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Remote Radio Head Scheduling in LTE-Advanced Networks

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Abstract

LTE-A network offers data rates up to 1 Gbps which is 10×faster than LTE catering to growing demand of users. LTE improves user experience by reducing latency and increasing bandwidth efficiency. The emerging services and key enhancements such as Further Enhancement of Downlink Multiple-Input Multiple-Output (MIMO), Heterogeneous Networks, and Carrier Aggregation (CA) in LTE-A has improved performance of LTE-A networks. Scheduling optimization still remains one of the biggest challenges in high speed data transmission network. Scheduling in LTE-A networks are performed at various levels; User Equipment (UE), Serving Gateway (SGW), Air Interface and eNodeB. Remote Radio Head (RRH) is an extremely specialized device installed at antenna of eNodeB for optical to electrical signal conversion, amplification of signals and Uplink and Downlink Scheduling. Resource scheduling at Antenna of eNodeB module is constituted as a significant research optimization area. This paper proposes a soft computing based scheduler for RRH. Results of proposed technique are evaluated on Fairness Index, Throughput, Spectral Efficiency and Rank Indicator Distribution. The proposed algorithm aims to improve performance of scheduling. From experimental results, it is observed that proposed model succeeds to achieve significantly better performance as compared to state-of-art algorithms.

Keywords LTE-A · RRH · Scheduling · Proportional fair algorithm

1 Introduction

LTE (Long Term Evolution) was introduced in last decade with 100 Mbps maximum speed, which was 10×faster than existing 3G networks. LTE-A (Long Term Evolution–Advanced)) network offers 1 Gbps data rate which is 10×faster than LTE. LTE improves user experience through increases in bandwidth efficiency and reduced latency. The first LTE networks (3GPP release 8) were confined to maximum frequency of 20 MHz [1]. But LTE-A increased frequency to 100 MHz by combining frequency of 5 carriers. LTE-A not only allows user more spectrums, it does so more efficiently by increasing number of antenna paths. Various physical layer technologies; MIMO and OFDMA

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have increased its performance [2]. The support for multimedia applications; (i) Video Conferencing, (ii) Audio Conferencing, (iii) HD Video Streaming has made LTE-A most significant for users and service providers [3]. Goals, LTE-A was expected to achieve;(i) Increased Data Throughput, (ii) Decreased Latency, (iii) Improved Flexibility of Spectrum Allocation, (iv) Increased Reliability of Data Transmission and (v) Increase in Communication Efficiency. Data rate should be increased when require more speed over the internet [4]. Latency is basically time required to travel data from source to destination with processing time. Decreased latency means reducing time for data travel and processing. Increased or improved flexibility of spectrum allocation means that transmission of data should be reliable and reliable data transmission at cell edges. Increase in throughput is basically dependent on two parameters. Increase in Transport Block (TB) size which is possible if there is an increase in modulation depth. To increase modulation depth, use of high modulation techniques is very important. Much advancement is fabricate in mobiles and its Networks. A network may be owned by private or Government, that obeys to 4G standards. It uses time division duplex (TDD) and frequency division duplex (FDD) modes for mobile station (UE) to correspond with base station (eNodeB). Increase in throughput is also dependent upon an increase in carriers. Therefore it is stated that throughput is directly proportional to number of carriers. Flexible spectrum allocation is yet another significant means by which throughput can be increased. MIMO is another factor which helps increase throughput [5].

Figure 1 illustrate the architecture of LTE with three basic components of LTE (i) UE (User Equipment), (ii) eUTRAN and (iii) EPC.

1.1 UE Architecture

Operators are migrating to VoLTE because it is affordable and more versatile. With appearance of IoT, the number of connected devices is predicted to 28 Billion by 2021. Now in this context latency seem more significant than bandwidth. So, a faster backhaul is the need of hour. In LTE permittable delay range is 50 ms to 300 ms depending upon standard of service. The significant changes were existed in radio access, but in order to access radio a device needed. The mobile device is referred to as User Equipment (UE). The internal architecture for user equipment in LTE is identical to UMTS and GSM (mobile equipment). The mobile equipment comprises of following modules as shown in Fig. 2. Mobile Termination- Handling of all communication functions by module. Terminal Equipment- It terminates all data streams and basically it consists of an antenna. Universal Integrated

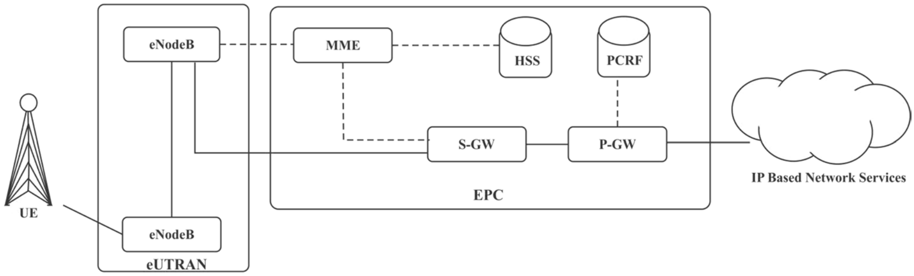


Fig. 1 Basic LTE architecture

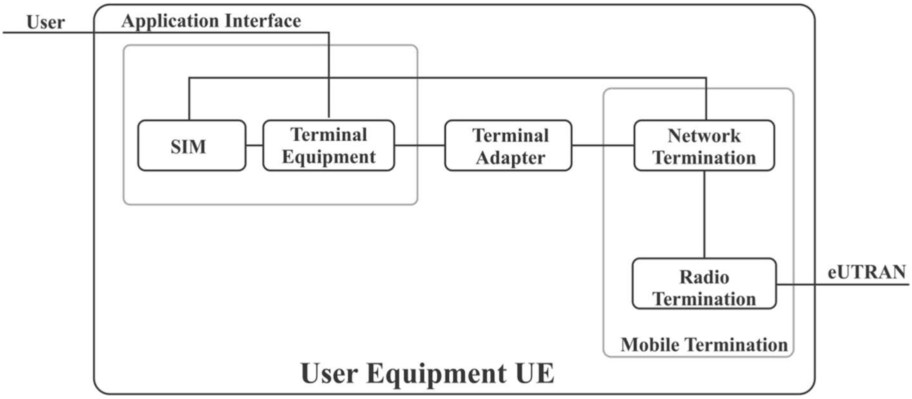


Fig. 2 Internal architecture of UE

Circuit Card- It as commonly known as SIM card. LTE, SIM card can either run an application called Universal Subscriber Identity Module (USIM).

