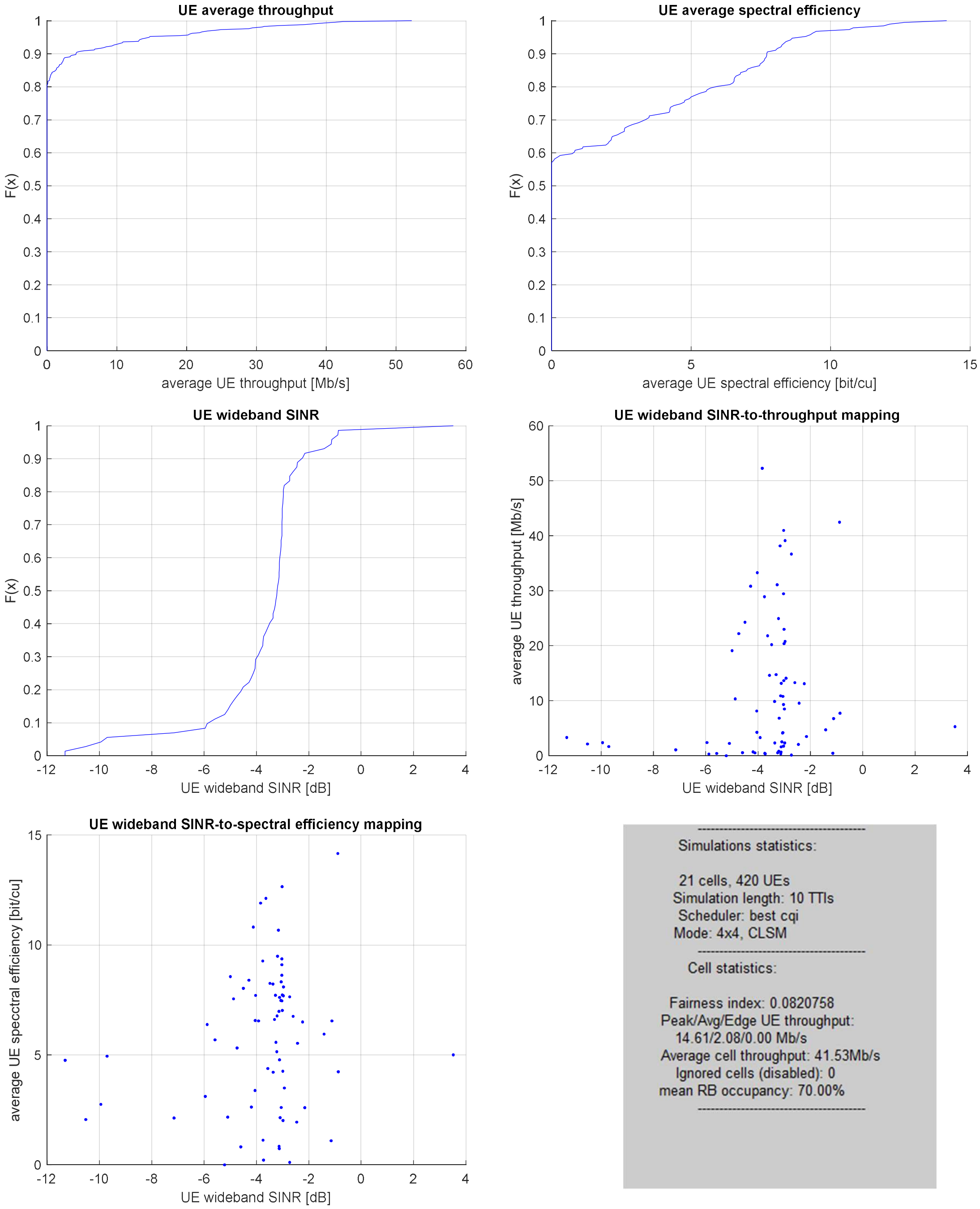
21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 4x4, CLSM

Cell statistics:

Fairness index: 0.327357
Peak/Avg/Edge UE throughput:
2.34/0.58/0.00 Mb/s
Average cell throughput: 11.64Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.55: nTx= 4 and nRx= 5, Prop Fair Sun

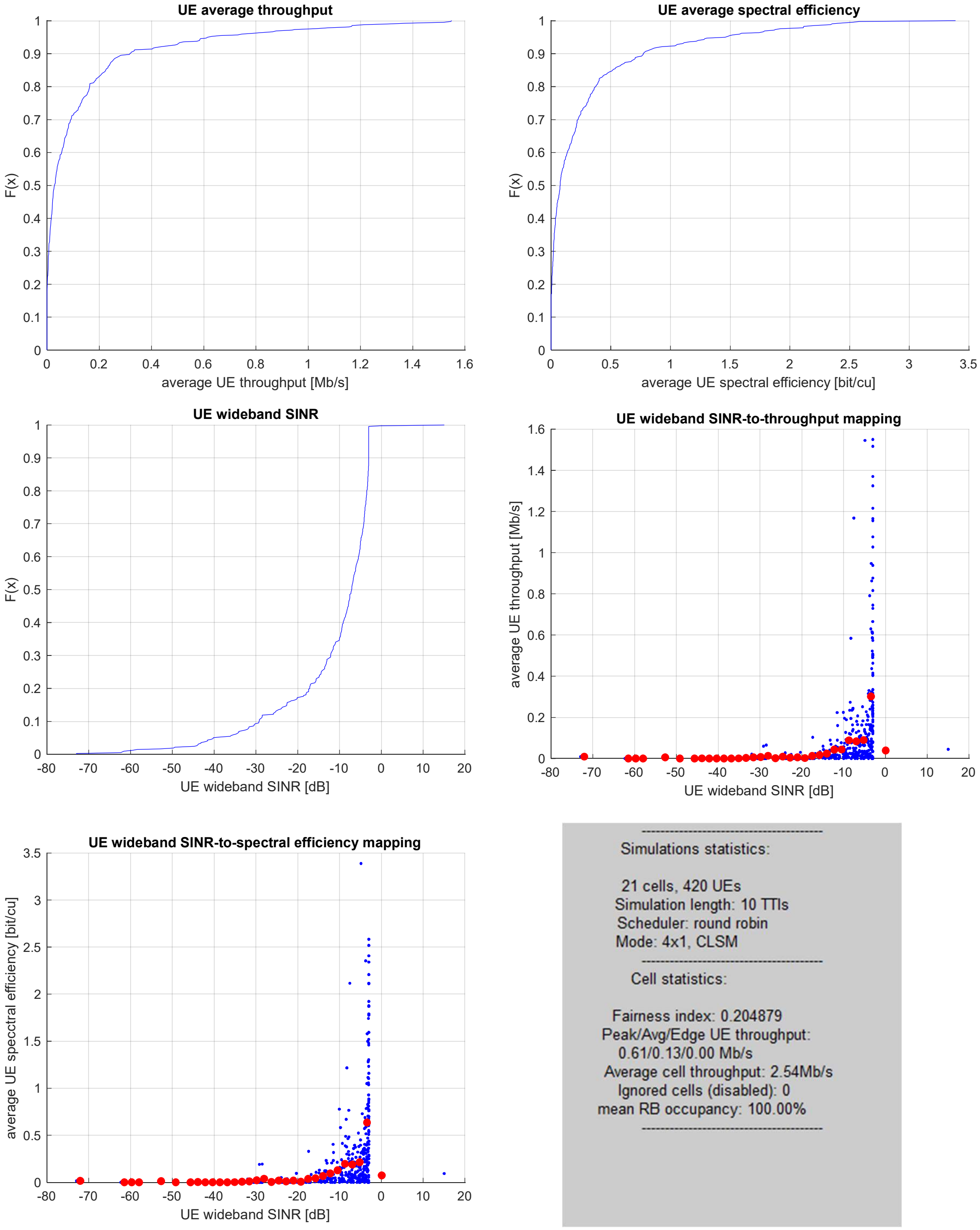
nTx= 4 and nRx= 4, Best CQI



```
------------------------------------------
Simulations statistics:

 21 cells, 420 UEs
Simulation length: 10 TTIs
 Scheduler: best cqi
Mode: 4x4, CLSM
------------------------------------------
Cell statistics:

Fairness index: 0.0820758
Peak/Avg/Edge UE throughput:
 14.61/2.08/0.00 Mb/s
Average cell throughput: 41.53Mb/s
 Ignored cells (disabled): 0
mean RB occupancy: 70.00%
------------------------------------------
```

Figure 4.56: nTx= 4 and nRx= 4, Best CQI

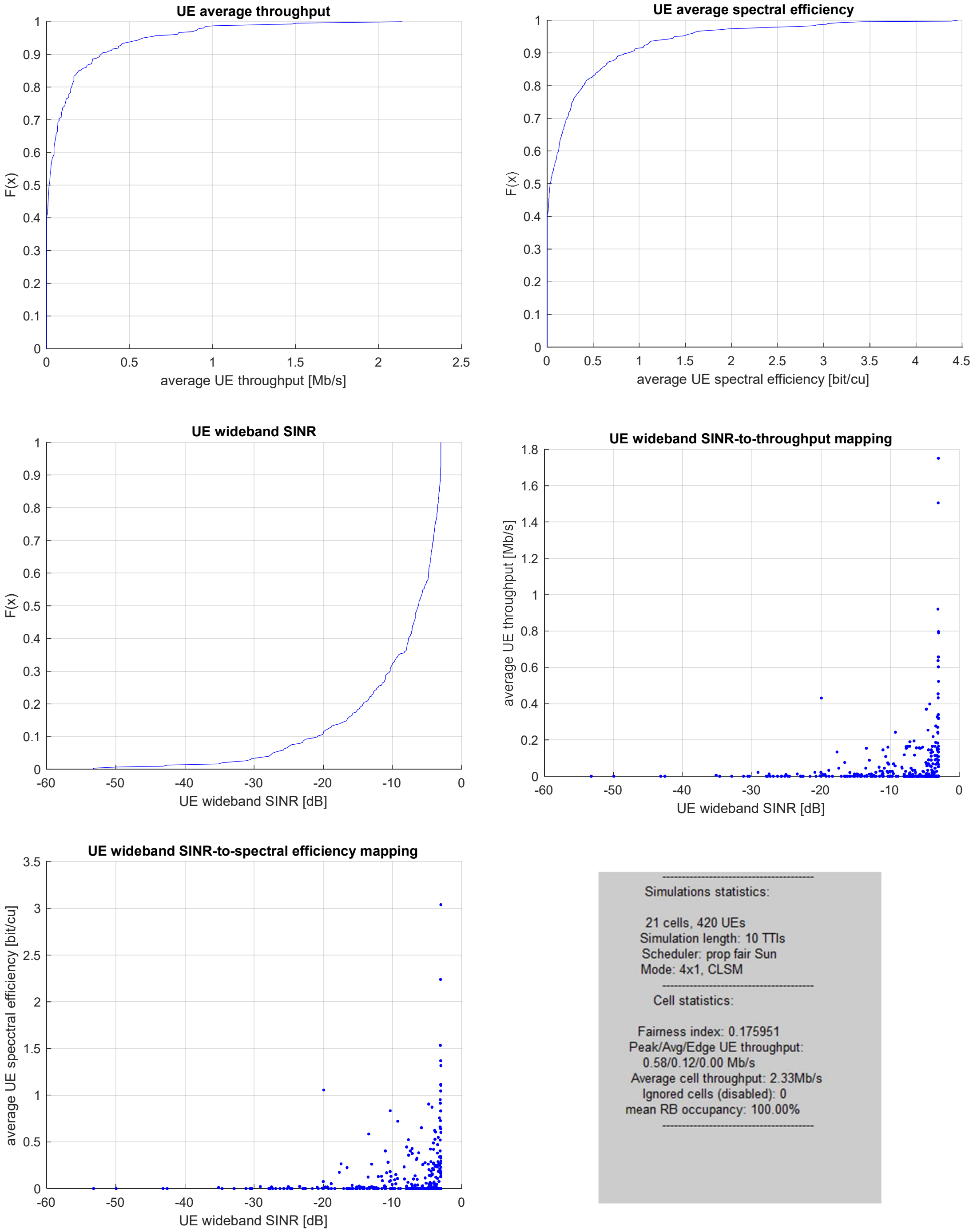
UE velocity= 5 km/h, nTx= 4 and nRx= 4, Round Robin



```
----------------------------------------
Simulations statistics:

 21 cells, 420 UEs
Simulation length: 10 TTIs
 Scheduler: round robin
Mode: 4x1, CLSM
----------------------------------------
   Cell statistics:

 Fairness index: 0.204879
Peak/Avg/Edge UE throughput:
 0.61/0.13/0.00 Mb/s
 Average cell throughput: 2.54Mb/s
 Ignored cells (disabled): 0
mean RB occupancy: 100.00%
----------------------------------------
```

