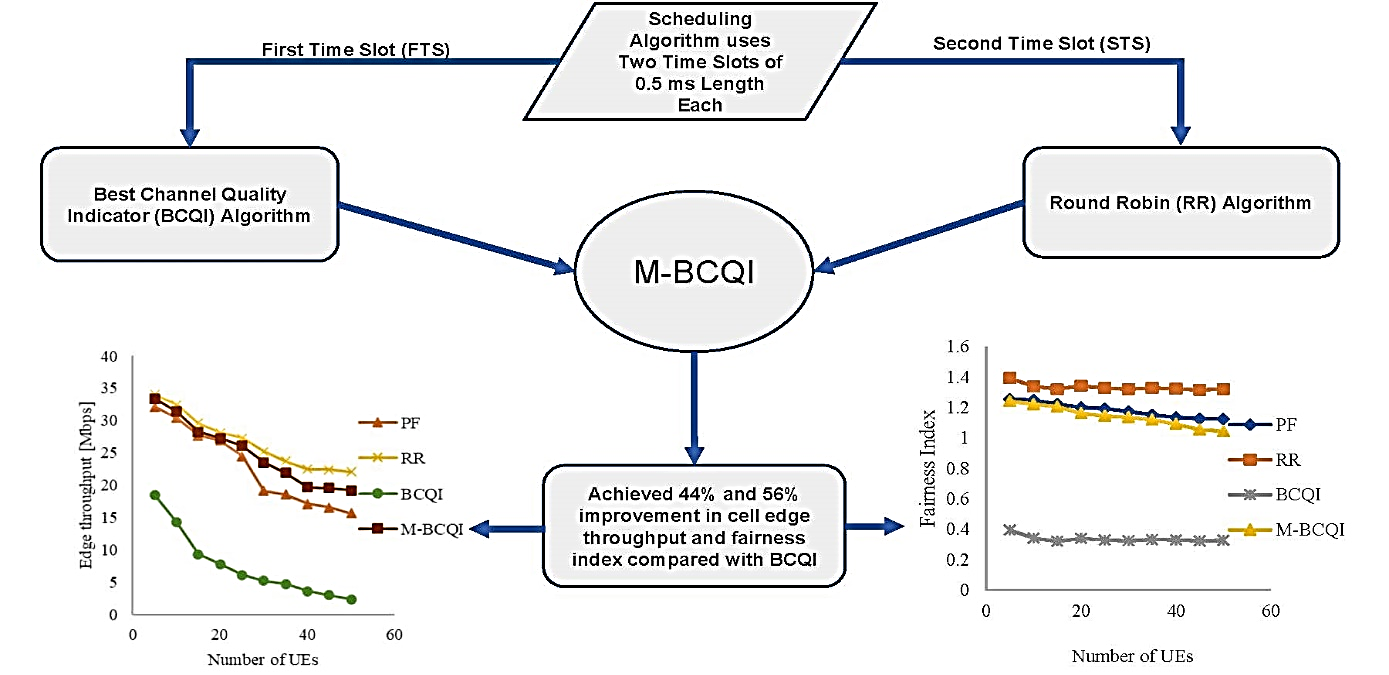
**Modified Best Channel Quality Indicator Scheduler for Heterogeneous LTE-A Network**

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| **الملخص:** هذا البحث يقترح جدولة معدلة لمؤشر جودة القناة الأفضل على المدى الطويل (M-BCQI) في نظام تطور طويل الأجل المتقدم (LTE-A) لتحسين أداء الإنتاجية على أطراف الخلية. تستخدم خوارزمية الجدولة فترتين زمنيتين، مدة كل منهما 0.5 مللي ثانية. الفترة الزمنية الأولى (FTS) تستخدم خوارزمية مؤشر جودة القناة الأفضل (BCQI) مع آلية تخصيص كتلة الموارد (RB) التي تركز على مؤشر جودة القناة، بينما تستخدم الفترة الزمنية الثانية (STS) خوارزمية روبن (RR) لتخصيص كتلة الموارد. تم استخدام محاكِ محاكاة مستوى نظام فيينا LTE لتقييم خوارزمية الجدولة المقترحة. أظهرت النتائج التي تم الحصول عليها تحسنًا ملحوظًا، حيث أشارت إلى تفوق بنسبة 44% في أداء أطراف الخلية وتحسن بنسبة 56% في مؤشر العدالة مقارنة بـ BCQI. ومع ذلك، فإن M-BCQI حقق أداء أقل بنسبة 4.2% في الإنتاجية المتوسطة مقارنة بـ BCQI وبنسبة 7% في مؤشر العدالة مقارنة بـ RR. | **ABSTRACT:**  In this paper, a Long-Term Evolution-Advanced (LTE-A) Modified Best Channel Quality Indicator (M-BCQI) Scheduler is proposed for enhanced cell edge throughput performance. The scheduling algorithm utilizes two time slots, each of 0.5 ms in length, with the First Time Slot (FTS) implemented with the Best Channel Quality Indicator (BCQI) algorithm has a CQI-focused Resource Block (RB) allocation mechanism, while the Robin (RR) algorithm is the mechanism used in the Second Time Slot (STS) for RB allocation. Vienna LTE system level simulator was used for the proposed scheduling algorithm assessment. The results obtained showed significant improvement, indicating 44% superior cell edge performance and 56 % better fairness index in comparison to BCQI. However, M-BCQI slightly underperformed by 4.2% in terms of average throughput in comparison to BCQI and by 7% in comparison to RR in terms of fairness index. |

