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OPTIMAL SCHEDULING ALGORITHMS WITH CARRIER AGGEREGATION

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Ahmed A Ali Alsabri
College of Information Technology
University of Zawia (UZ)
Alzawia, Libya
Ah.ali2060@gmail.com

Akrem Asmeida
College of Computer
Technology Zawia
Alzawia, Libya
Asmeidaakrem@gmail.com

ABSTRACT

This research investigates the effects of Channel Quality Indicator (CQI) feedback delays on the Joint User Scheduling Scheme (JUS) and the Separated Random User Scheduling Scheme (SRUS) within an LTE-Advanced (LTE-A) system utilizing carrier aggregation. The study will compare scenarios involving delayed channel information against those with perfect channel knowledge across various deployment contexts. The analysis considers CQI delays ranging from 3 to 6 milliseconds, with the upper limit set at 6 milliseconds, as delays exceeding this threshold are deemed impractical for LTE-A systems. This range effectively reflects the delays associated with LTE-A feedback protocols and the realistic processing times of evolved Node B (eNB). The focus is on a downlink Orthogonal Frequency Division Multiplexing (OFDM)-based carrier aggregation system, which comprises multiple eNode-Bs and numerous User Equipments (UEs) distributed randomly within the cell. Each component carrier (CC) is made up of R Resource Blocks (RBs), with each RB containing K subcarriers in the frequency domain and one frame in the time domain. The traffic model employed in this study is a continuous data stream (Full Buffer), which serves, as a useful baseline despite being an idealized scenario, as scheduling and user throughput remain unaffected by the volume of data in the transmission buffer.

Keywords: CQI delay, Scheduling, LTE-A

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خوارزميات الجدولة المثالية مع تجميع الناقل

أحمد علي الصابري، أكرم اصميدة

كلية تقنية المعلومات ،جامعة الزاوية

كلية تقنية الحاسوب الزاوية، جدايم

*Ah.ali2060@gmail.com, Asmeidaakrem@gmail.com

الملخص :

يحقق هذا البحث في تأثيرات تأخيرات ردود الفعل لمؤشر جودة القناة (CQI) على نظام جدولة المستخدم المشترك (JUS) ونظام جدولة المستخدم العشوائي المنفصل (SRUS) ضمن نظام LTE-A) LTE-Advanced) باستخدام تجميع الناقل. ستقارن هذه الدراسة السيناريوهات التي تتضمن معلومات قناة متأخرة مع تلك التي تتمتع بمعرفة كاملة بالقناة عبر سياقات النشر المختلفة. يأخذ التحليل في الاعتبار تأخيرات CQI التي تتراوح من 3 إلى 6 مللي في الثانية، مع تحديد الحد الأعلى عند 6 مللي في الثانية، حيث تعتبر التأخيرات التي تتجاوز هذا الحد غير عملية لأنظمة LTE-A. يعكس هذا النطاق بشكل فعال التأخيرات المرتبطة ببروتوكولات ردود الفعل LTE-A وأوقات المعالجة الواقعية للعقدة eNB) B) المتطورة. ينصب التركيز على نظام تجميع الموجات الحاملة القائم على تعدد الإرسال بتقسيم التردد المتعامد (OFDM) للوصلة الهابطة، والذي يشتمل على عدة eNode-Bs والعديد من معدات المستخدم (UEs) الموزعة بشكل عشوائي داخل الخلية. تتكون كل موجة حاملة مكونة (CC) من كتل موارد R (RBs)، حيث تحتوي كل RB على موجات حاملة فرعية K في مجال التردد وإطار واحد في المجال الزمني. نموذج المرور المستخدم في هذه الدراسة هو دفق بيانات مستمر (Full Buffer)، والذي يعد بمثابة خط أساس مفيد على الرغم من كونه سيناريو مثاليًا، حيث تظل الجدولة وإنتاجية المستخدم غير متأثرة بحجم البيانات في المخزن المؤقت للإرسال.

الكلمات الرئيسية : تأخير CQI، الجدولة، LTE-A

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1. Introduction

In both LTE-A and LTE networks, the fundamental task of allocating time slots to service classes or individual customers is quite identical. However, compared to LTE networks, LTE-A networks need to significantly improve speed and reliability. Moreover, solutions for networking and interoperability need to give consumers more freedom. Ensuring Quality of Service (QoS) in high-speed data networks like LTE-A is crucial, particularly to meet the demands of real-time data users regarding fairness, data rate, and packet delay. This criterion is especially difficult for networks. Different users observe a wireless channel's quality in various ways, and spurious changes in time occur on both slow and fast time scales. Furthermore, as wireless link capacity is a scarce resource, it must be utilised wisely. Finding effective methods to support Quality of Service (QoS) for real-time data (such as live audio and video streams) across wireless channels is therefore crucial.

The main aim of this research is to compare and evaluate a number of simulation results in order to assess the effectiveness of the algorithms introduced. Additionally, the study aims to develop a new scheduler for LTE-A by offering a solution to resource allocation issues that takes into account all of the resource allocation constraints presented. The influence of CQI feedback delay over Separated Random User Scheduling Scheme (SRUS) and Joint User Scheduling Scheme (JUS) on carrier aggregation is examined in the first section of this research. The second section of this paper investigates user scheduling schemes for carrier aggregation under various MIMO transmission modes. The final section suggests an additional Proportional Fair (PF) scheduling algorithm that takes SRUS into account and discusses the algorithm's performance.