In LTE, SIM card can run on an application named USIM. It also has ISIM (IP Multimedia Services Identity Module). ISIM carries significant information processed in SIP; (i) IMPI (IP Multimedia Private Identity), (ii) domain, (iii) IP Multimedia Public Identity (IMPU) and (iv) Cipher keys (encryption information). So these applications are processed for SIP/IMS procedures consequently VoLTE calls.

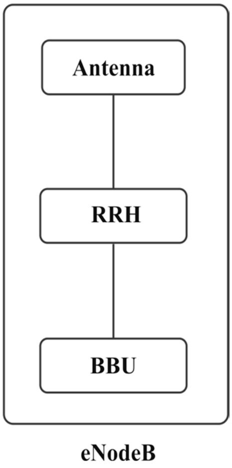
1.1.1 eUTRAN Structure

LTE architecture consists of eUTRAN (evolved Universal Terrestrial Radio Access Network) which consists of only node (eNodeB). It is derived from the UMTS (3G) base station "NodeB" with "e" referring to "evolved". eNodeB communicates with UE directly on one side as illustrated in Fig. 1 through an air interface and with EPC (Evolved packet Core) on other side with MME, PGW, SGW and PCRF.

The main function of eNodeB is to send/receive radio signals to/from antennas. The eNodeB has 4 important interfaces; (i) S1-U, (ii) SGW, (iii) S1-MME and (iv) XZ S1-U directly communicates with SGW (Serving Gateway) through routers. S1-MME communicates from eNodeB to MME and carries control plane information. XZ interface interconnects eNodeB through switches and routers. The most complex node in LTE-A is base station eNodeB. eNodeB consists of two major elements RRH (Remote Radio Head) and (Base Band Unit). RRH (antennas) is also called RRU (Remote Radio Unit) which is visible parts of mobile network. They are responsible for modulation and demodulation of signals transmitted/received over air interface. BBU (Base Band Unit) consists of digital modules for processing signals transmitted/received over air interface and acts as interface to core network over a high-speed backhaul connection (Fig. 3).

The Scheduling of uplink/downlink data to/from the UE are considered ad most significant research problem in literature. eNodeB scheduling is performed at various levels and devices but Remote Radio Head (RRH) scheduling is considered as a critical problem in literature [6] [7]. Figure 4 illustrates the RRH. In the proposed model scheduler is deployed at downlink channel processor of RRH and a comparative analysis is performed with existing models from literature [7] [92] [93]. Extensive literature analysis indicates less

Fig. 3 Internal architecture of eNodeB



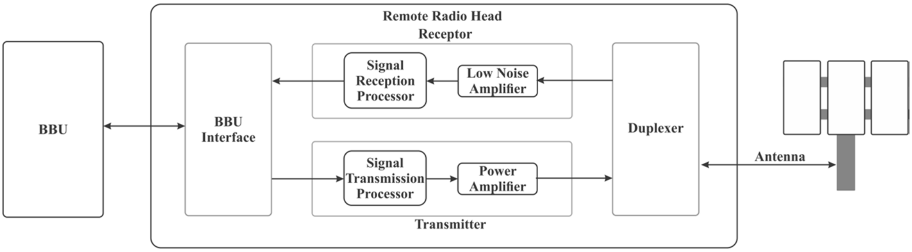


Fig. 4 Architecture of RRH

significant on schedulers is performed in LTE networks, however some significant work is performed in RRH for cloud based systems.

1.1.2 Evolved Packet Core (EPC)

The EPC is also referred to as the Core Network (CN). The EPC is responsible for command of User and Utility Equipment (UE). EPS consist of 5 components (i) Policy Control and Charging Rules Function (PCRF), (ii) Home Subscriber Service (HSS), (iii) Serving Gateway (S-GW), (iv) PDN Gateway (P-GW), (v) Mobile Management Entity (MME).The Operator can deploy each component as independent physical device, or merge it depending on needs and availability or.

1.2 Carrier Aggregation and Radio Resource Management

The major change that LTE-A possesses is support for carrier aggregation (CA). CA basically increases bandwidth by combining various spectrums of available bandwidth. For example, if three spectrums α, β and ɣ Hz and plan to employee them simultaneously like αβ and ɣ Hz or α and βɣ Hz or αβɣ Hz. This dynamic allocation of spectrum is significant for transferring large chunks of data. LTE supports 8 layers downlink and 4 layers uplink. LTE-A radio network reduced latency to 10 ms as compared to LTE. LTE-A also provides mission critical public safety communication and cost-efficient connectivity for IoT. In wireless systems, there are two types of handover procedures (i) horizontal and (ii) vertical handovers. Horizontal handovers procedure is performed between cells of homogeneous network. Vertical handover procedure is performed between two cells from different networks [7]. The physical components required in handover are UE and RRH (eNodeB). Hence efficient is necessary for smooth handover. Extensive literature lacks work on smoothening transition process (especially on RRH) and scheduling. Figure 5 illustrates various components of LTE-A.

Radio resource management is generalized term to represent all radio related functions (Assignment, Management and Scheduling). It is directly related to providing better QoS to user. QoS requirement by user are application specific. For example VoIP and browsing requires high data rate with low transmission loss and low latency in contrast to Video Streaming Dynamic environment need soft computing based schedulers which have a proven their significance [8] and scheduling can be termed as most significant problem in LTE.

DCI (Downlink Control Information) is a part of RRM plays important role during data transmission. Without DCI, data cannot be decoded. Figure 6 illustrates downlink scheduling.

DCI consist of following information (i) Resource block used to carry data (ii) Demodulation scheme to decode data (iii) Resource Allocation (iv) Power Control and (v) CQI Report Request. CSI (Channel State Information) is a collective name for several types of indicators (i) Channel Quality Indicator (CQI) (ii) Precoding Matrix Indicator (PMI) (iii) Precoding Type Indicator (PTI) and (iv) Rank Indicator (RI).