***Keywords:*** Best Channel Quality Indicator (BCQI); Resource Block; Round Robin (RR); Scheduling algorithm; Throughput.

**الكلمات المفتاحية:** أفضل مؤشر لجودة القناة (BCQI)؛ كتلة الموارد؛ الدوران المستدير (RR)؛ خوارزمية الجدولة؛ الإنتاجية.

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INTRODUCTION

The quest for improved technology in the telecommunication sector has grown astronomically, thereby eliciting the need for massive innovation, especially in wireless telecommunication standards, to enhance users’ experience and meet increasing demand. Over the years, the telecommunication group Third Generation Partnership Project (3GPP) has become a reference point in the introduction of new mobile communication standards with their annual releases (Freescale, 2008). In 2008, 3GPP Release 8 saw the introduction of the Fourth Generation and Long-Term Evolution (4G/LTE) standard comprising two subnetworks, namely: Evolved Universal Terrestrial Radio Access Network (E-UTRAN) and Evolved Packet Core (EPC) (Dahlman *et al.*, 2011). E-UTRAN interfaces between the Evolved Node Base Station (eNodeB) and the user equipment (UE) through the use of Orthogonal Frequency Division Multiple Access (OFDMA), which allows for high-speed data connection with low latency at the downlink. OFDMA is an offshoot of Orthogonal Frequency Division Multiplexing (OFDM) with its characteristic data transmission on a large number of closely spaced orthogonal subcarriers, forming several streams or channels (Uyan and Gungor, 2019).

The core reason given for the adoption of OFDM in LTE/LTE-Advanced systems, as reported by Carpin *et al.* (2015), is its adaptive flexibility in both the time domain and frequency domain. In the time domain, a frame usually made up of a 10 ms radio resource unit is further divided into ten subframes, each being 1 ms long. In the frequency domain, multiple subcarriers, each having 15 kHz bandwidth, are utilized. As highlighted in the case of the time domain, half a subframe (of 0.5 ms length) and 12 subcarriers from the frequency domain form a Resource Block (RB). As defined by Agrawal *et al.* (2015), Ameigeiras *et al.* (2016) and Elshennawy (2019), the time duration required for RBs to be allocated to users every 1 ms is referred to as Transmission Time Interval (TTI), while the resource allocation process is termed scheduling. Under 3GPP Release 8 specifications, Angri *et al.* (2018) noted that scheduling decisions are implemented on the Media Access Control (MAC) layer with the help of a suitable scheduling algorithm.

Despite multiple releases following Release 8 by 3GPP, Uyan and Gungor (2019) stated that no standard definition has been given for scheduling in LTE systems, allowing room for service providers to implement choice scheduling algorithms among various schedulers available to meet the real-time needs of their subscribers. This liberty to choose scheduling algorithms according to demand has been an inspiration for researchers, network design engineers, mobile network firms and operators to come up with schedulers tailored to suit different needs. According to Krishnamoorthy *et al.* (2019), due diligence is usually done when formulating a scheduler, especially because the overall system performance depends largely on it.

Long Term Evolution (LTE) Release 10 (also referred to as LTE-Advanced) was concluded at the end of 2011 by the Third Generation Partnership Project (3GPP) to be adopted among the International Mobile Telecommunication-Advanced (IMT-Advanced) viable candidates (ElNasjar *et al.*, 2014). Presently, LTE Releases 12 and 13, which are improvements of the preceding finalized LTE Release 10 and 11 specifications, are being fine-tuned to deliver more robust features and performance in comparison to previous releases. Part of the recommendations by 3GPP stipulates LTE-Advanced to be compatible with the transmission of bandwidths up to 100 MHz while also increasing the capacity of the user equipment (UE) in the process of signal transmission and reception (Ismail *et al.*, 2016).