2. LTE AND LTE-ADVANCED

LTE-Advanced is comparable to LTE Versions 10 and 11, with several enhancements introduced in Release 9 of the latest LTE specifications. The LTE-Advanced standard is progressing in a manner identical to IMT Advanced. LTE Advanced is able to provide more enhanced system performance as compared to LTE. Concerning peak data rates, the system supports up to 1 Gbps for downlink and 500 Mbps for uplink, in contrast to LTE-A, which offers 100 Mbps for downlink and 50 Mbps for uplink [1]. LTE Advanced represents a substantial advancement for both cells and users, promoting effective spectrum utilization and enhanced energy efficiency for both users and infrastructure. To achieve the notable performance mentioned, the prospective features of LTE-A technology are outlined below.

- Enhanced Bandwidth Support: LTE-Advanced (LTE-A) integrates multiple LTE carrier bandwidths, each not exceeding 20 MHz, to achieve an operational bandwidth of up to 100 MHz. Carrier aggregation is recognized as the most effective approach to enhance peak data rates, thereby meeting the requirements of IMT-Advanced (Shen et al. 2012). Each individual carrier is designated as a component carrier (CC). When these CCs are continuous and symmetrical, the configuration is referred to as Carrier Aggregation. Conversely, if the CCs are discontinuous and asymmetrical, it is termed Spectrum Aggregation [2]. The maximum number of CCs that can be utilized is five [3,4]. This flexibility in spectrum allocation provides network operators with a significant advantage, as they can leverage all available spectrum assigned to them by the regulatory authorities for LTE-A, as illustrated in Figure 1.

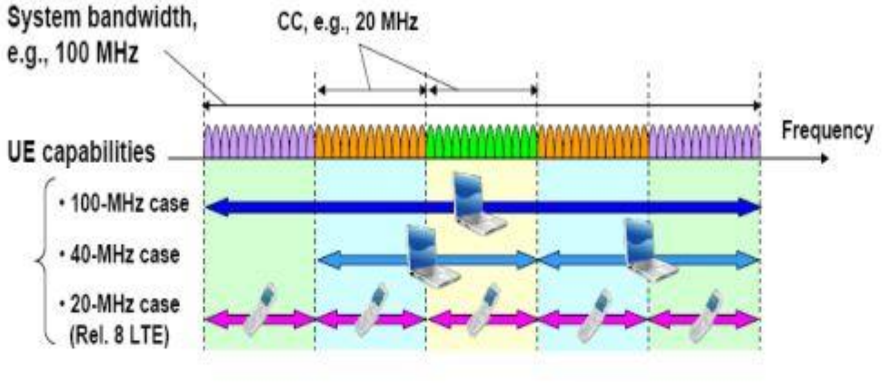

Figure1: Wider bandwidth

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- Multiple antennas at both the receiver and transmitter are facilitated by multiple input multiple output (MIMO) methodologies. The primary objective of MIMO is to provide a range of advantages, including spatial diversity and spatial multiplexing. Spatial multiplexing significantly increases capacity by enabling the simultaneous transmission of distinct data streams in parallel from different antennas [5].
- Asymmetric transmission bandwidth: In the context of the 3GPP family, up to LTE, the Frequency Division Duplex (FDD) mode allocates equivalent bandwidths for both uplink and downlink transmissions. However, in LTE-Advanced, the downlink bandwidth may vary from the uplink bandwidth due to differences in download and upload traffic patterns [5].
- Coordinated multipoint transmission and reception (CoMP): This mechanism involves the transmission and reception of data across multiple coordinated cells to enhance user throughput and extend cell coverage. It encompasses two primary types: Joint Processing (JP) and Coordinated Scheduling/Beamforming (CS/CB) [6].
- Relaying: Within the architecture of LTE-Advanced, a novel and crucial network component known as the Relay Node (RN) is utilized to receive signals from the eNodeB and subsequently relay them to create an expanded coverage area. The connection from the e-NodeB to the RN is referred to as the backhaul link, while the link from the RN to the User Equipment (UE) is designated as the access link (Chen et al.).

Table 1 Overview of all new characteristics of LTE-A and LTE [2]

Technology	LTE	LTE-A
Peak data rate DownLink (DL)	150 Mbps	1 Gbps
Peak data rate UpLink (UL)	75 Mbps	500 Mbps
Transmission bandwidth DL	20 MHz	100 MHz

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Transmission bandwidth UL	20 MHz	40 MHz (requirements as defined by ITU)
Mobility	Optimized for low speeds(< 15 km/hr) High performance at speeds up to 120 km/hr Maitain Links at speeds up to 350 km/hr	Same as that in LTE
Coverage	Full performance up to 5 km	a)Same as LTE requirement b) Should be optimized or deployment in local areas/micro cell environments
Scalable Band Widths	1.3,3,5,10 and 20 MHz	Up to 20 – 100 MHz
Capacity	200 active users per cell in 5 MHz	3 times higher than that in LTE

3. Simulation Results and Analysis

The throughput performance of various scheduling schemes under different deployment scenarios will be analyzed, followed by recommendations for the most suitable deployment scenario to maintain the desired Quality of Service (QoS) for a specified number of users. This research establishes a relevant baseline for Carrier Aggregation (CA) combinations and operations in the context of forthcoming fifth-generation mobile communications.