Figure 4.57: UE velocity= 5 km/h, nTx= 4 and nRx= 4, Round Robin

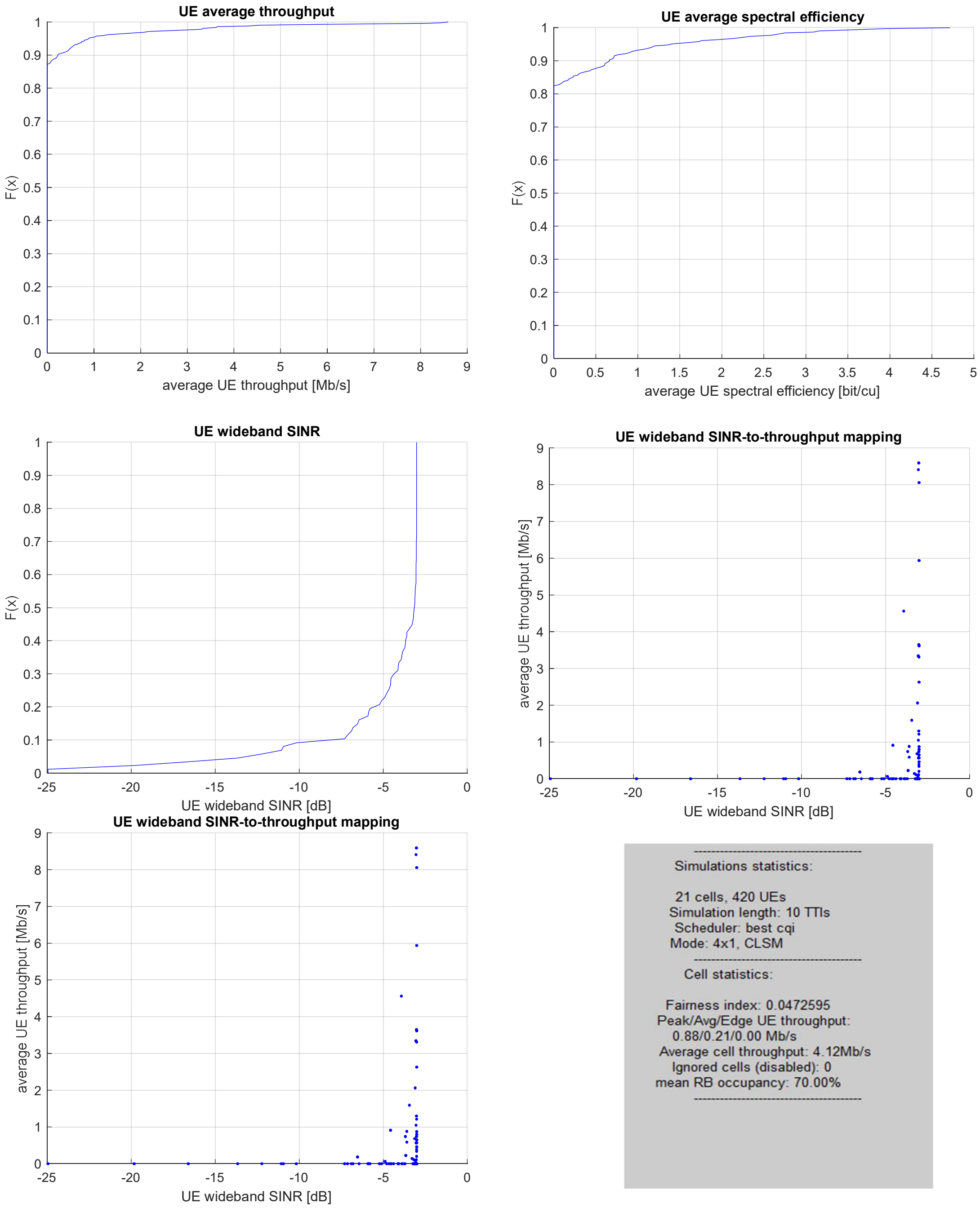
UE velocity= 5 km/h, nTx= 4 and nRx= 4, Prop Fair Sun



```
-------------------------------------
 Simulations statistics:

  21 cells, 420 UEs
 Simulation length: 10 TTIs
 Scheduler: prop fair Sun
 Mode: 4x1, CLSM
-------------------------------------
   Cell statistics:

 Fairness index: 0.175951
Peak/Avg/Edge UE throughput:
   0.58/0.12/0.00 Mb/s
 Average cell throughput: 2.33Mb/s
   Ignored cells (disabled): 0
mean RB occupancy: 100.00%
-------------------------------------
```

Figure 4.58: UE velocity= 5 km/h, nTx= 4 and nRx= 4, Prop Fair Sun

UE velocity= 5 km/h, nTx= 4 and nRx= 4, Best CQI



```
-----------------------------------------
Simulations statistics:

21 cells, 420 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 4x1, CLSM
-----------------------------------------
Cell statistics:

Fairness index: 0.0472595
Peak/Avg/Edge UE throughput:
0.88/0.21/0.00 Mb/s
Average cell throughput: 4.12Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 70.00%
-----------------------------------------
```

Figure 4.59: UE velocity= 5 km/h, nTx= 4 and nRx= 4, Best CQI

UE velocity= 5 km/h, Femto-Cell, Round Robin

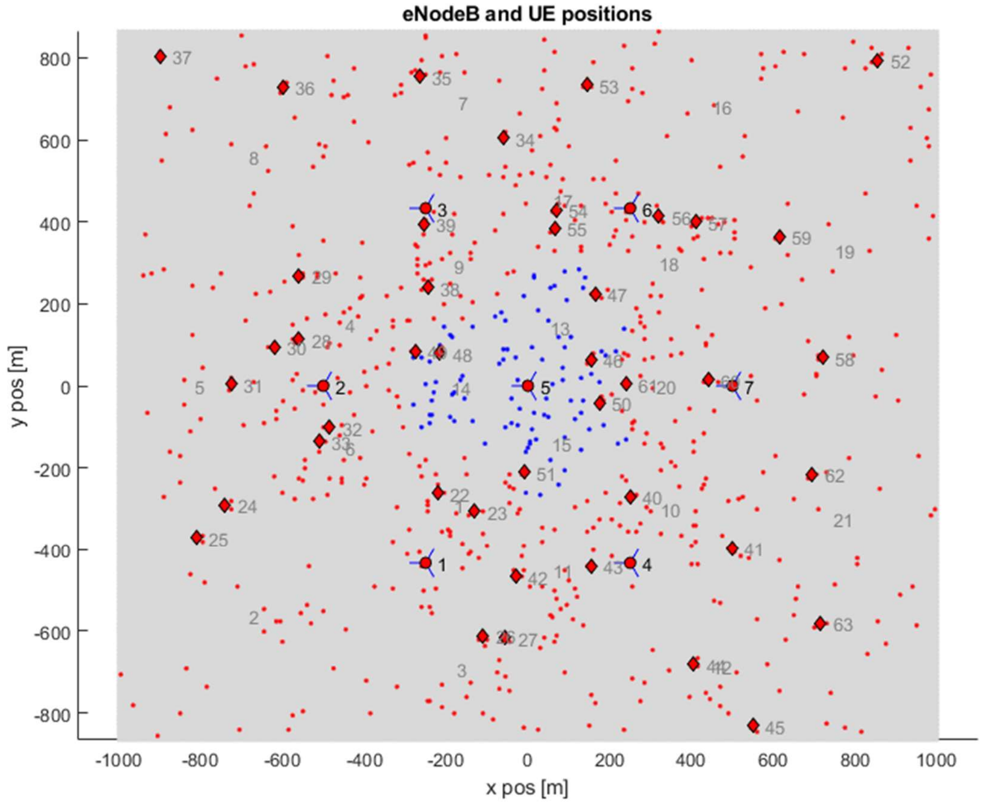
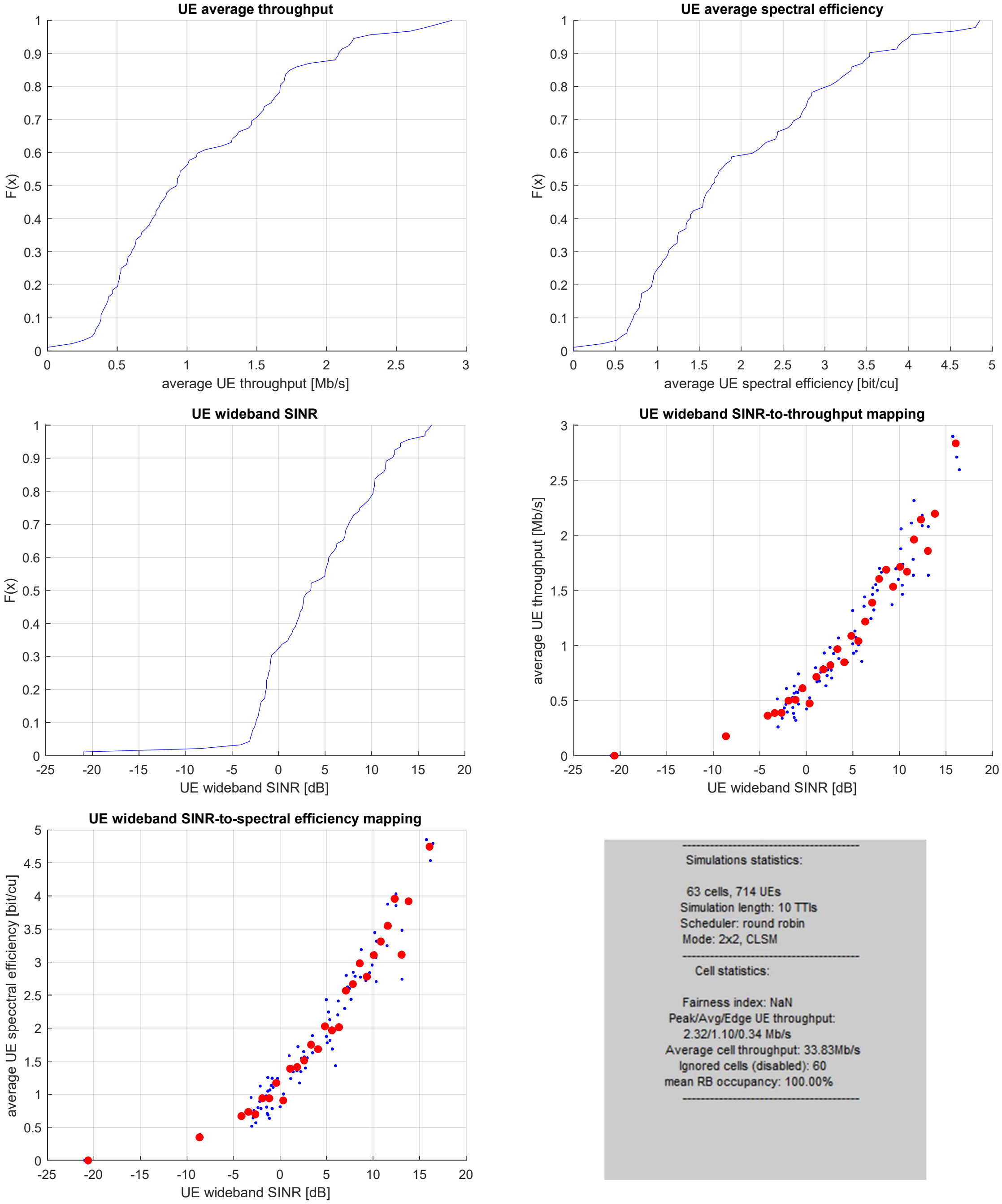