The QoS is directly proportional to scheduling algorithm adopted by NodeB and its submodules. RRH holds a very crucial position. The performance of LTE-A is evaluated on various parameters; (i) Throughput, (ii) Spectral Efficiency, (iii) Fairness Index and (iv) RI Distribution. The performance of LTE can be significantly improved by selection of most optimal scheduling algorithm [9]. Hence, scheduling algorithm selection is based upon RRM, data rate, bandwidth availability, application and traffic.

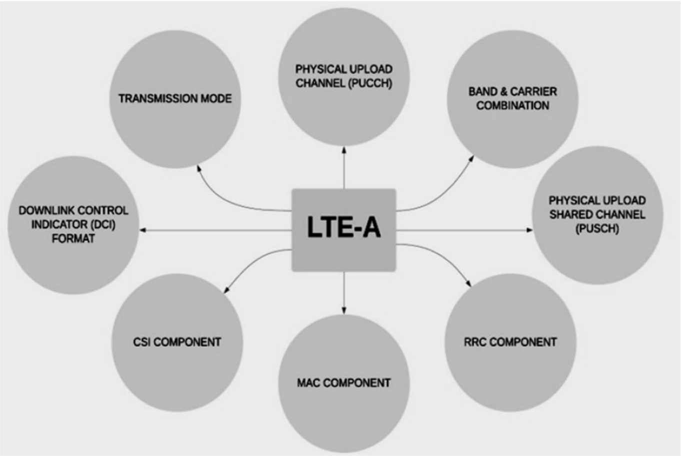


Fig. 5 Components of LTE-A

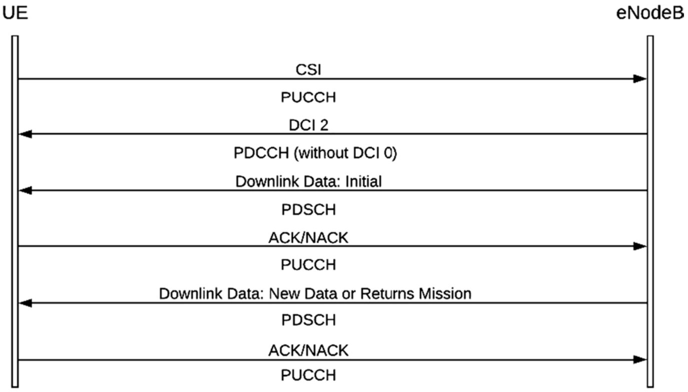


Fig. 6 Downlink scheduling overview

2 Literature

Previous generation, base stations were controlled by control device 2G: Base Stations Controller (BSC) and 3G: Radio Network Controller (RNC). The controllers were responsible for setting up radio links to wireless devices via base stations. LTE-A detached this concept as it required significant resources. Most applications on device only transmit information in bursts with a long timeout. During inactivity, interface between mobile devices has to utilize available bandwidth efficiently to reduce power consumption. Packet switching generates a lot of load due to frequent switching of unit interface state. So this management task was distributed to speed up connection establishment time and reduce time for handover which is crucial for real-time services. Thus LTE-A network is a simple flat network of interconnected base stations without a centralized controller.

Soomro et al. [10] discussed massive MIMO based upon restructuring of RRH for good mobility. They considered two scenarios is placement of RRH in each cell. One was circular distribution and other was PPP distribution. The results hence obtained were in favor of Circular Distribution instead of PPP Distribution. But scheduling algorithm was not discussed.

Capozzi et al. [11] discussed various issues while designing a scheduling algorithm. For example there are various algorithms which focusses more on fairness index while others focusses on throughput, spectral efficiency, latency etc. However research to strike a balance between all important parameters required to get optimal results. This is due to fact that different applications have different QoS requirements.

Monghal et al. [12] introduced a new scheduling algorithm based on PF algorithm that tried to balance coverage of network as well as cell throughput. Kwan et al. [26] proposed maximize throughput using PF algorithm. Author reports with increase in complexity of optimization problem, performance of PF algorithm also increased. A fairness index based approach was employed in Proebster et al. [6] and Li et al. [27]. This algorithm actually utilize adaptive scheduling which able to dynamically adjust fairness index based upon inputs received.

Saeed et al. [13] proposed a new mapping and planning scheme of QoS classes for converted Wi-Fi LTE network to ensure that end-to-end QoS support is provided transparently. A mapping was created between quality classes of LTE and Wi-Fi service and then a scheduling algorithm was presented. For scheduling, traffic is divided into components in real time (RT) and not in real time (NRT) with a complex two-step queuing strategy. In first phase, Deficit-Weighted Circular Queue (DWRRQ) and class-weighted average queue (CBWFQ) are employed for RT and NRT applications respectively, to separate and transfer traffic based on resource requirements. In second phase, Priority Control Queuing (RCPQ) is employed for all types of traffic to assign class an appropriate priority level. The evaluation of convergent network performance was performed on various measures (jitter, end-to-end delay, throughput and packet loss percentage). The simulation results show significant improvements on RT with a slight deterioration on NRT applications on new scheduling algorithm.

Leinonenet et al. [14] and Varadarajan et al.[15] discussed a round robin scheduler, which is among the conventional methods of efficiently distributing resources in networks. It ensures fairness by giving each client an equal share in transfer time of packet. The process frequency, tends to decrease significantly. The algorithm does not take into account channel's circumstances during decision-making process. Not all MS must be positioned at base station at same distance. As a result, value of channel far from base station deteriorates channel and not all channels can therefore be distributed at same rate. Likewise, the algorithm appears to waste resources through resource allocation of programs that are not resourceful. Not all clients, for instance, need same type of service, including VoIP, video, HTTP and SMS. Service has its own constraints on QoS, such as planned speed and package size.

Saito et al. [16] worked on CoMP (Coordinated Multipoint) coherent transmission using RRH in LTE-A network. The feedback of network was taken through CSI bits but scheduling was not considered. The results could have been better in terms of throughput if soft computing based scheduling algorithms could have been employed instead of generic algorithms. Table 1 illustrates scheduling strategies (literature) into major classes.