In the deployment scenario involving a main beam directed at the sector boundary, the eNB antennas associated with different component carriers (CCs) can exhibit distinct beam direction patterns. The intentional variation in antenna beam orientations across carriers is designed to enhance throughput at the sector boundaries. All CCs operate within the same 3GPP frequency band. Whether in noncontiguous or contiguous spectrum aggregation, the CCs share identical propagation characteristics, including fading, path loss, and shadowing effects. This resource allocation strategy

facilitates significant multi-user diversity gains. However, it necessitates that the scheduler possesses precise knowledge of the users' current Channel State Information (CSI) prior to transmission. Extracting this information from the received signal proves ineffective when fading and interference result in disparate uplink and downlink channel statistics. Consequently, to address these asymmetric channels, it is essential to obtain CSI from users through feedback mechanisms. In addition to transmission errors, inaccuracies arising from the measurement and quantization of CSI on the user side, as well as the inherent feedback delay, contribute to the overall error. High feedback delay values can lead to incorrect modulation decisions at the transmitter during uplink transmission. These three factors create a discrepancy between the observed and actual CSI, which can considerably impair the performance of the scheduler. Given that feedback delay often establishes the upper limit on achievable data rates in various mobile scenarios, our current focus is primarily on this particular impairment.
To determine the deployment scenario that meets the established Quality of Service (QoS) criteria for both the Scheduling with Resource Utilization Strategy (SRUS) and the Joint User Scheduling (JUS) schemes, we analyze various feedback channel delays alongside the average user throughput across different numbers of LTE-A users per sector. Figures 2 and 3 illustrate the impact of feedback channel delay on average user throughput, revealing a pronounced decline in performance as the delay increases. Specifically, the average user throughput decreases by approximately 21% for SRUS and 17% for JUS when the feedback channel delay rises from 3 ms to 6 ms. Furthermore, Figure 3 indicates that JUS consistently outperforms SRUS in terms of average user throughput across varying feedback channel delays.

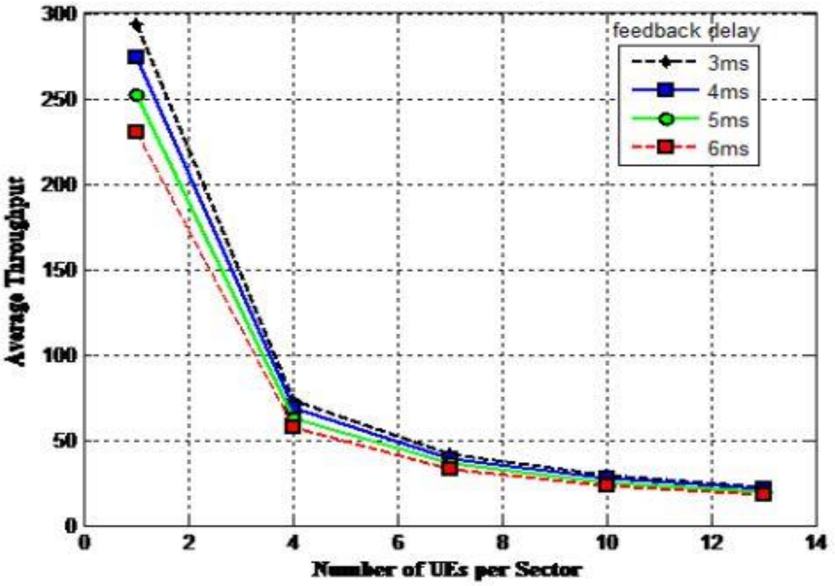

Figure 2: Average throughput per user (SRUS)

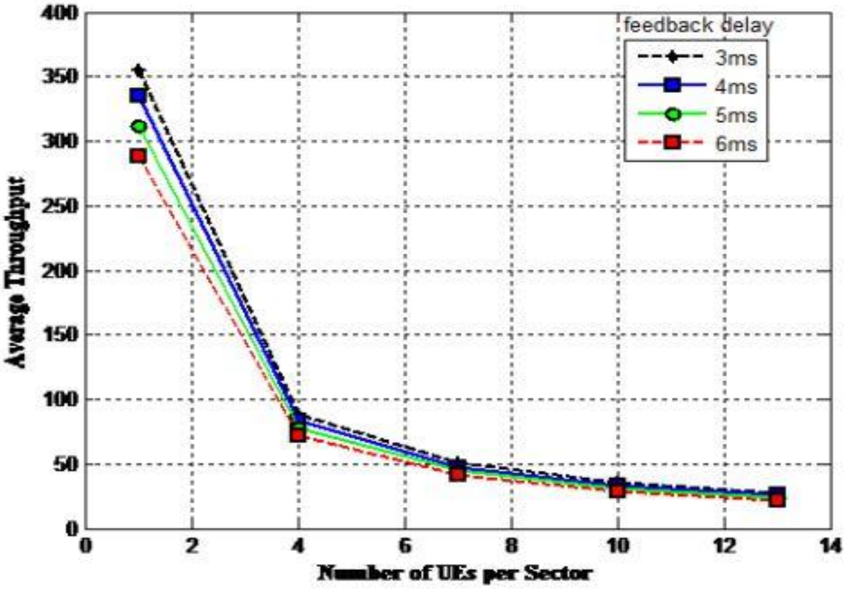

Figure 3: Average throughput per user (JUS)

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A common scenario in diverse coverage deployment involves the co-location of eNB antennas that utilize identical beam direction patterns across the component carriers (CCs), thereby offering similar coverage levels for all CCs, which operate on two distinct 3GPP frequency bands. The selected CCs exhibit varying propagation characteristics, leading to a situation where the coverage for higher frequency CCs may be less extensive than that of their lower frequency counterparts. Consequently, this results in an increased traffic load on the lower frequency CCs, which tend to deliver superior channel quality. As illustrated in Figures 4 and 5, the reduction in average user throughput associated with an increase in feedback channel delay is relatively minor. Specifically, the decline in average user throughput when feedback channel delay rises from a practical 3 ms to 6 ms is approximately 18% for the SRUS and 13% for the JUS. Figure 5 further demonstrates a significant enhancement in average user throughput with the JUS scheme across varying feedback channel delays, indicating that JUS outperforms SRUS. These findings suggest that the JUS scheme exhibits superior performance compared to the SRUS scheme within the context of diverse coverage deployment scenarios.