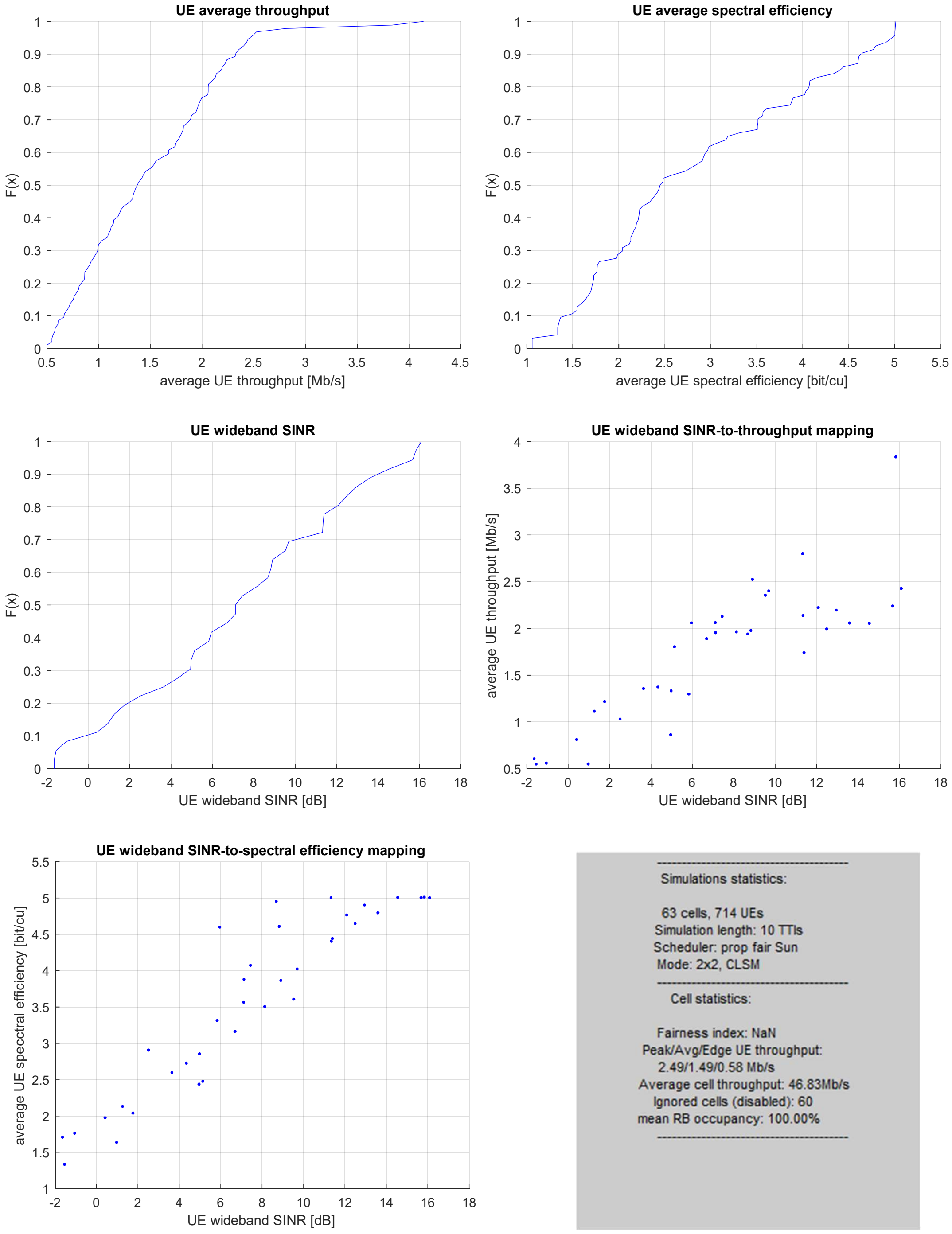
Figure 4.60: UE and eNodeB distribution



```
--------------------------------------------
 Simulations statistics:

 63 cells, 714 UEs
Simulation length: 10 TTIs
Scheduler: round robin
 Mode: 2x2, CLSM
--------------------------------------------
   Cell statistics:

 Fairness index: NaN
Peak/Avg/Edge UE throughput:
 2.32/1.10/0.34 Mb/s
Average cell throughput: 33.83Mb/s
 Ignored cells (disabled): 60
mean RB occupancy: 100.00%
--------------------------------------------
```

Figure 4.61: UE velocity= 5 km/h, Femto-Cell, Round Robin

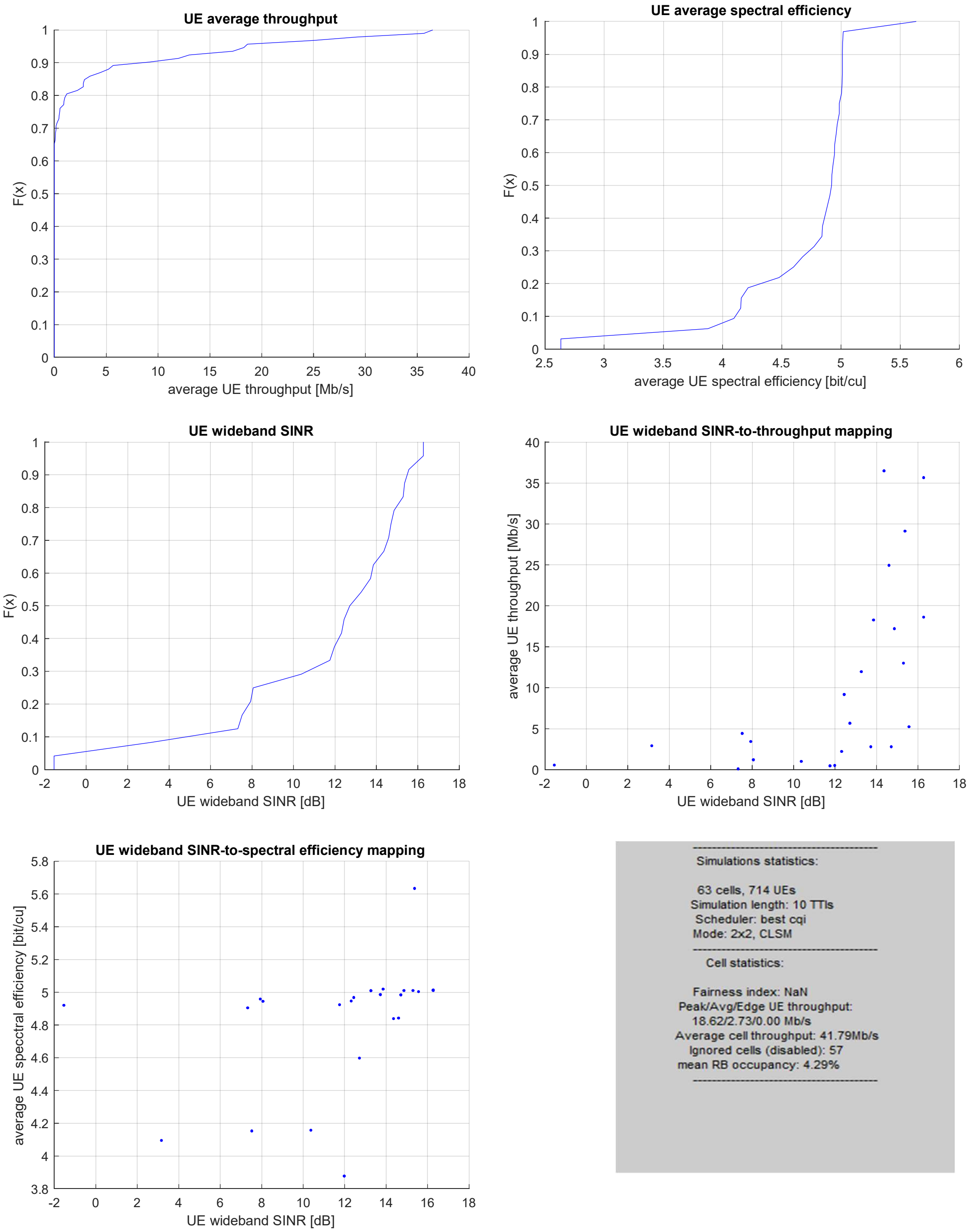
UE velocity= 5 km/h, Femto-Cell, Prop Fair Sun



```
 -----------------------------------------
  Simulations statistics:

  63 cells, 714 UEs
 Simulation length: 10 TTIs
 Scheduler: prop fair Sun
 Mode: 2x2, CLSM
 -----------------------------------------
    Cell statistics:

 Fairness index: NaN
Peak/Avg/Edge UE throughput:
  2.49/1.49/0.58 Mb/s
Average cell throughput: 46.83Mb/s
 Ignored cells (disabled): 60
mean RB occupancy: 100.00%
 -----------------------------------------
```