Downlink packet scheduling approaches can be broadly classified into Content Aware and Content Unaware Strategies (Fig. 7). Content aware strategies can be categorized

Table 1 QoS parameters used by various content unaware scheduling strategies

Scheduling approach	Channel parameters			QoS parameters		
	CSI	Avg. Data Rate	PLR	Queue Size	Service aware	Delay
Delay aware						
M-LWDF [17]	Yes	Yes			RT	Yes
EXP/PF [18]	Yes	Yes			RT, NRT	Yes
EXP-Rule [19]	Yes	Yes				Yes
Queue aware approaches						
PFPS [20]	Yes	Yes		Yes		
QoS unaware approaches						
PF [21]	Yes	Yes				
Max-rate [22]	Yes					
RR [22]						
Hybrid approaches						
Fuzzy logic [23]			Yes		RT	
OPLF [24]	Yes		Yes		RT	
FLS [25]	Yes	Yes		Yes	RT, NRT	

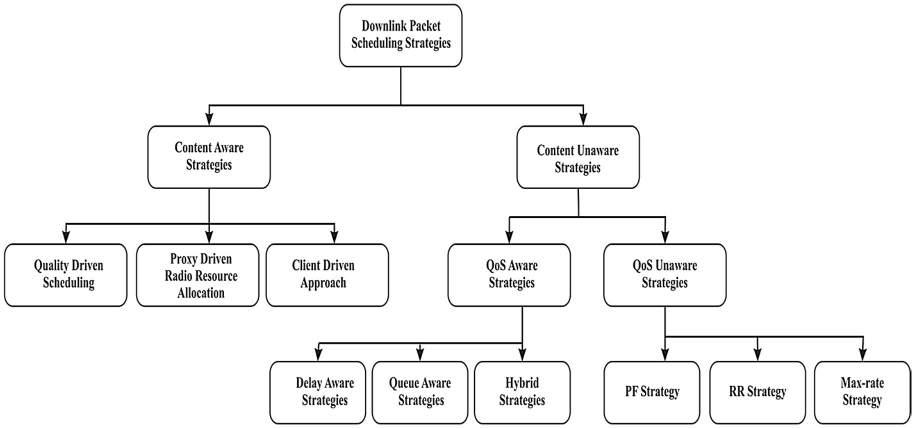


Fig. 7 Classification of downlink packet scheduling approaches

roughly into following subclasses; (i) Quality driven scheduling,, (ii) Proxy driven radio resource allocation strategy and (iii) Client driven approach quality driven scheduling approach focuses on scheduling strategies for video streaming traffic. Cross layer signaling is used for information of different types of video traffic flow to RAN. The objective of using this approach is to maximize user experience and quality of video content while considering channel and bandwidth constraints [28–72]. Proxy Driven radio resource allocation strategy uses basic packet scheduler at RAN. The traffic optimization is performing these tasks at cross layer module [73–85]. Client Driven Approach utilizes dynamic adaptive streaming over HTTP (true client driven approach) [86–91].

Content Unaware Strategies can be further classified (i) QoS aware and (ii) QoS unaware strategies. QoS Unaware Strategies, the authors are particularly interested in PF and RR Strategies. These two strategies are proposed for use in the simulations by the authors in this work. PF is the most researched algorithms in scheduling of LTE based networks. This is because of dynamic nature and dynamic data flow types. Soft computing based schedulers are best suited for dynamic environments. So PF scheduler was the solution. The simplicity and adaptability of PF algorithm made it most significant algorithms to employ in scheduling LTE based networks. Also, so far few creditable works are found on downlink scheduling in RRH which is considered significant part of RAN (Radio Access Network).

3 The Proposed Optimization Algorithm

3.1 System Model

A Proportional Fair (PF) Scheduler is deployed at Remote Radio Head (RRH). The simulations are run on MATLAB based academic licensed Downlink System Level Simulator (SLS) developed by University of Vienna. The simulations are run using Round Robin Scheduler as well as Proportional Fair Scheduler at various Transmission Time Intervals (TTI) with comparative analysis on results. The results are compared on same parameters but did not use scheduling at RRH. This establishes fact that what importance RRH scheduling holds.

LTE-A supports heterogeneous coming traffic having varying QoS requirements. Satisfying specific QoS requirements of each application is the responsibility of network. **Traffic Classifier** job is to classify traffic according to type of traffic. Traffic is classified in Real Time and Non-Real Time. Real Time Traffic has rigorous throughput requirements and is given more priority over Non-Real. The Non-Real Time traffic queue consists of packets which have data from delay sensitive applications.

One of the high priority applications is Control data which keeps a track of scheduling information. Similarly VoIP can also be accumulated in high priority application. On other hand application data such as video streaming which is classified to Non-Real Time application should also guarantee a minimum throughput so as to achieve desired quality output. Hence, FCFS (First Come First Serve) is applied on UE in first queue and second queue handles data which is delay sensitive and have a bound for maximum delay.

Optimizer holds a very important position in data transmission process. It optimizes data transferred to other end. In the optimization, priorities of data transmitted is taken into consideration. Optimizer calculates Average Throughput and Average delay keeping in account channel conditions, priority and type of traffic. It will first check traffic type and RB's will be defined according. Subsequently data will be transmitted after allocation of RB's to traffic. The unused RB's may be allocated to traffic with lowest priority.

When optimized data reaches scheduler, it is scheduled using a scheduling algorithm. The scheduling algorithm may be a Traditional Scheduling Algorithm, Genetic Scheduling Algorithm or Soft Computing Based Scheduling Algorithm. In the present research work, a soft computing based PF Scheduler is used. The PF scheduler makes scheduling decisions based upon CQI and actual packet delay. The main advantage of using PF scheduler is that it prioritizes real time applications over others and consequently guaranteeing a bounded delay to data packets hence maximizing system throughput. The user prioritization in PF algorithm is expressed as:

$$\mathrm{P} = \frac{\mathrm{T}^{\propto}}{\mathrm{R}^{\beta}} \tag{1}$$

T denotes the data rate potentially achievable for the station in the present time slot. **R** is the historical average data rate of this station.α and β tune the "fairness" of the scheduler.