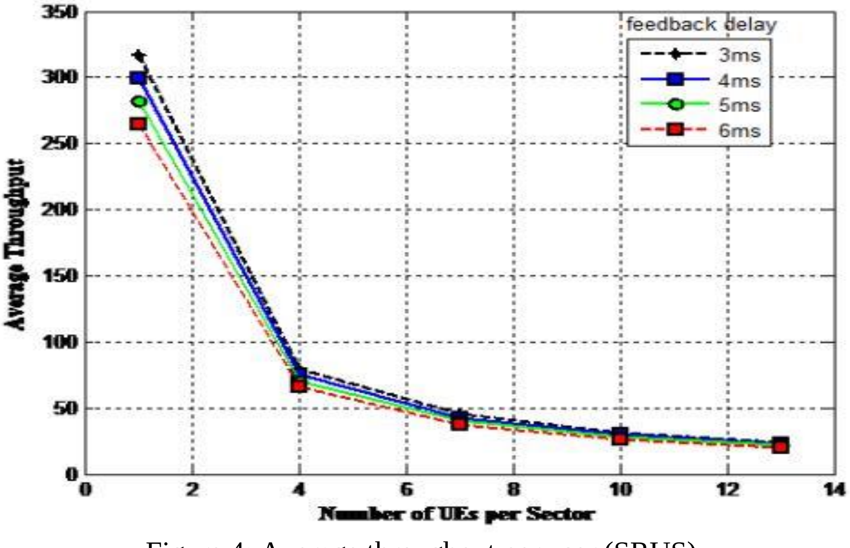

Figure 4: Average throughput per user (SRUS)

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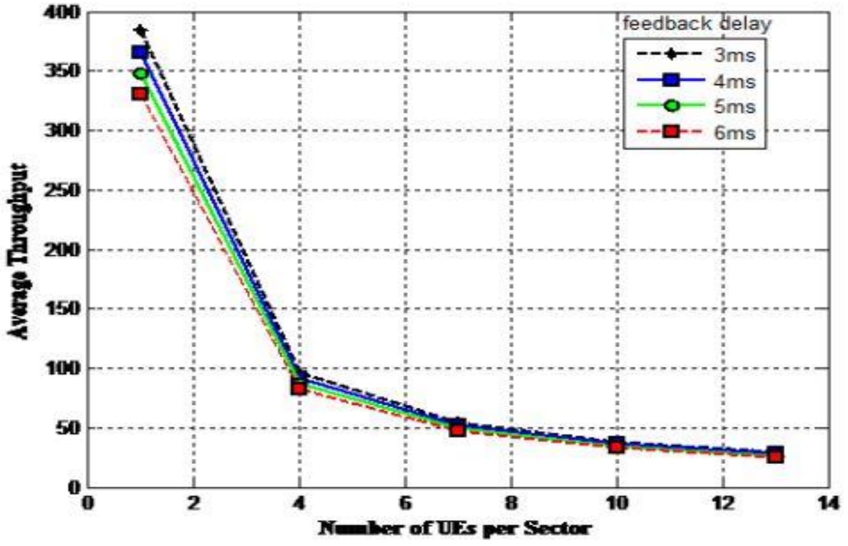

Figure 5: Average throughput per user (JUS)

Our analysis revealed that the diverse coverage deployment scenario exhibited superior performance compared to the main beam directed at the sector boundary deployment scenario. Moreover, this scenario facilitated a marked increase in average user throughput, which can be attributed to enhanced channel quality in both JUS and SRUS. This situation typically arises when the CCs are either operating on different bands or the same band. Notably, the decline in performance for the diverse coverage deployment scenario due to feedback channel delay was considerably less than that observed in the main beam directed at the sector boundary deployment scenario. Likewise, diverse coverage is identified as the optimal selection for both scheduling schemes.

4. Investigation Of User Scheduling Schemes

Notably, LTE-A is designed to facilitate high-speed data transmission and voice support in conjunction with multimedia broadcast services. The scheduler located in the MAC Layer of the eNode-B endeavors to create an optimal allocation of resources, targeting specific objectives such as:

- The empirical assessment of Quality of Service (QoS) for various applications..
- An optimal spectral operation aimed at ensuring elevated cell throughput in accordance with the prevailing channel conditions.
- Equitable treatment of User Equipments (UEs).
- Mitigating interference impacts through targeted management of users situated at the cell edges.
- The distribution and reallocation of load across different cells.

The six downlink channels include the Physical Multicast Channel (PMCH), Physical Downlink Shared Channel (PDSCH), Physical Hybrid ARQ Indicator Channel (PHICH), Physical Downlink Control Channel (PDCCH), Physical Control Format Indicator Channel (PFCICH), and Physical Broadcast Channel (PBCH). This research primarily concentrates on the PDSCH channel [7], which serves as the sole dedicated traffic channel for downlink communication in LTE-A. It is designed to utilize various MIMO techniques, including transmit diversity and beamforming, to improve data rates and throughput, alongside spatial multiplexing. The subsequent information is presented with a particular emphasis on the scheduler, based on the allocation of downlink resources [8].