Figure 4.62: UE velocity= 5 km/h, Femto-Cell, Prop Fair Sun

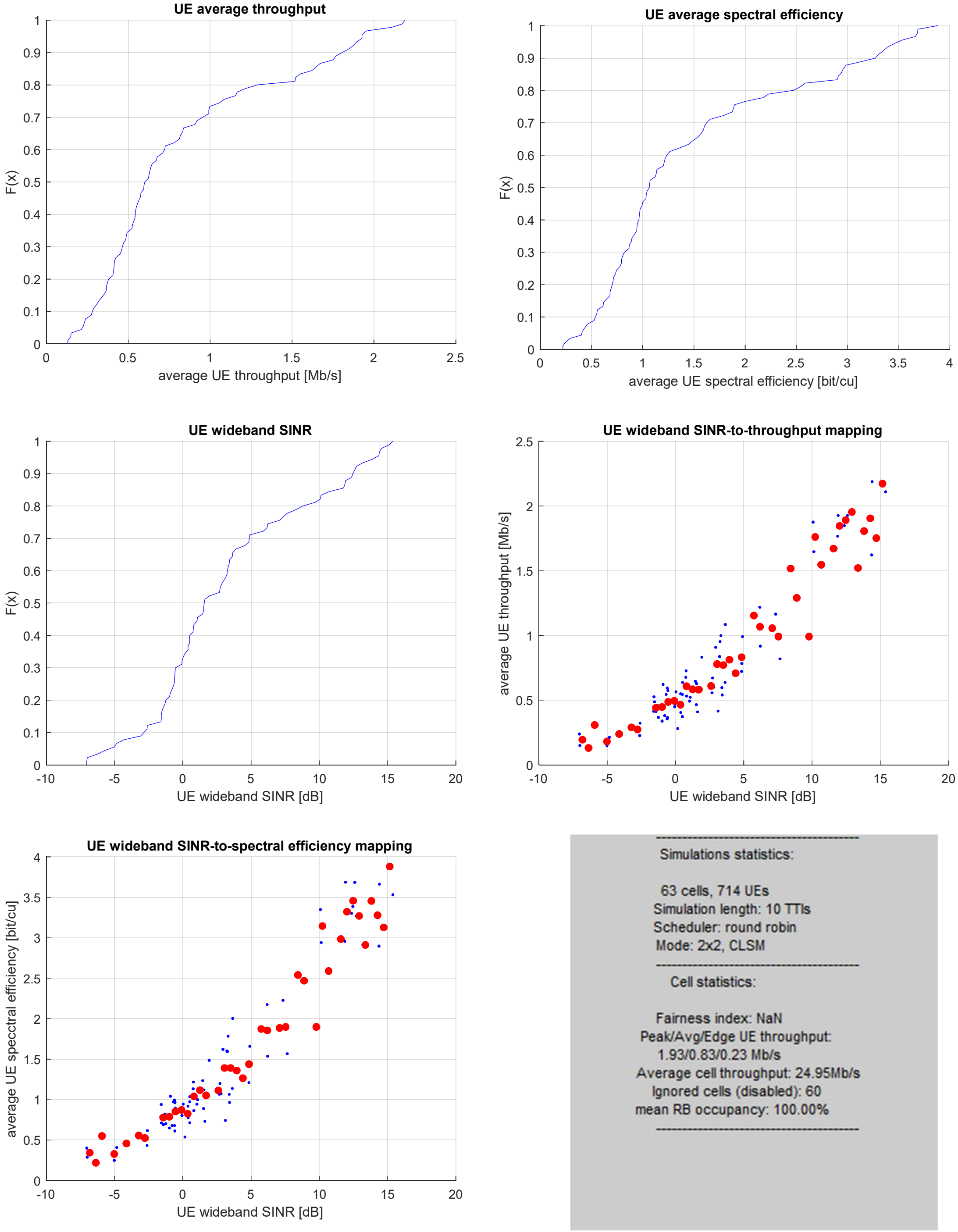
UE velocity= 5 km/h, Femto-Cell, Best CQI



```
------------------------------------------
 Simulations statistics:

 63 cells, 714 UEs
Simulation length: 10 TTIs
 Scheduler: best cqi
Mode: 2x2, CLSM
------------------------------------------
   Cell statistics:

Fairness index: NaN
Peak/Avg/Edge UE throughput:
  18.62/2.73/0.00 Mb/s
Average cell throughput: 41.79Mb/s
  Ignored cells (disabled): 57
mean RB occupancy: 4.29%
------------------------------------------
```

Figure 4.63: UE velocity= 5 km/h, Femto-Cell, Best CQI

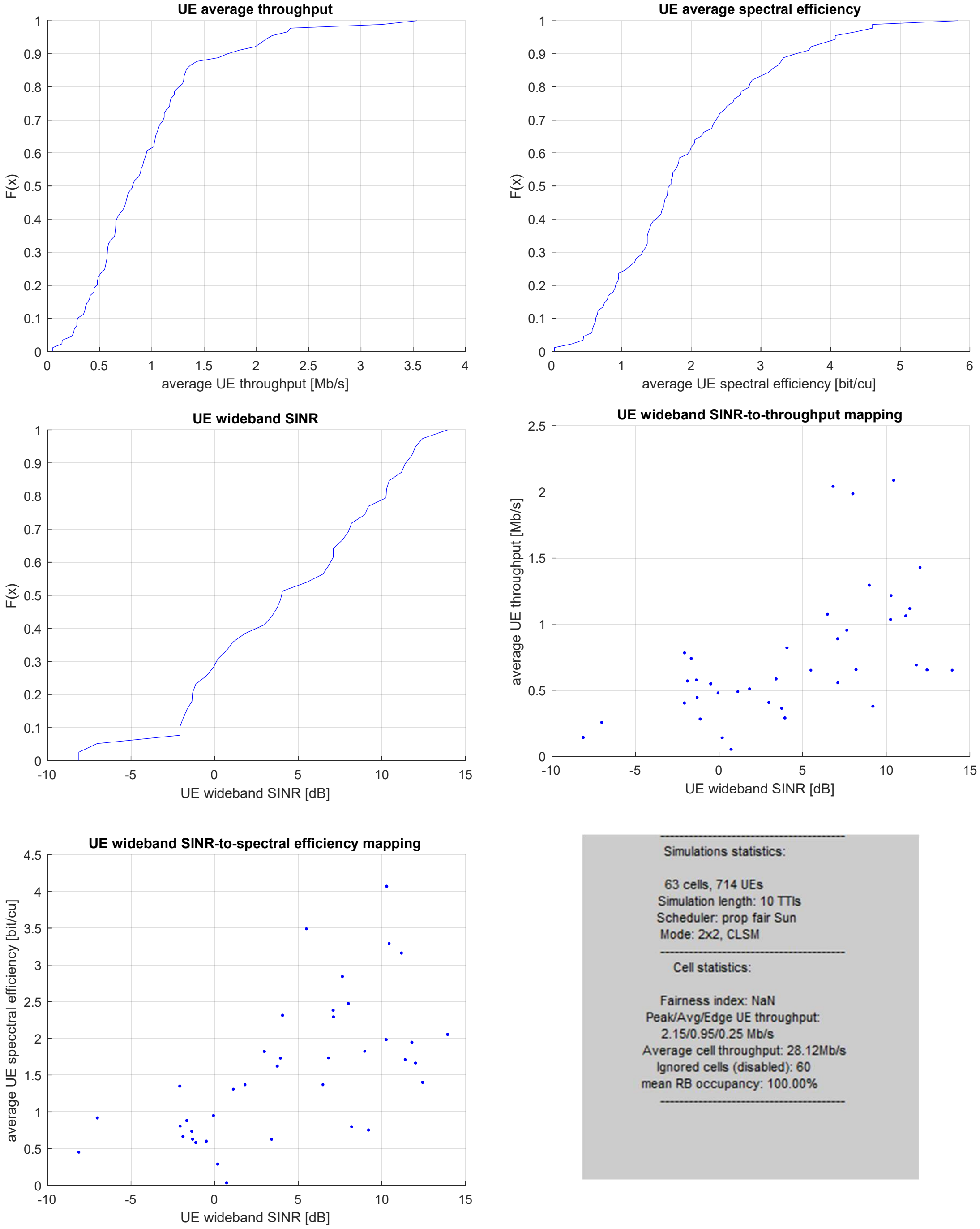
UE velocity= 40 km/h, Femto-Cell, Round Robin



```
-----------------------------------------
Simulations statistics:

 63 cells, 714 UEs
Simulation length: 10 TTIs
Scheduler: round robin
Mode: 2x2, CLSM
-----------------------------------------
 Cell statistics:

Fairness index: NaN
Peak/Avg/Edge UE throughput:
   1.93/0.83/0.23 Mb/s
Average cell throughput: 24.95Mb/s
 Ignored cells (disabled): 60
mean RB occupancy: 100.00%
-----------------------------------------
```

Figure 4.64: UE velocity= 40 km/h, Femto-Cell, Round Robin

UE velocity= 40 km/h, Femto-Cell, Prop Fair Sun



Simulations statistics:

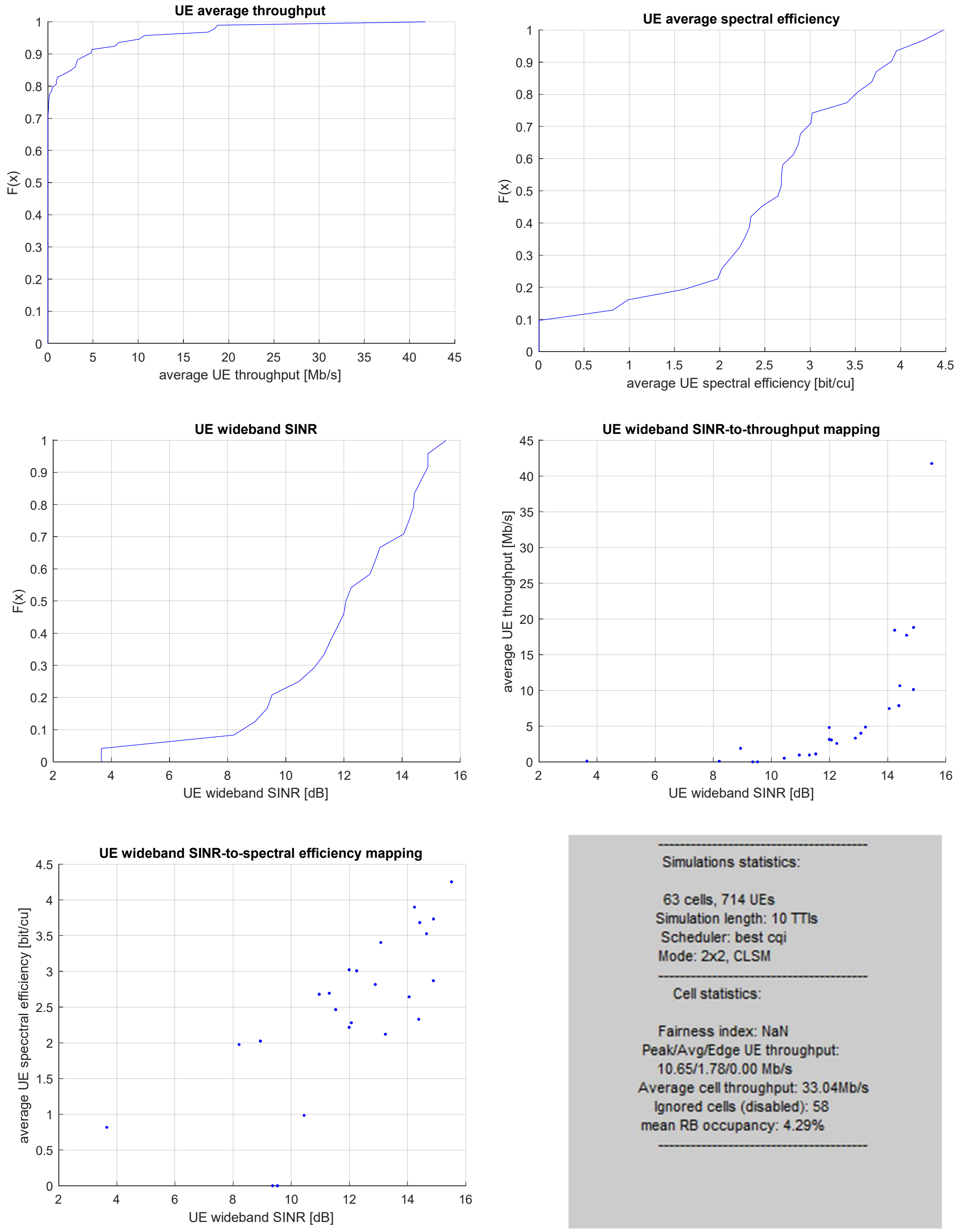
63 cells, 714 UEs
Simulation length: 10 TTIs
Scheduler: prop fair Sun
Mode: 2x2, CLSM

Cell statistics:

Fairness index: NaN
Peak/Avg/Edge UE throughput:
2.15/0.95/0.25 Mb/s
Average cell throughput: 28.12Mb/s
Ignored cells (disabled): 60
mean RB occupancy: 100.00%

Figure 4.65: UE velocity= 40 km/h, Femto-Cell, Prop Fair Sun

UE velocity= 40 km/h, Femto-Cell, Best CQI



Simulations statistics:

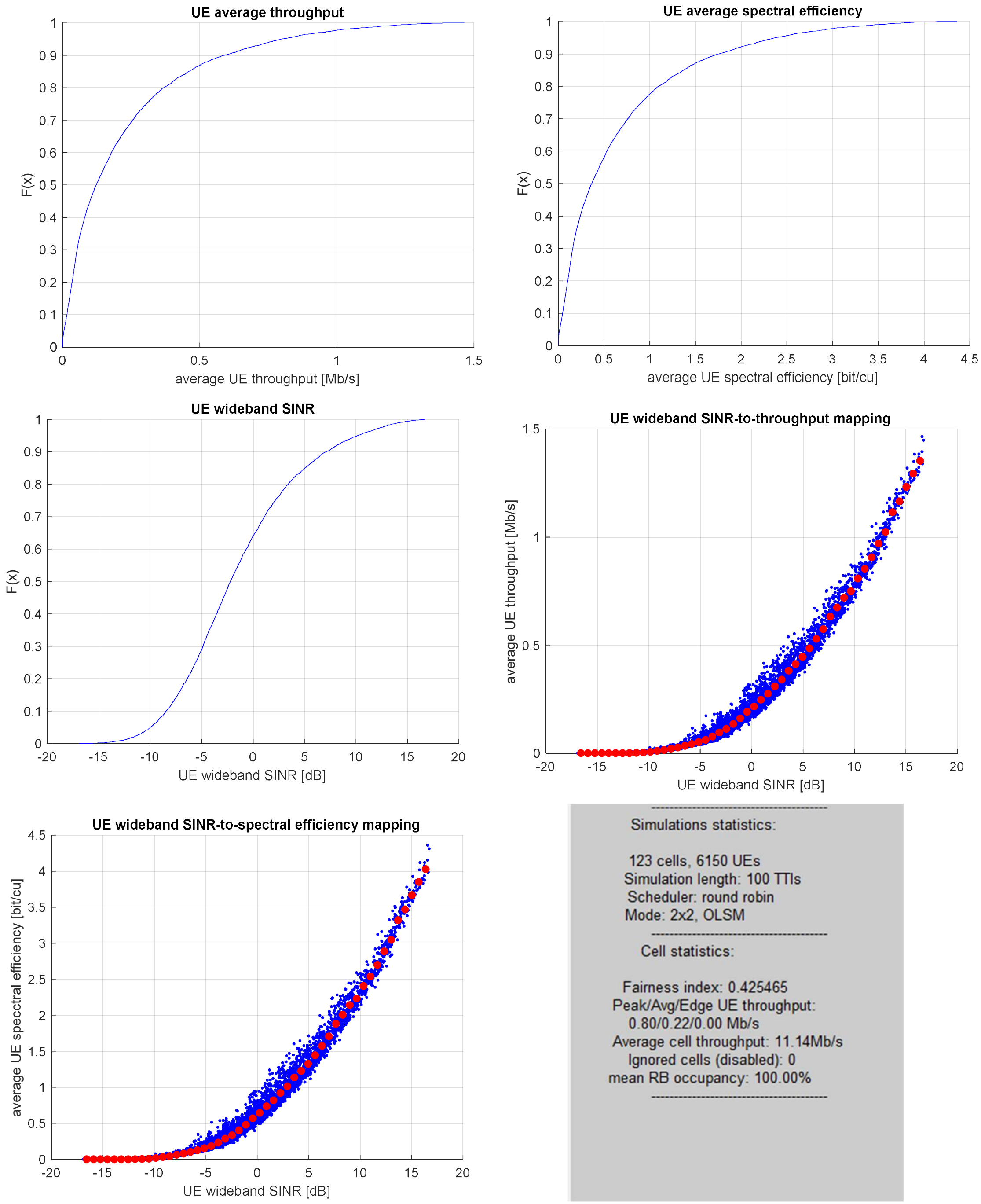
63 cells, 714 UEs
Simulation length: 10 TTIs
Scheduler: best cqi
Mode: 2x2, CLSM

Cell statistics:

Fairness index: NaN
Peak/Avg/Edge UE throughput:
10.65/1.78/0.00 Mb/s
Average cell throughput: 33.04Mb/s
Ignored cells (disabled): 58
mean RB occupancy: 4.29%

Figure 4.66: UE velocity= 40 km/h, Femto-Cell, Best CQI

Transmission Mode: Open Loop Spatial Multiplexing, Round Robin



Simulations statistics:

123 cells, 6150 UEs
Simulation length: 100 TTIs
Scheduler: round robin
Mode: 2x2, OLSM

Cell statistics:

Fairness index: 0.425465
Peak/Avg/Edge UE throughput:
0.80/0.22/0.00 Mb/s
Average cell throughput: 11.14Mb/s
Ignored cells (disabled): 0
mean RB occupancy: 100.00%

Figure 4.67: Transmission Mode: Open Loop Spatial Multiplexing, Round Robin

Chapter 5

Performance Analysis

All the simulation data are collected in the following tables:

UE Speed	FREQ, BW	Particulars	Round Robin	Prop Fair Sun	Best CQI
0 km/h	2GHz 10MHz	Peak throughput (Mbps)	1.17	1.2	2.17
		Average throughput (Mbps)	0.3	0.2	1.08
		Cell edge throughput (Mbps)	0	0	0
		Cell throughput (Mbps)	5.95	3.91	21.68
		Avg. Spectral efficiency (bits/cu)	0.71	0.49	0.71
		Fairness Index	0.346524	0.145097	0.038163
	5Ghz 15Mhz	Peak throughput (Mbps)	0.82	0.73	2.22
		Average throughput (Mbps)	0.17	0.13	0.48
		Cell edge throughput (Mbps)	0	0	0
		Cell throughput (Mbps)	3.34	2.62	9.58
		Avg. Spectral efficiency (bits/cu)	0.26	0.26	0.33
		Fairness Index	0.264806	0.179362	0.0352528
5 km/h	2Ghz 10Mhz	Peak throughput (Mbps)	0.68	0.58	0.94
		Average throughput (Mbps)	0.16	0.14	0.23
		Cell edge throughput (Mbps)	0	0	0
		Cell throughput (Mbps)	3.3	2.75	4.63
		Avg. Spectral efficiency (bits/cu)	0.39	0.36	0.26
		Fairness Index	0.302819	0.197047	0.0377262
40 km/h	2GHz 10MHz	Peak throughput (Mbps)	0.73	0.7	1.05
		Average throughput (Mbps)	0.2	0.17	0.23
		Cell edge throughput (Mbps)	0	0	0
		Cell throughput (Mbps)	4	3.3	4.7
		Avg. Spectral efficiency (bits/cu)	0.47	0.4	0.29
		Fairness Index	0.360877	0.311114	0.0434995
120 km/h	2GHz 10MHz	Peak throughput (Mbps)	0.77	0.73	0.89
		Average throughput (Mbps)	0.21	0.18	0.26
		Cell edge throughput (Mbps)	0	0	0
		Cell throughput (Mbps)	4.16	3.51	5.11