3.2 Simulator Architecture

The simulator is Vienna LTE-A Downlink System Level Simulator developed by University of Vienna. This simulator runs on MATLAB and have standardized scenarios to work. The Initialization module performs task of traffic generation and initializing eNodeB and UE. Another task which it performs is to create shadow fading using correlated log normal model. Traffic Module is used to generate traffic as per user requirement. The generated traffic may be Real Time, non-real time, Video, VoIP. It also performs the task of keeping a record of packets which are likely to be generated, dropped or scheduled. **Traffic Differentiator** module differentiates one traffic type from the other depending upon the QoS requirements.

Scheduling Module schedules traffic based upon the scheduling algorithm used. Each scheduling algorithm is used again with each TTI. **Resource Allocation Module**, resources are allocated to data. The resources include the Resource Blocks (RB's). Another function which it performs is prioritization of UE based upon delay and throughput. **System Performance Module** basically monitors and calculates the system performance. The parameters for calculation of system performance includes throughput, spectral efficiency, SINR and their mapping with each other. The complete process is illustrated in Fig. 7. The parameters used to run the simulation have been listed in Table 2.

As illustrated in Fig. 8, the proposed model takes inputs from the antenna. As soon as the input reaches the RRH, it is sent into the default traffic classifier for classifying the traffic into real-time and non-real time traffic for an efficient scheduling. The traffic requiring high QoS is basically differentiated from the traffic having low QoS requirements. This is essentially done by considering two most important factors which are delay and throughput and the traffic is further sent for optimization. Then the traffic scheduling is done by the scheduler, process of which is explained in Fig. 7. The output hence generated will be compared with existing literature.

3.3 Simulation Environment

This section will analyze, through simulation, performance of soft computing based Proportional Fair Algorithm with comparative analysis between PF and RR scheduler on identical scenario.

3.3.1 Simulation Scenario

This experiment simulate scenario with Micro Sites and Remote Radio Heads (RRH). The Micro Sites are arranged to a hexagonal grid with an intercell distance of 500 m. Each site is equipped with 3 sector eNodeB's, each eNodeB deploys one antenna on microsite and 3 RRH's. The RRH's are located 150 m away from microsite and are equidistantly placed on an arch of 80 degree.

Simulate at a central frequency of 2.14 GHz and an LTE-A bandwidth of 2 MHz. The total transmits power for eNodeB including the RRH is assumed to be 40 watts. The eNodeB on microsites employ a directional antenna while remote radio heads are equipped with Omnidirectional antennas. The RRH are assumed to have a delay free connection associated with eNodeB. The signal propagation is characterized by a log distant dependent path loss correlated log normal shadowing and fast fading. Each UE has 2 receive antennas and employs a zero forcing receiver. Within each eNodeB sector assumed 20 active users which are uniformly distributed and move at a speed of 5 km/hr. Employed closed loop spatial multiplexing. For responding to transmission mode for LTE-A, the feedback comprises Channel Quality Indicator (CQI), Precoding Matrix Indicator and Rank Indicator.

The feedback is delayed by 3 Transmission Time Intervals also known as TTI and computed with perfect channel knowledge. The resources are assigned according to a proportional fair scheduler. We have assumed a full buffer traffic model and simulation length of total 10 TTI. A detailed flowchart of simulation process has been illustrated in Fig. 9.

Table 2 Parameters for simulations

Parameter	Round Robin scheduler at 10 TTI	Proportional fair scheduler at 10 TTI	Parameters for simulation for round robin scheduler at 100 TTI	Proportional fair scheduler at 100 TTI
Frequency	2.14 GHz	2.14 GHz	2.14 GHz	2.14 GHz
LTE-A bandwidth	20 MHz	20 MHz	20 MHz	20 MHz
eNodeB transmit Power	40 W	40 W	40 W	40 W
eNodeB antenna gain in dB	$A(\theta) = -\min\left(12\left(\frac{\theta}{70^\circ}\right), 20dB\right)$	$A(\theta) = -\min(12\left(\frac{\theta}{70^\circ}\right), 20dB)$	$A(\theta) = -\min(12\left(\frac{\theta}{70^\circ}\right), 20dB)$	$A(\theta) = -\min(12\left(\frac{\theta}{70^\circ}\right), 20dB)$
RRH antenna gain	Omni-directional	Omni-directional	Omni-directional	Omni-Directional
RRH backhaul connection	Radio over fiber, no delay	Radio over fiber, no delay	Radio over fiber, no delay	Radio over fiber, no delay
Path loss model	128.1 + 37.6 log 10, R in Km	128.1 + 37.6 log $_{10}$, R in Km	128.1 + 37.6 log $_{10}$, R in Km	128.1 + 37.6 log $_{10}$, R in Km
Minimum coupling loss	70 dB	70 dB	70 dB	70 dB
Shadow fading model	Correlated log normal, 8 dB Standard Deviation	Correlated log normal, 8 dB Standard Deviation	Correlated log normal, 8 dB Standard Deviation	Correlated log normal, 8 dB Standard Deviation
Channel model	ITU-R Pedestrian-B	ITU-R Pedestrian-B	ITU-R Pedestrian-B	ITU-R Pedestrian-B
Antennas per UE	2	2	2	2
Receiver type	Zero Forcing	Zero Forcing	Zero Forcing	Zero forcing
Noise power spectral density	−174 dBm/Hz	−174 dBm/Hz	−174 dBm/Hz	−174 dBm/Hz
Receiver noise figure	9 dB	9 dB	9 dB	9 dB
Active UE's	20	20	20	20
UE speed	20 km/hr	20 km/hr	20 km/hr	20 km/hr
UE distribution	Uniform	Uniform	Uniform	Uniform
MIMO mode	Closed loop spatial multiplexing	Closed Loop Spatial Multiplexing	Closed Loop Spatial Multiplexing	Closed Loop Spatial Multiplexing
Feedback	AMC: CQI, MIMO: PMI & RI	AMC: CQI, MIMO: PMI & RI	AMC: CQI, MIMO: PMI & RI	AMC: CQI, MIMO: PMI & RI
Feedback delay	3 TTI	3 TTI	3 TTI	3 TTI
Channel knowledge	Perfect	Perfect	Perfect	Perfect
Scheduler	Round robin	Proportional Fair	Round robin	Proportional fair
Traffic model	Full buffer	Full buffer	Full Buffer	Full Buffer
Simulation length	10 TTI	10 TTI	100 TTI	100 TTI

4 Results and Discussion

In this section, results obtained through simulations while we tested different scheduling strategies at RRH have been analyzed. The simulation scenario is kept identical and parameters are obtained from Vienna LTE-A Downlink System Level Simulator. The scenarios are standardized scenarios for Vienna LTE-A Downlink SLS.