- The Channel Quality Indicator (CQI) provides information from User Equipments (UEs) regarding the assessment of channel quality.
- Quality of Service (QoS) evaluates the Evolved Packet System (EPS) bearer associated with the User Equipment (UE). This information is accessible within the eNode-B through the downlink data stream.

The throughput experienced by any User Equipment (UE) is expected to vary significantly due to factors such as the scheduling algorithm employed, the speed of the UE, the use of multiple antenna techniques, the multipath propagation environment, and the distance from the eNode-B. This research employs system-level simulations of LTE-Advanced (LTE-A) to assess the effects of different transmission modes throughout the operational and

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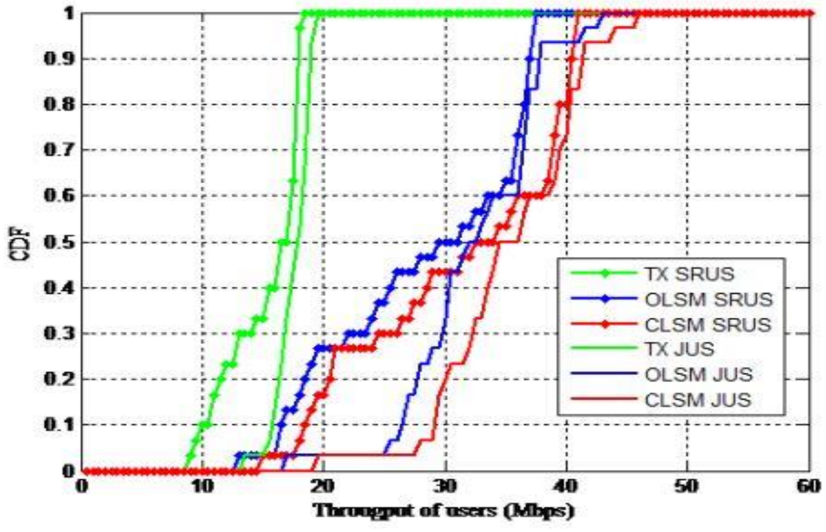
scheduling processes. Additionally, various Multiple Input Multiple Output (MIMO) transmission techniques are implemented to achieve data rate optimization in accordance with LTE-A standards. A key focus of this study is the operational techniques of Transmit Diversity (TxD), Closed Loop Spatial Multiplexing (CLSM), and Open Loop Spatial Multiplexing (OLSM), particularly in relation to their performance when used with Separate Random User Scheduling (SRUS) and Joint User Scheduling (JUS) within an LTE-A framework that incorporates carrier aggregation.

5. Simulation Results and Analysis

To assess the impact of CCs scheduling schemes on system fairness among users, it is crucial to analyze the distribution of user throughput. Figure 6 illustrates the cumulative distribution function (CDF) of user throughput, based on the scenario of 16 user equipment (UEs) per eNodeB, utilizing two component carriers (CCs) with a bandwidth of 20 MHz within the 2 GHz 3GPP frequency band. The traffic model employed in this investigation is a Continuous Data Stream (Full Buffer). It is evident that closed-loop spatial multiplexing offers a more favorable balance between throughput and fairness when compared to open-loop spatial multiplexing and transmit diversity. Under certain conditions, users can achieve higher bit rates exceeding 7 Mbps and 20 Mbps when closed-loop spatial multiplexing is utilized, in contrast to the performance observed with open-loop spatial multiplexing and transmit diversity, respectively. The JUS scheme effectively enhances both system fairness and average user throughput.



. Figure 6 :The CDF of user's throughput

Figure 7 illustrates the transmission modes utilizing SRUS, highlighting the average cell throughputs for open-loop spatial multiplexing and closed-loop spatial multiplexing, which are approximately 41.3% and 45.16% greater than those achieved with transmit diversity. The enhanced throughput of closed-loop spatial multiplexing can be attributed to the availability of comprehensive feedback information. In contrast, the transmission modes employing JUS demonstrate average cell throughputs that exceed those of SRUS by approximately 17.14% and 20.51%. This signifies a substantial improvement in average user throughput when utilizing the JUS scheme. Under conditions of heavy traffic, JUS exhibits superior performance compared to SRUS. Furthermore, the majority of LTE-Advanced user equipment tends to access data from the first component carrier (CC) more frequently than from the second CC. The JUS scheme effectively mitigates the issues associated with unstable traffic loads that may arise when employing the SRUS scheme. Consequently, it can be concluded that the performance of the JUS scheme surpasses that of the SRUS scheme across various transmission modes.