		Avg. Spectral efficiency (bits/cu)	0.47	0.41	0.4
		Fairness Index	0.364151	0.271806	0.027697

Table 5.1: Simulation stats of generic simulations for various UE speed and various frequency for different scheduler configurations

UE speed	UE/cell	Peak throughput (Mbps)	Average throughput (Mbps)	Cell Edge throughput (Mbps)	Cell throughput (Mbps)	Avg. Spectral Efficiency (bits/cu)	Fairness Index
10	10	1.36	0.82	0.19	8.16	3.24	0.81028
	30	0.45	0.24	0.05	7.2	2.86	0.759759
40	10	1.36	0.66	0.15	6.63	2.63	0.737161
	30	0.45	0.19	0.03	5.82	2.31	0.680124

Table 5.2: Simulation stats for Beamforming

Configuration	UE Speed	Peak throughput (Mbps)	Average throughput (Mbps)	Cell Edge throughput (Mbps)	Cell throughput (Mbps)	Avg. Spectral Efficiency (bits/cu)	Fairness Index
CoMP	0 km/h	1.58	0.77	0.33	7.74	0.9	0.81957
	5 km/h	3.19	1.65	0.61	16.47	2.03	0.787949
	40 km/h	1.47	0.74	0.3	7.37	0.92	0.790822
CoMP with Runtime Precoding	0 km/h	2.97	1.44	0.44	14.36	2.03	0.779345
	5 km/h	2.82	1.36	0.24	13.63	1.91	0.70373
	40 km/h	1.24	0.54	0.12	5.4	0.76	0.667873

Table 5.3: Simulation stats for CoMP vs CoMP with Runtime Precoding

UE speed	Particulars	Round Robin	Prop Fair Sun	Best CQI
5 km/h	Peak throughput (Mbps)	2.32	2.49	18.62
	Average throughput (Mbps)	1.1	1.49	2.73
	Cell edge throughput (Mbps)	0.34	0.58	0
	Cell throughput (Mbps)	33.83	46.83	41.79
	Avg. Spectral efficiency (bits/cu)	1.99	2.84	4.73
	Fairness Index	NaN	NaN	NaN
40 km/h	Peak throughput (Mbps)	1.93	2.15	10.65
	Average throughput (Mbps)	0.83	0.95	1.78
	Cell edge throughput (Mbps)	0.23	0.25	0
	Cell throughput (Mbps)	24.95	28.12	33.04
	Avg. Spectral efficiency (bits/cu)	1.48	1.94	2.5
	Fairness Index	NaN	NaN	NaN

Table 5.4: Simulation stats for Femto cell

UE Speed	Particulars	Round Robin	Prop Fair Sun	Best CQI
0 km/h	Peak throughput (Mbps)	3.79	0.83	4.29
	Average throughput (Mbps)	0.59	0.14	1.36
	Cell edge throughput (Mbps)	0	0	0
	Cell throughput (Mbps)	5.88	1.36	13.57
	Avg. Spectral efficiency (bits/cu)	0.7	0.27	0.66
	Fairness Index	0.159044	0.0536789	0.0446717
5 km/h	Peak throughput (Mbps)	1.07	1.02	5.87
	Average throughput (Mbps)	0.18	0.11	0.81
	Cell edge throughput (Mbps)	0	0	0
	Cell throughput (Mbps)	1.8	1.11	8.15
	Avg. Spectral efficiency (bits/cu)	0.19	0.25	0.72
	Fairness Index	0.0847288	0.0942127	0.0543071
40 km/h	Peak throughput (Mbps)	1.37	0.95	3.24
	Average throughput (Mbps)	0.25	0.14	0.87
	Cell edge throughput (Mbps)	0	0	0
	Cell throughput (Mbps)	2.5	1.38	8.69
	Spectral efficiency (bits/cu)	0.27	0.26	0.92
	Fairness Index	0.128904	0.100533	0.0450554

Table 5.5: Simulation stats for mm-Wave

Inferences:

In Table 5.1, a generic comparison for transmission mode CLSM for different schedulers was done, where the best values for the results have been highlighted for each case. In each case, the values were obtained for the whole site, i.e. all the values were averaged. Here, we took two parameters into consideration, one being channel frequency & bandwidth, while the other being velocity.

For static case, it is seen that, apart from fairness index, everything is better for the best CQI scheduler. Fairness index can be considered as an inherent property of a scheduler since for most cases, they do not vary much. It is seen for the next simulations that the spectral efficiency reduces for the best CQI cases, while still giving higher peak throughput and average throughput.

For all the cases except the static case, it is seen that, the spectral efficiency and fairness index has quite a close relationship. The scheduler having higher fairness index has a higher spectral efficiency.

So, if we aim to satisfy the customers and considering the efficiency of the overall site, then round robin will be the preferable scheduler. But as far as throughput is concerned, undoubtedly, best scheduler takes the cake.

In table 5.2, different cases were observed for the transmission mode beamforming, where the scheduler configuration chosen was Round Robin and the parameters subjected to change were UE per cell and velocity of UE

In table 5.3 a comparison was made between CoMP and runtime precoding [11] to verify if runtime precoding can be applied in practical scenario and with what tradeoffs. It is seen that, if we are to choose runtime precoding, we have to sacrifice throughput to an extent for mobile UE. Again, according to the choice of the service provider, one can choose to either reduce complexity to an extent, sacrificing data rate in the process, or to maximize the data rate.

In table 5.4, different schedulers for a heterogeneous network composed of Femto-cells and macro eNBs were tested. It was found out that, for lower speed of UE, prop fair Sun is more suitable, whereas best CQI is suitable for higher frequency cases. But another critical parameter, for which femto-cells are used, is the cell edge throughput, which is 0 Mb/s for best CQI case, which is a downside. The fairness index is given as NaN because in this case the simulator calculates the fairness index taking femto-cells as macro eNBs along with normal macro eNBs.

Lastly for mm-wave case, in table 5.5, a comparison was made between the schedulers, varying the UE mobility. It is seen that for this case, spectral efficiency of best CQI is higher than that of round robin as seen in table 5.1, since in both the cases the transmission mode is same, UE velocity and number of UEs are the same, the only difference lies in the channel frequency & bandwidth (28 GHz & 10MHz).

Chapter 6

Non-Orthogonal Multiple Access (NOMA)

6.1 Introduction

To continue to ensure the viability of mobile communications networks over the next decade, it is necessary to identify and develop new technology solutions that can adapt to emerging challenges. In view of the expected exponential increase in the volume of mobile traffic, e.g. beyond a 500-fold increase in the next decade, significant gains in capacity and quality of user experience (QoE) are required for future radio access (FRA) in the 2020s. Such a framework would allow networks to serve as many users as possible without undermining spectral efficiency or device equity. Multiple access is a requirement for all types of wireless communication. Depending on their various connectivity systems, the ages of communication technologies were distinguished. In conventional OMA (Orthogonal Multiple Access) system, the allocated resources, be it in time or frequency domain are orthogonal in nature in order to reduce the amount of interference among the users. It, in effect, cannot optimize a mobile network's number of users due to the lack of enough radio resources. But the Web, especially the mobile Internet, is riddled with interconnected devices that continuously exchange information between them, thus growing data traffic by thousands of times. Non-orthogonal multiple access (NOMA) [21,22] for 5G has shown great prospects of promoting huge convergence and increasing spectral efficiency compared to existing OMA systems in order to provide leeway around these constraints. It is known to be a promising candidate for wireless communication networks of the fifth generation.

6.2 Basic Concept of NOMA

Non-orthogonal multiple access (NOMA) has gained considerable interest in developing fifth-generation (5G) wireless networks and beyond radio access strategies. The basic concept behind NOMA is to support more than one client, e.g. a time slot, subcarrier, spreading code or space in the same resource frame [42]. With this, NOMA facilitates huge convergence, decreases latency, improves user fairness and spectral efficiency, and increases consistency relative to multiple access orthogonal (MA) strategies. A variety of NOMA systems has attracted a lot of attention and we can classify them into two classes in particular:

- Power domain NOMA
- Code domain NOMA

Again, different types of code domain NOMA exist, such as Multiple Access with Low-Density Spreading (LDS) [23], Sparse Code Multiple Access (SCMA) [24], Multi-User Shared Access (MUSA) [25].

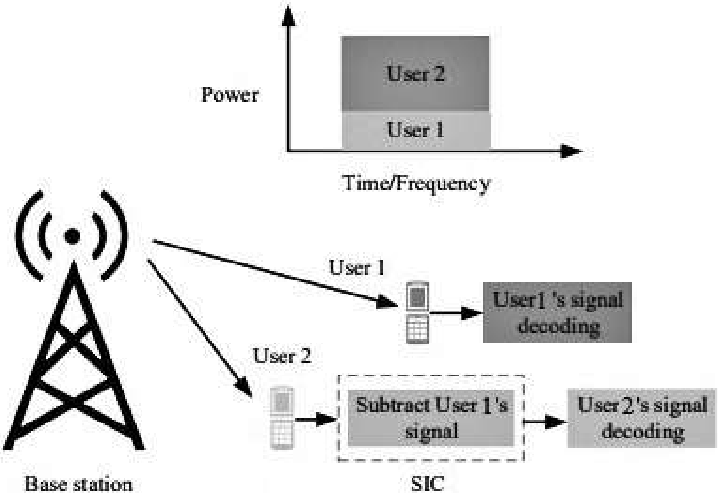


Figure 6.1: Basic structure of downlink NOMA

In NOMA, the base station (BS) transmits signal over the same frequency and time assets to multiple users. Successive interference cancelation (SIC) is used to decipher users with weaker channel coefficients. It enables multiple users to use power domain or code domain multiplexing to share time and frequency resources in the same spatial layer [37]. Cellular connectivity data may typically be categorized as either downlink or uplink. The BS transmits messages to multiple users concurrently in the downlink stream, while multiple users transmit data to the same BS in the uplink network. In power domain downlink NOMA, less power is allocated to the UE with high channel gain and more power is allocated to the UE with low channel gain [39, 44]. Such a large power gap enables the effective decoding (high probability) and thus the efficient cancelation of the signal allocated for UE (high power allocation) on the UE (low power allocation) transmitter. Therefore, the signal designated for weaker UE is decoded directly at the weaker UE receiver by considering the disturbance from the signal designated for stronger UE as noise. Due to NOMA's power domain user multiplexing, the transmit power allocation (TPA) [31] to one user influences not only that user's feasible bandwidth, but also the other user's throughput. The order of SIC encoding depends solely on the order of SNR at the receivers, or the size of the channel gains equivalently. More precisely, in order to achieve the capability area, with $|h_1| \geq |h_2|$, user 1 must first decode the signal of user 2 regardless of the amount of energy allotted to users, and apply SIC to decode its own message free of interference, which is shown in the figure 5.1. Furthermore, when decoding its own message, user 2 must treat the signal of user 1 as noise.