While setting parameters for simulation, first task is fixing number of UE's. As described by Taranetz et al. [93], the number of UE's is 1140 and number of cells is 57. The simulations were run at 10 TTI as illustrated in Figs. 10 and 11 earlier, for validation on accuracy; the simulations are run at 100 TTI with similar parameters as depicted in Figs. 12 and 13.

4.1 Simulation Results

Simulation is designed, developed and executed according to standardized parameters [93] in Table 2, average UE throughput employing RR scheduling is 3.14 Mb/s in contrast for PF Algorithm average UE throughput is 3.70 Mb/s which is a significant improvement by 17.83% as illustrated in Table 6. This is a significant increase over traditional RR Scheduling Algorithm.

To calculate sum throughput, we considered following metrics:

$$\text{Sum throughput} = \left(\sum_{i=1}^{I} \frac{1}{n_{f_i} - n_{s_i}} \sum_{m=n_{s_i}}^{n_{f_i}} P_{t_i}^{(m)} \right) \tag{2}$$

where n_{si} and n_{fi} are starting and finishing time interval for the flow i. P_{ti}^(m) indicated the size of flow and I indicates total number of flows.

The next parameter is Average UE Spectral Efficiency. The results clearly indicated that PF scheduler has better Average Spectral Efficiency in contrast to RR Scheduler. It means that PF scheduler stands more efficient than RR scheduler in terms of utilizing the spectrum available. The results indicate a great deal of improvement while utilizing available spectrum. The data transmission is undoubtedly more efficient and optimized. It also indicates proficiency of data transmission in allocated spectrum by physical layer protocols. Spectral efficiency can be calculated:

$$\text{Spectral efficiency} = \frac{\text{Net} \quad \text{data rate}}{\text{Channel} \quad \text{bandwidth}} \tag{3}$$

Another important parameter to discuss is RI Distribution. RI acts as most significant inputs to eNodeB, which will help in selection of transmission layer in downlink data transmission which can be Tx Diversity or MIMO. As it is significantly lucid that PF scheduler gave more priority to Rank 1 transmission, it means that majority of data will be transmitted preferably in Tx Diversity, which is more optimized than MIMO. In Rank 2 distribution it can be clearly seen that Rank 2 in RR scheduling is significantly high which clearly indicates priority of MIMO over the Rank 2 in PF Scheduling. In [3] it has been proved that precoder which maximizes mutual information exchange in LTE-A and utilizes full system bandwidth and subframe duration is Tx Diversity, in comparison to MIMO.

Fig. 8 Proposed model

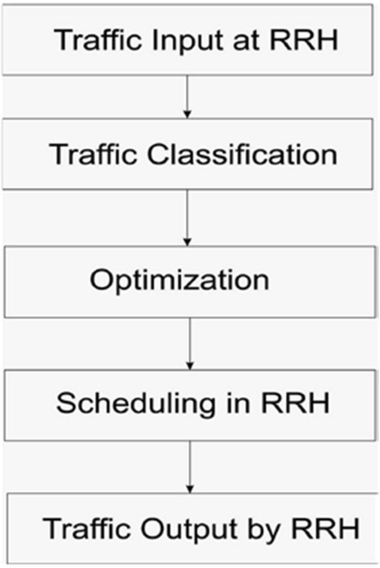
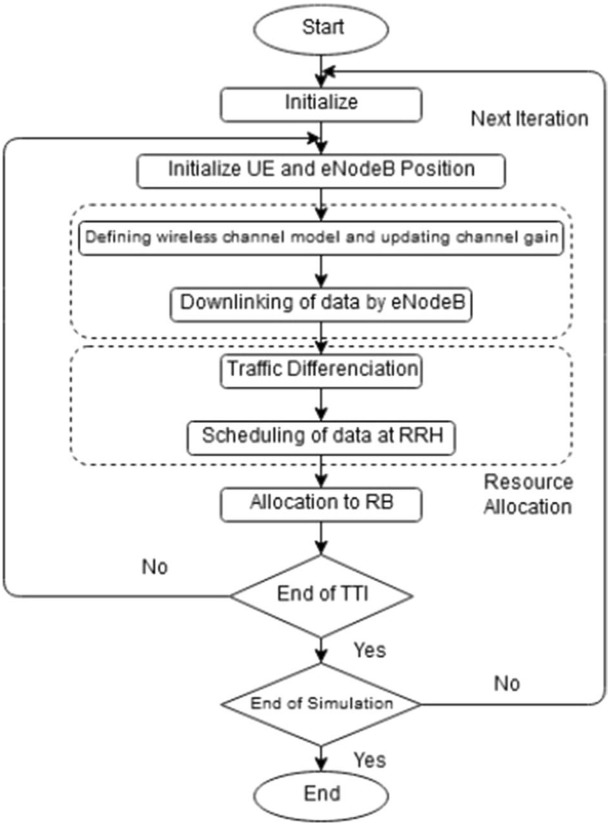


Fig. 9 Flowchart of simulation



Fairness Index is a metric to determine whether an application or a user is getting a share of system resources or not. While comparing the fairness index of RR and PF scheduling, the fairness index of RR Scheduling is 0.706048 in contrast PF Scheduling is 0.711594 which is a marginal 0.78% increase in final value at 10 TTI. The Fairness Index is calculated using Jain's Fairness Index [3].

$$\mathcal{J}(x_1, x_2, \ldots, x_n) = \frac{\left(\sum_{i=1}^{n} x_i\right)^2}{n \cdot \sum_{i=1}^{n} x_i^{\,2}} = \frac{\overline{\mathbf{x}}^2}{\overline{\mathbf{x}^2}} = \frac{1}{1 + \widehat{c_v}^2} \tag{4}$$

Here n is number of users, x_i is output for i^{th} connection and $\widehat{c}_v$ is sample coefficient of variation. The range of result is 1/n (worst case scenario) to 1 (bestcase scenario) and it will be maximum when all resources will get equal treatment. The fairness index will be k/n when k number of users will equally share channel.