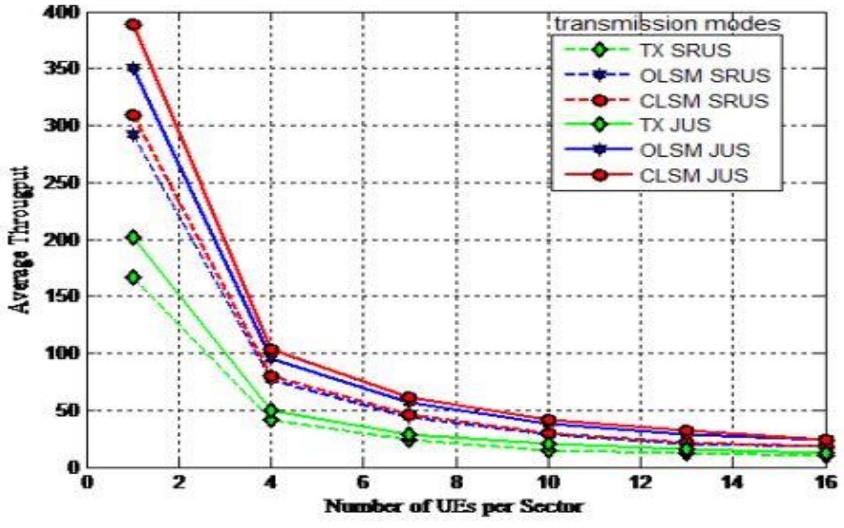


Figure 7 :Average throughput per user

In scenarios where the serving queues of a Radio Station (RS) are empty within the Single Radio Access Network (SRUS), all the Component Carriers (CC) associated with that RS will remain inactive, regardless of the operational status of CCs in other RSs that continue to function effectively. This situation indicates that the traffic distribution across the CCs can become unstable under SRUS. Conversely, the Joint User Scheduling (JUS) scheme demonstrates superior operational efficiency; however, it necessitates the use of LTE-Advanced user equipment along with multiple CCs that must be properly configured. This requirement introduces additional control signaling in advance, leading to potential power inefficiencies in user equipment. Nevertheless, research has shown that JUS consistently achieves significantly higher throughput and average user throughput across various transmission modes when compared to SRUS. JUS is thus identified as the optimal solution for Continuous Link Scheduling Mode (CLSM), Opportunistic Link Scheduling Mode (OLSM), and Transmit Diversity (TxD), providing enhanced overall throughput and average user throughput relative to SRUS.

6. SRUS Scheduler Based on CQI

6.1. Problem Formulation and Justification

In LTE-A, the implementation of solely opportunistic algorithms for resource allocation does not ensure the desired levels of fairness and optimal resource utilization. The analysis of the JUS and SRUS algorithms in previous sections reveals a persistent lack of equilibrium between fairness and throughput efficiency.
Moreover, an effective scheduling system is evaluated based on its objectivity in the allocation of resources among diverse users. The system's advantageous calculations encompass throughput alongside spectral cost and overall effectiveness. Conversely, fairness is assessed based on the ability to meet delay constraints and the varying data rates of users. Consequently, the two primary objectives of any scheduling algorithm are:

- Leverage the benefits of technique and the rapidity of execution by allocating resources to the most appropriate users.
- Guarantee that all users receive equitable treatment without bias or discrimination. However, these two goals are inherently conflicting, posing a risk of achieving one at the expense of the other. Consequently, the scheduler must strive to maintain a balance between operational efficiency and equitable distribution.

When the Joint User Scheduling (JUS) algorithm is implemented, the eNodeB is tasked with assessing the throughput of users across all component carriers. Nevertheless, the complexity associated with this method escalates significantly when managing a large number of users and component carriers simultaneously. In contrast, if a Separated Random User Scheduling (SRUS) approach is adopted, the eNodeB only evaluates user throughput within a single component carrier, thereby reducing the complexity compared to the JUS algorithm. From our viewpoint, the existing research on resource scheduling in carrier aggregation lacks depth. The author introduces novel proportional fair algorithms that emphasize user grouping in reference [9]. Additionally, the author develops another resource scheduling algorithm for the uplink in the LTE-Advanced system, as noted in references [10, 11]. This algorithm has the potential to enhance both the average sector throughput and the throughput for cell-edge users, while also considering the power constraints of user equipment. However, it is important to note that this technique has not been applied in the downlink scenario with carrier aggregation, as indicated in reference [11].

Consequently, the problem can be articulated as follows: How can we enhance the fairness of opportunistic schedulers while simultaneously ensuring high bitrate efficiency? This approach emphasizes the development of scheduling algorithms aimed at increasing user throughput and improving overall system fairness. To realize this objective, it is proposed to refine the Proportional Fair (PF) algorithm by incorporating the concepts of the Systematic Resource Utilization Strategy (SRUS), thereby enhancing system fairness without significantly increasing complexity. This research specifically aims to provide an effective solution for scheduling and resource allocation among multiple users in Long-Term Evolution Advanced (LTE-A) networks. Simulation results indicate that the proposed algorithm successfully achieves greater fairness among users while also improving average throughput compared to the SRUS algorithm.

6.2. Proposed SRUS Scheduler Based on Measuring CQI Efficiency

The Proportional Fair (PF) scheduling algorithm operates effectively under conditions where users experience homogeneous channel environments. However, when there are fluctuations in the channel or when users traverse diverse channel conditions, the PF scheduling algorithm tends to provide limited fairness among users. This issue can be addressed by implementing a new scheduling algorithm on the SRUS platform. The resource block (RB) allocation process will determine the quantity of RBs assigned to each user based on the current channel conditions and the average rate achieved by the user. Consequently, the scheduler functions as follows:

The effective channel quality indicator (CQI) can be linked to a specific modulation and coding scheme (MCS) assigned to the user. The efficiency rate represents the user’s bit rate when all RBs are allocated to that user, while the average throughput for the i-th component carrier (CC) is denoted as the user's average throughput. Additionally, the estimated throughput for user k at the m-th physical resource block (PRB) group of the i-th CC during time slot t can be calculated, allowing for the determination of the number of RBs to allocate to user k.