In this paper, the main drawback associated with the BCQI scheduler is examined in detail. A modified Best Channel Quality Indicator (M-BCQI) scheduler is proposed to enhance users’ experience at the cell edge since they are mostly marginalized in resource allocation. The marginalization in resource allocation is due to the poor channel condition notorious of cell edge users as a result of their far location from the eNodeB (base station). Aside from the challenge of distance, other reasons for the exacerbated poor channel quality include obstacles along the UE path resulting in multipath fading and dynamic change of position by UEs. To adequately correct the cell-edge anomaly of BCQI, both static and mobile users’ scenarios are considered in the simulation of the proposed algorithm.

The remainder of this paper is organized as follows. Section 2 presents the review of related literature. The M-BCQI algorithm is explained in detail in Section 3. Performance assessments are presented in Section 4. Finally, the paper is concluded in Section 5.

REVIEW OF RELATED LITERATURE

Every scheduler in a telecommunication system is typically formulated with a trade-off in mind between throughput and fairness. Throughput and fairness represent the two metric extremes in scheduling decisions as captured by BCQI and RR schedulers. Asvial *et al*. (2015) stated that while BCQI allocates RBs based on user with the highest Channel Quality Index (CQI), giving rise to high overall system throughput but poor fairness performance, RR, on the other hand, is channel-blind in that channel quality is not considered and RBs are allocated based on traffic arrival requests thereby resulting in near perfect system fairness with poor overall throughput. A popular scheduling algorithm known as the Proportional Fairness (PF) scheduler was designed with the aim of achieving a balance between the two extremes of throughput and fairness (Khawam, 2006).

However, given the uniqueness of every environment under which network services are deployed, a number of modifications to BCQI, RR and PF have been put forward by different authors to suit the needs of different service providers around the globe. Krishnamoorthy *et al.* (2019) proposed an enhanced BCQI scheduler that prioritizes VoIP traffic by modifying the traffic model used, leading to better VoIP throughput in comparison to BCQI, but fairness was poor. Asvial *et al.* (2015) proposed a scheduler based on modified RR and BCQI scheduling methods for 3GPP LTE downlink. The author realized better throughput than RR and slightly better delay performance than BCQI due to the double decision involving CQI and RB size comparison in the second slot. Elshennawy (2020) proposed a Quadratic Proportional Fair (QPF) scheduler that utilized Root Mean Square (RMS) for the determination of average throughput. QPF proposed by the author performed better than PF in terms of average throughput, spectral efficiency and energy per bit at different mobility speeds, but it underperformed in terms of throughput in comparison to the BCQI algorithm.

MODIFIED BEST CHANNEL QUALITY INDICATOR (M-BCQI)

Ismail *et al.* (2016) reported that RR, BCQI and PF are the most popular schedulers in LTE-A systems, with PF representing a trade-off between throughput and fairness. The proposed scheduler is a variant of BCQI that uses two-time slots for its scheduling. The principle of this new algorithm is that it combines the strength of BCQI and RR schedulers. For each subframe in the First Time Slot (FTS), RBs are allocated to the user with the highest CQI based on the BCQI algorithm, while RR is applied to each subframe in the second time slot (STS) for RB allocation. Considering FTS, in an instance when multiple users emerge with the highest CQI, the scheduler picks the user based on the priority rank in each TTI. The flowchart of the M-BCQI scheduler is presented in Figure 1.

The aim of this M-BCQI algorithm is to find a suitable balance for users with good channel quality located close to the eNodeB and those with moderate-to-bad channel quality at the cell edge. For FTS, the expression for the M-BCQI algorithm proposed is derived by dividing the size of the packet, P, with the highest achievable throughput by the user at any instant, Then, the average throughput values are aggregated, as illustrated in Equations 1 and 2.

(1)

(2)

where It is the instantaneous throughput computed for each user, and N is the number of average throughput values.

For STS, on the other hand, Quality of Service (QoS) fairness is prioritised irrespective of channel condition to ensure that every user is allocated equal radio resources at equal times. As highlighted by Uyan and Gungor (2019), the metric used for accessing this resource allocation is defined such that when a packet is successfully delivered, it is then incremented by 1. Otherwise, it is incremented by a factor constituted by dividing the amount of transmitted data by the packet size, as given in Equation 3.

(3)

where Is the fairness value for the user in the TTI, Is the number of remnant data bits at the end of the requested delay, It is the number of successful data bits transmitted, and P is the size of the transmitted packet.

When Have been computed for each user, its average is deduced by dividing the sum by the number of users, Within the cell coverage area, as illustrated in Equations 4 and 5. This deduced average is referred to as the eventual fairness, F.

(4)

(5)

RESULTS AND PERFORMANCE ASSESSMENT

The simulation parameters for the proposed scheduler are outlined in Table 1. The simulator adopted for the scheduler assessment is the Vienna system-level simulator, which is a MATLAB-based simulator.