To achieve a given fairness level F, one approximate method is to let $x_{k\,=}\,A.k^{\alpha}$, where

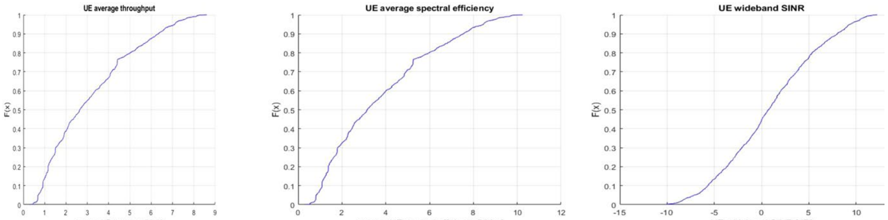
$$\alpha = \frac{1 - \mathrm{F} + \sqrt{1 - \mathrm{F}}}{\mathrm{F}} \tag{5}$$

and A is an arbitrary factor.

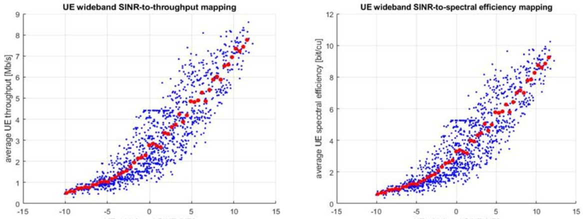
Comparing peak throughput of both scheduling strategies noticed a considerable performance surge of 13.38% while using a PF Scheduler.

The peak throughput is RR scheduling was 7.10 Mb/s whereas in PF Scheduling it is 8.05 Mb/s thereby a massive 13.3% improvement at 10 TTI. This indicates that flow of data is more optimized in PF Scheduling in RRH.

Similar upward trend can be seen in PF scheduler in line of 20% and 12.2% on parameters of Edge UE Throughput and Average Cell Throughput respectively while comparing with RR Scheduling while numbers of ignored cells were zero and mean RB occupancy was 100% in both scenarios as shown in Tables 3 and 4.

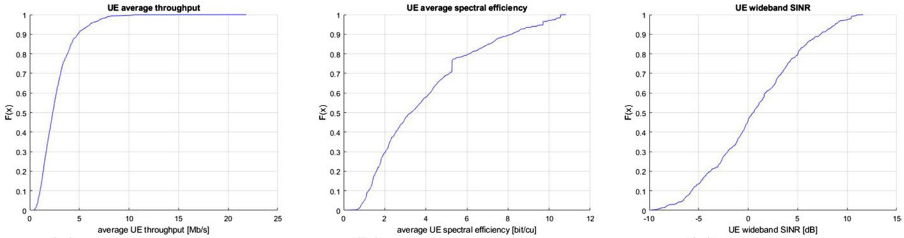


(a) UE Average Throughput **(b)** UE Average Spectral Efficiency **(c)** UE Wideband SINR

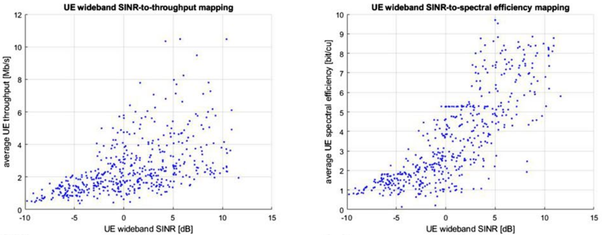


(d) UE Wideband SINR to Throughput Mapping **(e)** UE Wideband SINR to Spectral Efficiency Mapping

Fig. 10 RR scheduling at 10 TTI

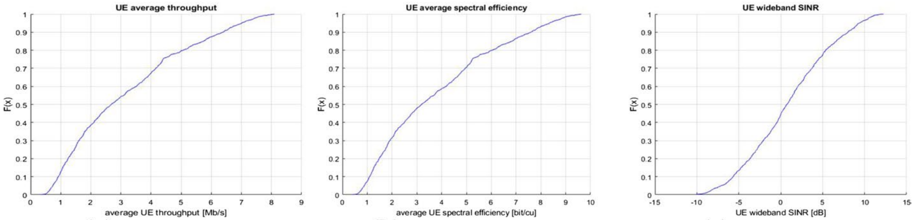


(a) UE Average Throughput **(b)** UE Average Spectral Efficiency **(c)** UE Wideband SINR

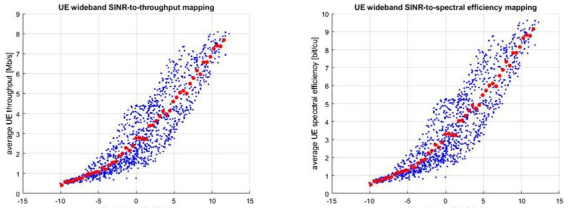


(d) UE Wideband SINR to Throughput Mapping **(e)** UE Wideband SINR to Throughput Mapping

Fig. 11 PF scheduling at 10 TTI



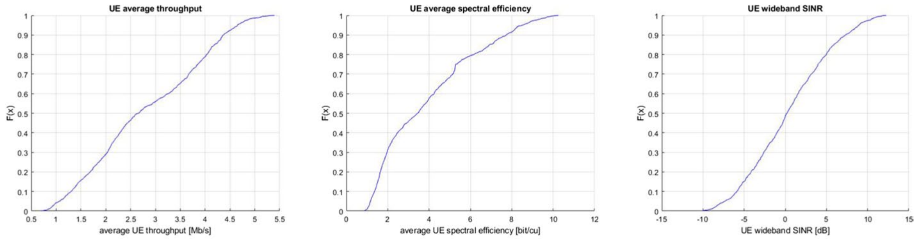
(a) UE Average Throughput **(b)** UE Average Spectral Efficiency **(c)** UE Wideband SINR