6.3. Simulation Parameters

A downlink utilizing the OFDM framework of a Carrier Aggregation (CA) system is examined. This system comprises a series of evolved Node B (eNB) units serving 21 User Equipments (UEs), with each sector accommodating 7 UEs. The UEs are uniformly distributed throughout the cell. Each Component Carrier (CC) consists of N resource blocks, each containing K subcarriers in the frequency domain, along with a time-domain frame. The Proportional Fair (PF) scheduling algorithm is implemented, and Adaptive Modulation with Coding (AMC) is employed during transmission to achieve elevated data rates. The UEs are equipped to assess the downlink transmission through Channel Quality Information (CQI) and relay their feedback to the eNB. Simulation results indicate the identification of two component carriers for aggregation. All CCs are configured to transmit with equivalent power levels. In terms of PF scheduling, the average window length T is set at 1000. The primary parameters utilized in the simulation are consistent with those presented in Table 1.

Simulation Metrics

In this study, a variety of metrics are employed to assess the simulation results. Emphasis is placed on evaluating the performance of schedulers based on average throughput per user, fairness, and cumulative distribution function (CDF), among other factors, during the quality of service (QoS) assessment. The performance metrics under consideration are delineated as follows:

- ***Average Throughput per User:*** The LTE-A downlink system level simulator facilitates a straightforward calculation of throughput. To evaluate the performance of the schedulers, the average throughput is analyzed, which is quantified in megabits per second (Mbit/s).

- ***Fairness Index:*** To derive a metric that reflects the level of fairness, we employ Jain's fairness index methodology [13], as illustrated in equation (2).

The term ***"aggregate throughput"*** refers to the total data transmission capacity, while "n" denotes the number of users involved. The equation presented above serves to assess the fairness tradeoff among users, illustrating both the variability in the rates achieved by individual users and the overall average rate.
The Cumulative Distribution Function (CDF) serves as a metric designed to quantify the percentage of the achievable bit rate for the average user. This approach facilitates a more nuanced exchange between throughput and fairness, thereby illustrating the variability in the rates achieved by users as represented by the average value.

6.4. Simulation Results and Analysis

This section assesses the efficacy of the proposed PF scheduling algorithm grounded in SRUS. Figure 8 illustrates a comparison of the proposed scheduler's performance with that of traditional SRUS and JUS, utilizing the fairness index derived from the average bit rate achieved by users. Fairness in network resource allocation is a critical metric, as it ensures that users facing suboptimal channel conditions receive a minimum level of performance.
The equation (2) serves to assess the fairness tradeoff among users, illustrating both the variation in the achieved rate and the average value for each user. Figure 8 presents a comparative analysis of the fairness index across SRUS, JUS, and SRUS-CQI, providing a succinct representation of the superior fairness offered by these methods. The simulation outcomes demonstrate that the proposed algorithm significantly enhances user throughput while simultaneously improving system fairness. Specifically, the SRUS-CQI method exhibited a 40% increase in the fairness index relative to SRUS and an 8.89% increase compared to JUS. Furthermore, the cell throughput for SRUS-CQI rose by 25% in comparison to SRUS and by 8.75% when juxtaposed with JUS. It is noteworthy that both SRUS and JUS tend to marginalize users located at the cell boundary. In terms of cell throughput, as illustrated in Figure 9, SRUSCQI outperformed both SRUS and JUS.

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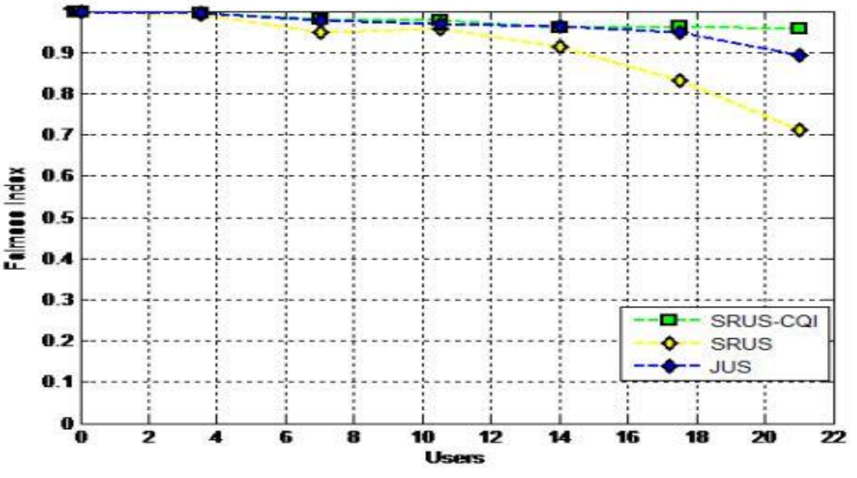

Figure 8:Fairness index comparison

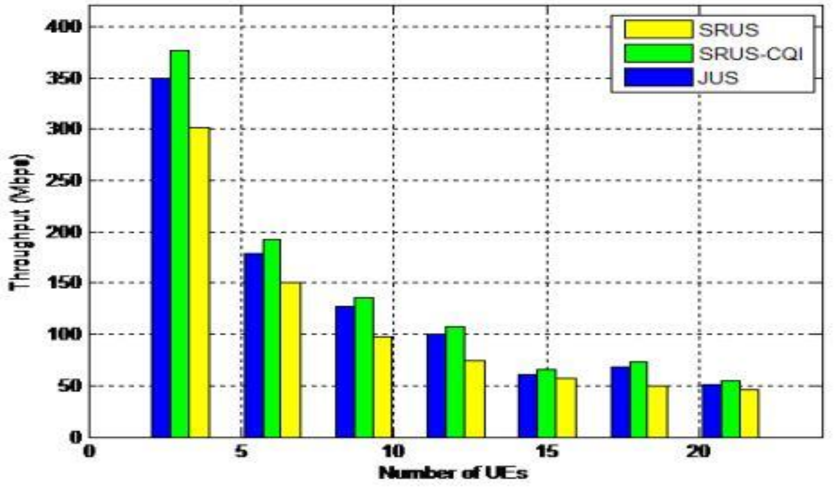

Figure 9: User’s throughput comparison

To facilitate a comparison of the performance of the proposed scheduler, we illustrate in Figure 10 the average user's Cumulative Distribution Function (CDF) for achievable bit rates.
This representation allows for a more nuanced evaluation of the trade-off between throughput and fairness, highlighting the variation in rates achieved by users as reflected in the average value.