6.3 Performance gain of NOMA over OMA

Different applications are distributed to orthogonal radio services in time frequency and code domain in traditional OMA schemes. Ideally, owing to the orthogonal resource allocation in OMA, there is no interference between multiple users, and simple single-user identification can be used to distinguish the signals from different users. Theoretically, it is understood that the sum-rate potential of multi-user wireless networks cannot always be reached by OMA [26]. NOMA uses superposition coding (SC) for the transmitter (BS) and successive interference cancelation (SIC) for the receiver to expand the OMA frequency field. So, by using non-orthogonal resource allocation, NOMA can therefore handle far more users than OMA. Let’s take an example to compare the efficient sum-rate of OMA and NOMA.

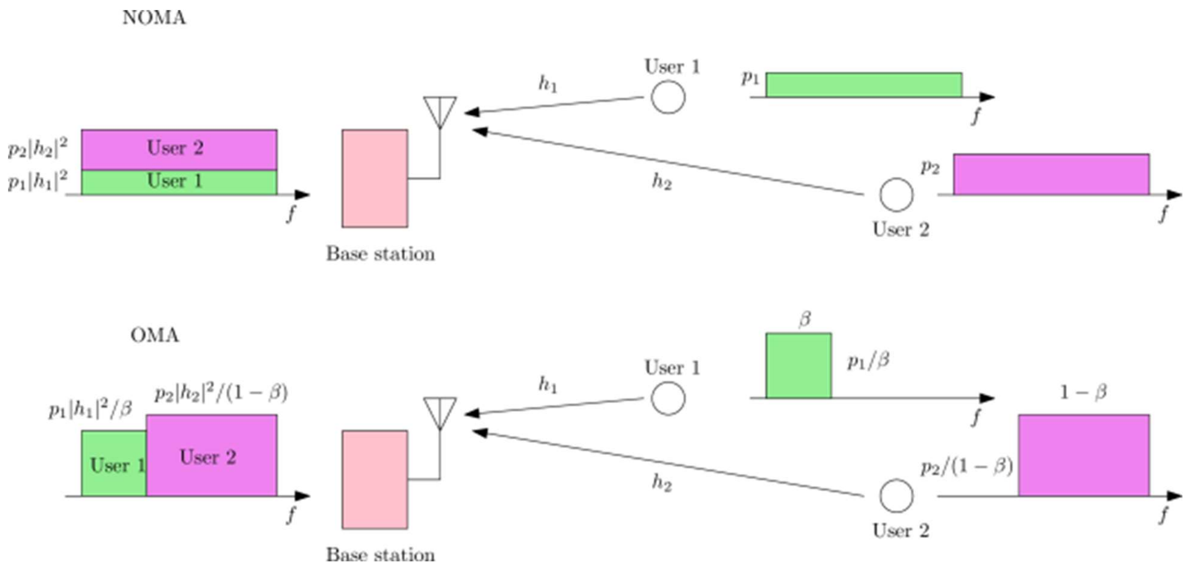


Figure 5.2: Resource allocation of NOMA and OMA

For conventional OMA scheme, assuming a FDMA scheme where a fraction β of frequency ($0 \leq \beta \leq 1$) is dedicated to user 1 and a fraction (1-β) of time is dedicated to user 2. Power P_1 & P_2 are allocated to the users 1 & 2, respectively. So, the data transfer rate of two users are,

$$R_1=\frac{\beta}{2}\log_2(1+|h_1|^2P_1) \qquad (5.1)$$

$$R_2=\frac{1-\beta}{2}\log_2(1+|h_2|^2P_2) \qquad (5.2)$$

Here, h_1 & h_2 are the received signal-to-noise ratio (SNR) and the channel gain for users 1 & 2, respectively and the noise power is normalized to unity. For NOMA scheme, in particular, the BS allocates fractions α, $0 \leq \alpha \leq 1$, and $\beta=(1-\alpha)$ of its power P to the signals of user 1 and user 2, respectively. So, the achievable sum rate for NOMA will be:

$$R_3=\frac{1}{2}\log_2(1+\alpha P|h_1|^2) \qquad (5.3)$$

$$R_4=\frac{1}{2}\log_2(1+\frac{(1-\alpha)P|h_2|^2}{1+\alpha P|h_1|^2}) \qquad (5.4)$$

So, the efficient sum-rates of OMA & NOMA are,

$$R_{OMA}= R_1+R_2 = \frac{1}{2}[\beta\log_2(1+|h_1|^2P_1)+(1-\beta)\log_2(1+|h_2|^2P_2)] \qquad (5.5)$$

$$R_{NOMA} = R_3 + R_4 = \frac{1}{2}\left[\log_2(1+\alpha P|h_1|^2) + \log_2\left(1+\frac{(1-\alpha)P|h_2|^2}{1+\alpha P|h_1|^2}\right)\right] \quad (5.6)$$

Now, taking $|h_1|^2=100|h_2|^2=5$ & transmit power $P_1=P_2=P=40$dBm, we have plotted the efficient throughput sum-rates R_{OMA} & R_{NOMA} against the power transmission coefficient, which is shown in figure 5.2.

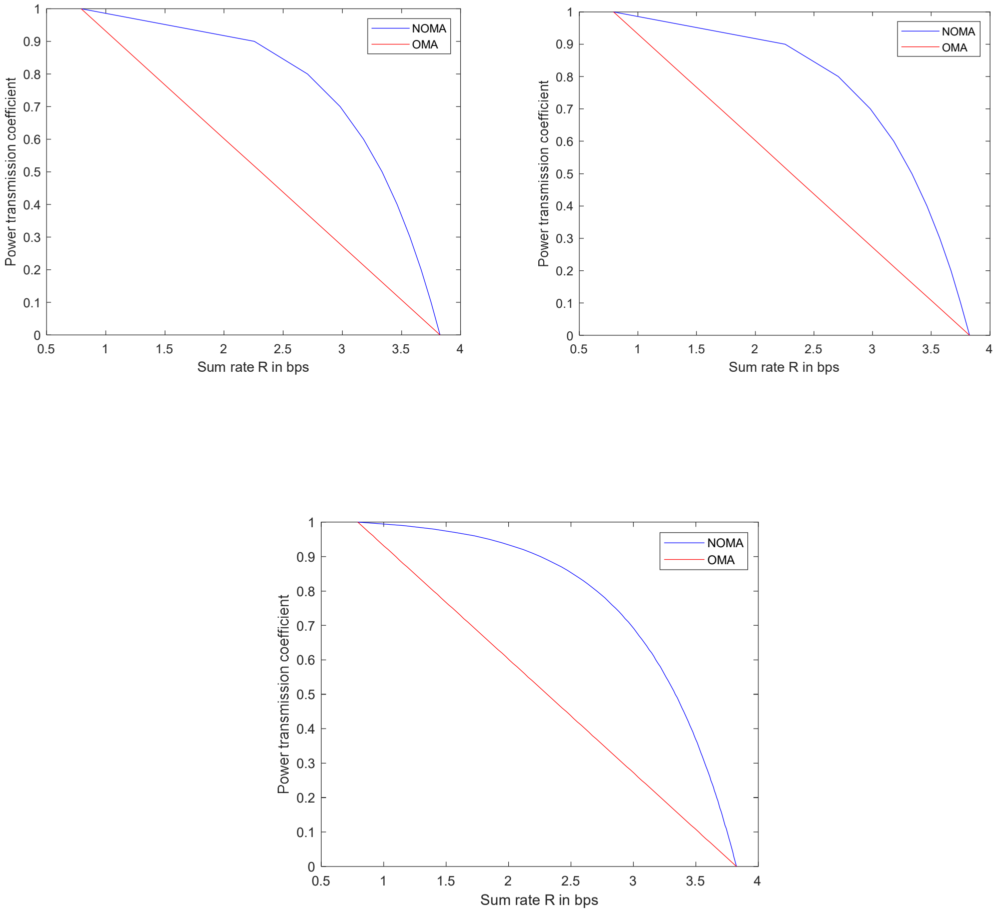


Figure 5.3: Performance gain of NOMA over OMA

From the figure 5.3, we can see that, conventional OMA is sub-optimal where NOMA scheme is the optimal solution to achieve better sum-rate & efficient spectral efficiency for better user fairness. If we want to obtain maximum sum-rate, we can give all power to the strong users. But if the user fairness is considered, the power should be allocated among users according to the channel gains of the users. So we can control the desired throughput of cell-center & cell-edge users by selecting a suitable power allocation factor, which is not possible in the conventional OMA schemes.

6.4 Multi-cell NOMA

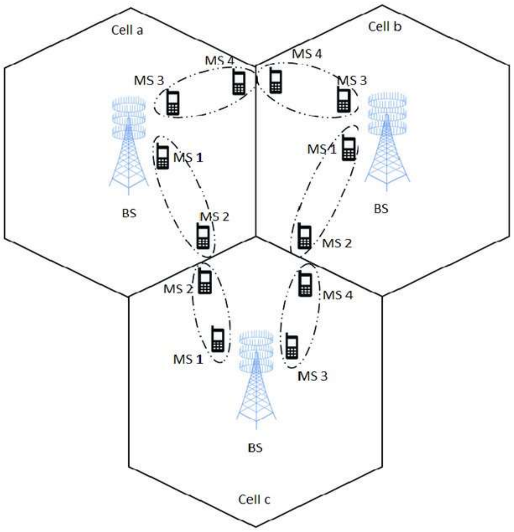


Figure 5.4: Multi-Cell NOMA

In the downlink single-cell scheme, NOMA can be used efficiently to achieve better throughput, spectral efficiency & user fairness [36]. But in the multi-cell scheme, the case is different. In multi-cell, the users are paired in different clusters by optimal user-pairing algorithm [29, 31, 45]. It is necessary to perform user clustering to strike a balance between system performance and computational complexity in large NOMA systems. For multi-cell scenario, MU-MIMO (Multi-user Multiple Input Multiple output) NOMA is deployed [28, 33, 34, 43]. Mobile users are typically clustered into a cluster in the same geographic direction but with different transmission lengths, and a transmit beam is transmitted among users in a cluster. Now assuming that, there are M clusters and each cluster contains N users. So, the BS transmits a signal, x_i for the users in the i^{th} cluster as follows,

$$x_i = \sum_{j=1}^{N} \sqrt{P_{i,j}} X_{i,j} \qquad (5.7)$$

Here, $P_{i,j}$ is the transmit power for the j^{th} user in the i^{th} cluster, and $X_{i,n}$ is the information signal of unit norm. So, the total transmit signal is given by,

$$\mathbf{X} = \sum_{i=1}^{M} Y_i x_i \qquad (5.8)$$

where Y_i is the transmit beam for *i*th cluster. The received signal $S_{i,j}$ at the j^{th} mobile user in the i^{th} cluster is given by,

$$\mathbf{S}_{i,j} = s_1 + s_2 + s_3 + s_4 + \mu_{i,j} \qquad (5.9)$$

where, $s_1 = H_{ij} Y_i \sqrt{\varepsilon_{i,j} P_{i,j}} X_{i,j}$ = desired signal,