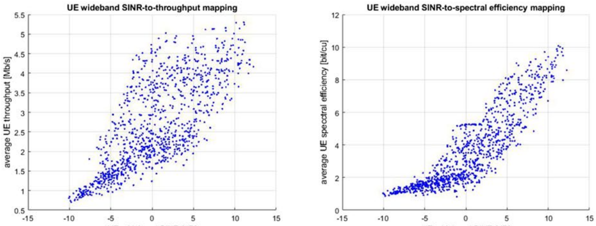
(d) UE Wideband SINR to Throughput Mapping **(e)** UE Wideband SINR to Spectral Efficiency Mapping

Fig. 12 RR scheduling at 100 TTI

From [92] it can be analyzed that without giving any importance to scheduling at RRH, throughput is 1.4 Mb/s. In proposed work, scheduler like RR outclasses it by almost 2.5 times on average throughput. The peak throughput achieved is 7.10 Mb/s using RR scheduler and 8.05 Mb/s using PF scheduler. These experiments [92] were performed at 1 TTI, experiments were performed at 10 and 100 TTI both in order to establish more verified and accurate results.



(a) UE Average Throughput **(b)** UE Average Spectral Efficiency **(c)** UE Wideband SINR to Throughput Mapping



(d) UE Wideband SINR to Throughput Mapping **(e)** UE Wideband SINR to Throughput Mapping

Fig. 13 PF scheduling at 100 TTI

While running both simulations at 100 TTI which is supposed more accurate as number of iterations has increased tenfold as depicted in Tables 5 and 6, it can be analyzed that a significant 20.88% increase in PF Scheduler in contrast to Average UE throughput. A marginal 3.71% increase can be analyzed in Average UE Spectral efficiency while employing PF Scheduler. The rank distribution in PF scheduler is more rational as compared to RR Scheduler.

19.85% increase can be noticed in Fairness Index while using PF scheduling. A negative trend of 13% is seen in Peak Throughput while using PF scheduler. This indicated that PF scheduler has more consistency as there is less deviation from peak to average throughput of PF scheduler as compared to RR Scheduler. A performance increase 20.8, 43.2 and 4.8% in Average Throughput, Edge UE Throughput and Average Cell Throughput respectively while using PF scheduler.

5 Conclusion

This paper presented a classification for better understanding of downlink scheduling in LTE-A networks. It presented a comparative analysis of generic and soft computing based scheduler employed on RRH. RRH in downlink scheduling is least explored research areas. The sole purpose was to provide an algorithm for optimized resource management and scheduling while downlinking. The results indicate that better scheduling algorithms

Table 3 Comparison of simulation statistics for RR and PF scheduler at 10 TTI

Parameters	Values using RR scheduling	Values using PF scheduling
Number of UE's	1140	1140
Number of cells	57	57
Simulation length	10 TTI	10 TTI
Scheduler	RR	PF
Mode	1*4 CLSM	1*4 CLSM
Average UE throughput	3.14 Mb/s	3.70 Mb/s
Avg. UE spectral efficiency	3.74 bit/cu	3.96 bit/cu
Average RBs/TTI/UE	5.00 RBs	5.00 RBs
Rank Indicator (RI) Distribution	Rank 1–60.25%	Rank 1–84.24
	Rank 2–38.94%	Rank 2–15.45
	Rank 3–0.81%	Rank 3–0.32

Table 4 Comparison of cell simulation statistics for RR and PF scheduler at 10 TTI

Parameters	Values using RR Scheduling	Values Using PF Scheduling
Fairness Index	0.706078	0.711594
Peak Throughput	7.10 Mb/s	8.05 Mb/s
Average Throughput	3.14 Mb/s	3.70 Mb/s
Edge UE Throughput	0.70 Mb/s	0.84 Mb/s
Average Cell Throughput	62.83 Mb/s	64.05 Mb/s
Ignored Cell (disabled)	0	0
Mean RB Occupancy	100%	100%

deployment on RRH has attained significant output from LTE-A. Results were compared with existing work and are found significantly better. It has also been proved in the present work that soft-computing based schedulers are significantly better than generic scheduler. An extensive literature survey states that many components of LTE-A are still unexplored like the concept of shadow fading and its effect on LTE-A. Future research goals can be enacted on them.

Table 5 Comparison of simulation statistics for RR and PF scheduler at 100 TTI

Parameters	Values using RR Scheduling	Values Using PF Scheduling
Number of UE's	1140	1140
Number of Cells	57	57
Simulation Length	100 TTI	100 TTI
Scheduler	RR	PF
Mode	1*4 CLSM	1*4 CLSM
Average UE Throughput	3.16 Mb/s	3.82 Mb/s
Avg. UE spectral Efficiency	3.77 bit/cu	3.91 bit/cu
Average RBs/TTI/UE	5.00 RBs	5.00 RBs
Rank Indicator (RI) Distribution	Rank 1–55.44% Rank 2–43.63% Rank 3–0.94%	Rank 1–66.26% Rank 2–32.83% Rank 3–0.91%

Table 6 Comparison of cell simulation statistics for RR and PF scheduler at 100 TTI

Parameters	Values using RR scheduling	Values using PF scheduling
Fairness Index	0.713359	0.854068
Peak Throughput	7.01 Mb/s	6.05 Mb/s
Average Throughput	3.16 Mb/s	3.82 Mb/s
Edge UE Throughput	0.74 Mb/s	1.06 Mb/s
Average Cell Throughput	63.27 Mb/s	66.35 Mb/s
Ignored Cell (disabled)	0	0
Mean RB Occupancy	100%	100%

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Declarations

Conflicts of interest The authors declare that there is no conflict of interest.

Ethical approval Not Applicable.

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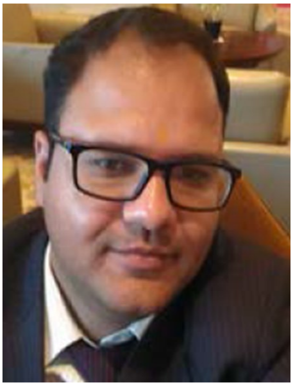

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