Throughput

Figure 2 gives the comparative distinction in walking speed (3 km/hr) of the average UE throughput between the proposed scheduler (Modified BCQI), BCQI, PF and RR on a 1 km radius of coverage by the eNodeB. A 4.2% marginal difference in average UE throughput is observed between the proposed scheduler and the base BCQI that was modified. Figures 3 and 4 show the average UE throughput at 60 km/hr and 120 km/hr, respectively.



**Figure. 1.** Flowchart of the proposed M-BCQI scheduler.

**Figure. 2.** Comparison of UE throughput at 3 km/hr.

**Figure. 3.** Comparison of UE throughput at 60 km/hr.

**Table 1**. Simulation parameters.

|  |  |
| --- | --- |
| Parameter | Value |
| Carrier Frequency | 2 GHz |
| Bandwidth | 20 MHz |
| Duplexing | FDD |
| No. of transmitter | 2 |
| No. of receiver | 2 |
| Transmission mode | CLSM |
| eNodeB height | 20 |
| eNodeB antenna gain | 15 dB |
| eNodeB power | 45 dBm |
| Femto (cell) power | 30 dBm |
| TTI | 100 ms |
| Number of UEs per cell | 10 |
| Number of UE per eNodeB | 20 |
| Number of eNodeB | 1 |
| Number of cells | 1 |
| UE speed | 3 km/hr, 60 km/hr, 120 km/hr |
| Pathloss Model | TS 36.942, Free space |
| Simulation Environment | Urban, Rural |
| eNodeB antenna output | 49 dBm |
| Channel mode | Winner+ |
| Scheduler | M-BCQI, BCQI, PF, RR |

**Table 2**. Edge throughput comparison at different speeds.

|  |  |  |  |
| --- | --- | --- | --- |
| Scheduler | Speed  (3 km /hr) | Speed  (60 km/hr) | Speed  (120 km/hr) |
| RR (Mbps) | 34.07 | 27.52 | 11.39 |
| PF (Mbps) | 32.13 | 26.49 | 10.08 |
| BCQI (Mbps) | 18.53 | 8.85 | 3.71 |
| M-BCQI (Mbps) | 33.41 | 27.16 | 11.50 |

**Figure. 4.** Comparison of UE throughput at 120 km/hr.

**Figure. 5.** Throughput comparison of schedulers at the cell edge.

**Figure. 6.** Fairness index comparison at 3 km/hr.

**Figure. 7.** Fairness index comparison at 60 km/hr.

**Figure. 8.** Fairness index comparison at 120 km/hr.

In terms of cell edge throughput at 3 km/hr, as given in Figure 5, a 2.6% performance difference is observed between RR and M-BCQI and a 37 % improvement in comparison to BCQI.

Table 2 gives a summarized comparison of edge throughput at different UE speeds.

Fairness Index

A comparison of four schedulers is presented in this subsection. This was done to ascertain their individual performance with respect to the fairness index. This metric is measured at a specific time frame when the number of users competing for resource allocation is on the rise at the eNodeB, as illustrated in Figure 6. A moderate difference in fairness index is observed with speed variation, as illustrated in Figures 7 and 8, respectively.

Spectral Efficiency

One of the aims of this metric is to ascertain how well M-BCQI utilized the allocated spectrum (20 MHz). Considering that the proposed algorithm was formulated with the intention of finding a good balance between throughput and guaranteed fairness, the utilization of allocated spectrums’ RBs by the Modified BCQI, as illustrated in Figure 9, is seen to be better than the traditional BCQI and the RR scheduler, as these schedulers (BCQI and RR) represent the two imaginable location extremes in terms of cell centre and cell edge.

**Figure. 9.** Spectral efficiency vs number of UEs.

**Figure. 10.** Energy per bit comparison.

Energy per Bit

Figure 10 gives the energy per bit vs the number of UEs at a walking speed of 3 km/hr. From 10, it is evident that the proposed M-BCQI uses less energy in the transmission of each bit as compared to BCQI. Nonetheless, with an increasing number of UEs at the eNodeB, a decreasing trend in energy efficiency is noticeable mainly due to the extra energy required for switching between time slot one and time slot 2, which facilitates the implementation of different scheduling techniques (BCQI and RR) for received signal traffic.

CONCLUSION

In this paper, a modified BCQI scheduling algorithm has been proposed. The performance of the M-BCQI algorithm was assessed using network metrics such as energy per bit, fairness index, throughput and spectral efficiency. These metrics formed the basis for the comparison of the proposed scheduler characteristics with some existing downlink schedulers such as RR, PF and BCQI. The results of the comparison showed that the M-BCQI performed creditably well in terms of fairness, throughput, spectral efficiency and energy per bit ratio against the increasing number of UE at the eNodeB. The improvement in overall cell throughput, along with superior system fairness (over 56 % better performance) in comparison to the original BCQI, justifies that the proposed scheduler has met the outlined objectives of the research.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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