Figure 10 clearly indicates that the SRUS-CQI offers a more favorable trade-off when assessing throughput against fairness in comparison to both SRUS and JUS. Under certain conditions, users utilizing SRUS-CQI can achieve bit rates exceeding 5 Mbps and 3 Mbps, respectively, when compared to SRUS and JUS. Conversely, users employing SRUS and JUS may experience starvation, particularly at the cell boundary, with approximately 50% of users in the cell attaining bit rates below 38 Mbps. Therefore, SRUS-CQI demonstrates effective control over the resource allocation process, which enhances fairness among users. Furthermore, the scheduling mechanisms of SRUS and JUS are significantly influenced by the instantaneous bit rate, which contributes to a substantial loss of fairness.

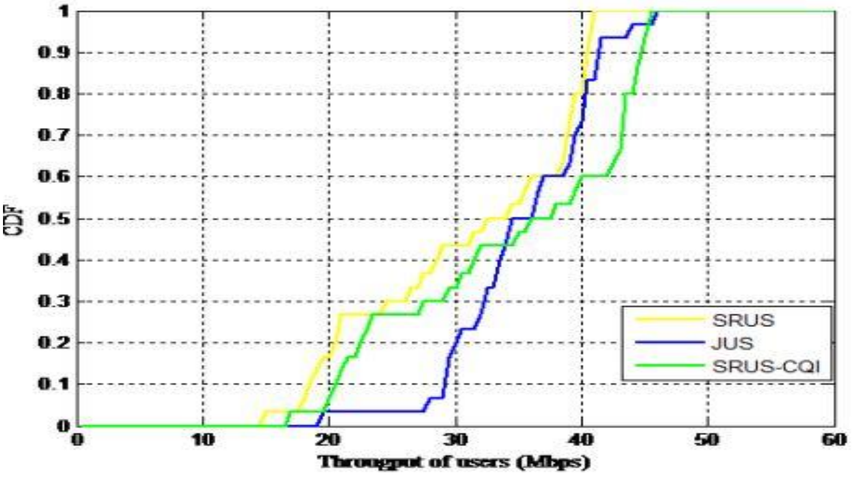

Figure 10 :The CDF of user's throughput

The findings indicate that the SRUS-CQI effectively allocates resources to users based on their assigned needs. This mechanism allows the SRUS-CQI to exercise enhanced control over the resource allocation process, which may contribute to improved fairness among users. Furthermore, the scheduling rules of SRUS and JUS are significantly affected by the current bit rate, which provides a clearer understanding of the substantial fairness deficits.

Moreover, when compared to SRUS and JUS, the SRUS-CQI exhibits fewer complications in its implementation.

7. Conclusions

In conclusion, the effects of Continuous Quality Improvement (CQI) feedback delay on two scheduling schemes, namely SRUS and JUS, within the context of an LTE Advanced system utilizing carrier aggregation. An initial investigation focused on specific scenarios of carrier aggregation in actual LTE Advanced deployments to evaluate the extent of performance degradation attributable to delays in the feedback channel. The findings indicate that the diverse coverage deployment scenario exhibits greater accuracy and less variance compared to the main beam directed at the sector boundary deployment scenario. Furthermore, the diverse coverage deployment scenario demonstrates reduced performance degradation due to feedback channel delays when contrasted with the main beam directed at the sector boundary. Consequently, diverse coverage emerges as the superior option for both scheduling schemes, yielding higher overall throughput and enhanced average user throughput relative to scenarios where beams are directed at sector boundaries.

Additionally, the performance of the JUS and SRUS scheduling methods was analyzed under three distinct downlink transmission modes in LTE-A. The Closed Loop Spatial Multiplexing (CLSM) mode was found to deliver superior performance across various user equipment (UE) locations within the cell. It was also observed that JUS frequently outperforms SRUS in terms of throughput and average user throughput across different transmission modes. Thus, JUS is identified as the optimal choice for CLSM, Open Loop Spatial Multiplexing (OLSM), and Transmit Diversity (TxD), providing higher overall throughput and average user throughput compared to SRUS.

This paper also introduces a novel resource scheduling scheme for the LTE-A downlink system. The proposed scheduler aims to strike a balance between capacity and fairness, employing a straightforward approach whereby the Adaptive Modulation and

Coding (AMC) strategy is adjusted immediately following the resource block (RB) assignment process. The scheduler allocates RBs to users based on a utility function that considers both the average bit rate and the instantaneous requirements of the users. Notably, the performance of SRUS-CQI surpasses that of SRUS.

8. Acknowledgment

More research still can be done in the LTE-A downlink scheduling because it is a very interesting field. The authors would like to thank Universiti Kebangsaan Malaysia(UKM) to overcome numerous obstacles and would like to display gratitude to staff members of wireless lab for providing the simulation.

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