$s_2 = \sum_{n=1,n\neq j}^{N} H_{ij} Y_i \sqrt{\varepsilon_{i,j} P_{i,n}} X_{i,n}$ = Intra-cluster interference,

$s_3 = \sum_{m=1,m\neq i}^{M} \sum_{n=1}^{N} H_{i,j} Y_m \sqrt{\varepsilon_{i,j} P_{m,n}} X_{m,n}$ = Inter-cluster interference,

$s_4 = \sum_{k=1}^{K} \sum_{l=1}^{L} \sum_{p=1}^{P} \text{Ħ}_{k,a,b} \text{ß}_{k,l} \sqrt{\text{Ø}_{k,a,b} \text{Þ}_{k,l,p}} \text{ȗ}_{k,l,p}$ = Inter-cell interference,

$\mu_{i,j}$ = Additive White Gaussian Noise (AWGN).

Here, $H_{i,j}$ is the conjugate of channel fading vector, $\varepsilon_{i,j}$ is the path loss of the j^{th} user of the i^{th} cluster and $\text{Ħ}_{k,a,b}$, $\text{ß}_{k,l}$, $\text{Ø}_{k,a,b}$, $\text{Þ}_{k,l,p}$ and $\text{ȗ}_{k,l,p}$ are the conjugate of channel fading vector, transmit beam, path loss, transmit power and information signal for b^{th} user of a^{th} cluster of kth interfering cell, respectively.

In multi-cell, Inter-cell Interference (ICI) occurs which reduces the throughput rate of cell-edge users [30]. Actually, as wireless networks are becoming denser and denser, inter-cell intrusion (ICI) is becoming a major obstacle to NOMA's benefits. When a user moves away from the BS, their signal-to-interference-plus-noise ratio (SINR) usually reduces for two main reasons:

- the signal energy obtained is reduced due to attenuation,
- the interference power from the adjacent cells, or ICI, is enhanced because the user is getting closer to the adjacent BS.

ICI arises in adjacent cells belonging to the same wavelength of reciprocal transmission. For modern cellular networks, cell-edge users usually benefit from worse QoS due to standard frequency reuse. This effectively reduces the device array's overall performance. Intuitively, ICI is negatively affected by growing the signal propagation capacity of cell-edge consumers. But there is no optimal method of ICI cancellation is established yet. Without cancelling ICI, NOMA scheme can't be implemented in practical aspects.

6.5 Possible methods of ICI cancellation

Number of antennae

From the theoretical model of NOMA, we can see that, the average throughput of cell-edge users is independent of total number of antennae, but ICI depends on it inversely [30]. So, for a large number of antennae, the amount of ICI will be negligible. But in practical scenario, the maximum number of antennae is basically up to 68. So, this method is not quite suitable for ICI cancellation.

Fractional Frequency Reuse (FFR):

The basic idea of fractional frequency reuse (FFR) [46] is to divide the bandwidth of a cell into multiple sub-bands and allocate sub-bands orthogonally for the neighboring cell edge regions. This concept contrasts with NOMA in which, due to its suboptimality, orthogonalization is avoided. Although theoretically suboptimal, FFR is important as it offers a simple ICI management approach without requiring CSI. Therefore, investigating methods that can bring together NOMA and FFR-based networks is important. A simple concept for using both FFR and NOMA is to apply NOMA separately in the cell-center band and cell-edge band, which would combine cell-center users (in the cell-center band) and cell-edge users (in the cell-edge band). However, it is not expected that such users will have very different channel conditions, and it may not be worth noting any NOMA gain. Another idea is to combine a cell-center user with a cell-edge user in the cell-edge band in order to avoid ICI. Such a pairing will reduce the rates of cell-edge users, as cell-center users can also share their specific bands, which sacrifices the rates of cell-edge users. This, in turn, deteriorates user-fairness. This in turn worsens user-friendliness.

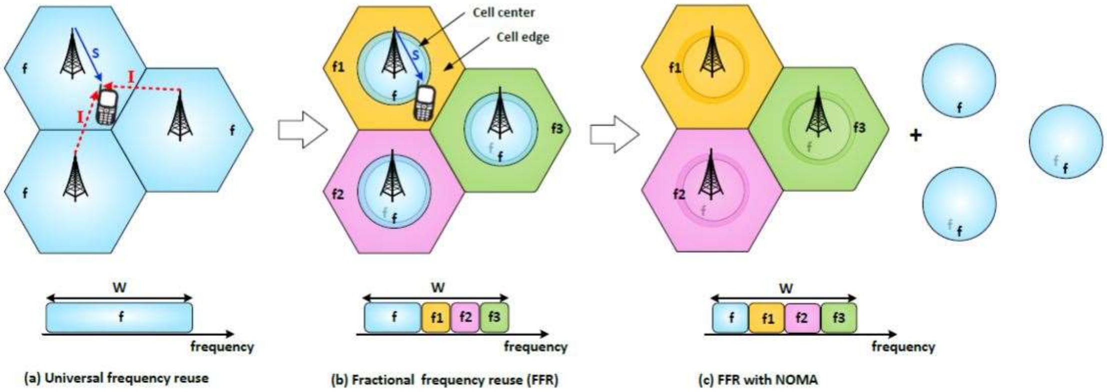


Figure 5.5: ICI cancellation using FFR technique [46]

Joint Precoding

_It is possible to call joint precoding of NOMA users' signals from adjacent cells to minimize inter-cell conflict. This requires that all users' data and CSI are available on multiple BSs, but finding the optimal precoder is not trivial [34, 35, 36]. On the other hand, the multi-user precoding used for single-cell NOMA may not be practical for the case of the NOMA network, as the precoder for geographically different BS antennas does not actually shape the actual beam that can be conveniently used for intra-beam NOMA. Users' data symbols are available in NOMA-JP at more than one BS. We can divide NOMA-JP further into two categories based on the number of active BSs a user supports:

- NOMA-joint transmission (JT)
- NOMA-Dynamic Cell Selection (DCS).

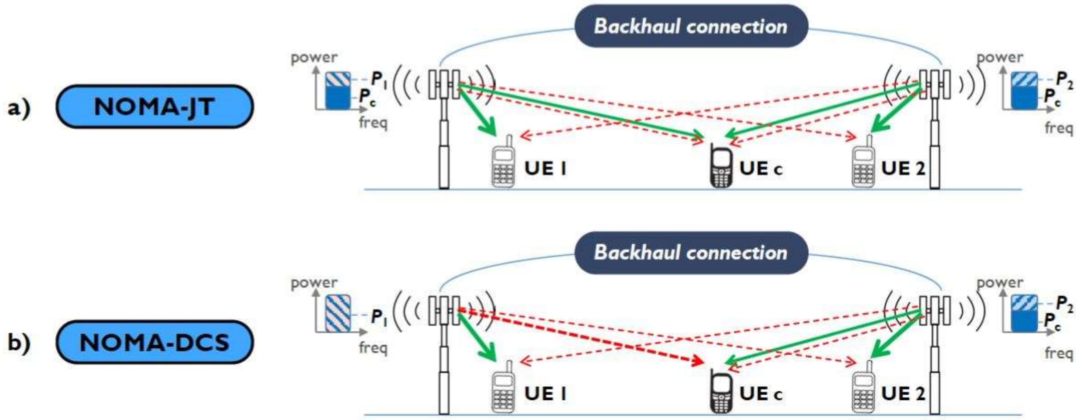


Figure 5.6: NOMA-JT and NOMA-DCS

6.6 NOMA-JT:

This approach requires multiple BSs to support a user using a single wireless network at the same time, rather than competing with each other. It greatly enhances the quality of the signal transmitted to cell edge users at a slightly lower price at the expense of cell center users. This collaborative environment is comparable to a single-cell NOMA because using MIMO network technique, the ICI can be completely cancelled for cell-edge users. Each cell-center user is served by their corresponding BS in this scheme while both BSs serve the cell-edge user. In particular, two BSs transmit Alamouti coded [32] signals to a cell-edge user for a higher transmission rate, while each BS also transmits signals to the cell-center user. It has been shown that the coordination between two cells enables NOMA to provide a reasonable rate of transmission to a common cell-edge user without sacrificing the rates of cell-center users.

6.7 NOMA-DCS:

In this scenario, multiple BSs share the user's data, but it is transmitted only from one selected BS. Note that the BS transmission can be changed dynamically over time using order statistics. Suppose $|h_{c,2}|2 > |h_{c,1}|2$; then for a cell-edge user, BS 2 becomes the sole serving BS until the order statistics are changed. That is, only BS 2 uses NOMA strategy to support at the same time a couple of cell-edge and cell-center users, while BS1 only serves its corresponding cell-center user.

Chapter 7

Conclusion and Future Prospects

Our work here involved the extensive study of the transmission modes & scheduler configuration based on various network parameters. We can safely say that no one scheduler or transmission mode is the best. It mostly depends on the topography of the site, as to which transmission mode and scheduler should be chosen. The transmission mode CLSM is a fairly balanced one in all respects, which is why in practical cases, CLSM is chosen. Amongst the schedulers, though best CQI provides more throughput and is logically the one to choose for the best utilization of resources, but due to low fairness index it is not practically implemented. Amongst the upcoming 5G technologies, considering the current establishment, a study of beamforming and MMW channels was in order. But for a better and efficient methodology, the challenging prospect of NOMA was also reviewed.

Future Prospects

Our future prospects involve

- Further study of the network parameters and their impacts in practical cases for the ITU and U-Ma channels.
- Fine tuning our simulations to a greater extent.
- Removing the complexities of CoMP in a more efficient manner, using runtime precoding.
- Using CoMP and runtime precoding as a basis to establish NOMA JT scheme for multiple users in practical cases.
- Researching more efficient ways to remove ICI for the NOMA case.

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