Aggregated Assessment of Downlink Resource Scheduling Techniques in Indoor Environments via a Comparative Factor

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***Abstract* - To provide an excellent Quality of Service (QoS) to indoor users is a main goal of next-generation networks (NGNs). Intelligent radio resource distribution techniques play an important role in improving the overall performance of NGNs. A key challenge is to achieve an optimal trade-off between data rates and fairness for cell-centre and cell-edge users. In this paper we compare several downlink Resource Scheduling Techniques (RSTs) in indoor environments, simulated using the Realistic Indoor Environment Generator (RIEG). A Comparative Factor (CF) that simultaneously takes into account the average throughput of the indoor users, the fairness and the outage ratio is proposed. The results show the best choice for downlink RST in indoor wireless networks when a balance between several performance parameters is required.**

***Keywords* – Resource scheduling techniques; Small cells; Indoor communication environment; Comparative Factor**

I. INTRODUCTION

Of late, the continually increasing demands of users in terms of the services offered has led to the next generation of wireless telecommunications utilising more efficient radio access methods. Blockage objects in indoor environments hinder signal propagation and thus lead to a deterioration in the users' QoS. The use of multiple access points to provide uninterrupted coverage is a highly regarded approach. Femtocells are often used as a cost-effective way to optimise indoor coverage, especially in overcrowded confined spaces such as large houses, office buildings, shopping centres, etc. Their low transmission power and ability to be positioned by the consumers themselves make femtocells a preferred solution for improving indoor wireless environments.

The performance of the users' equipment (UE) depends on many factors, such as: scheduling algorithms, distance from the serving transmitter, the multipath environment, multiple antenna techniques, etc. The problem of the increasing volume of smartphone data traffic demands causing insufficient channel capacity at the base stations (BSs) can be solved by intelligent scheduling of frequency and time resources. The downlink RSTs are responsible for determining which user data to transmit on a given time/frequency resource unit. Spectrum portions should be distributed among the users in every transmission time interval (TTI). An efficient resource allocation approach should satisfy users' data rate and QoS requirements for all the different newly-emerging services. Moreover, a balance between fairness provisioning and user throughput expansion should ideally be achieved.

Different types of downlink RSTs for heterogeneous networks, comprising macro- and small-cells, have been well studied. However, the comparison is mainly done as regards the average user throughput and the fairness, while the throughput of cell-edge users and the number of outages are often disregarded. The system models proposed thus far have therefore defined a network based on insufficiently realistic parameters [1], [2], [3]. Each RST has its advantages and disadvantages, and typically a compromise has to be made when designing the scheduler. For example, the proportional fairness technique is considered to be one of the best choices and constitutes a compromise between system fairness and throughput. The main objective of a fairness algorithm is to ensure the optimum fairness which satisfies either the target throughput or the highest possible throughput [4].

In this paper a Comparative Factor (CF) comprising four performance parameters – average user throughput, cell-edge users' throughputs, fairness and number of outages, is introduced with the focus on an indoor scenario. Using the CF, five downlink RSTs are experimentally compared, thereby allowing a particular RST to be recommended depending on the number of users and the positions of the femtocells. The experimental results are obtained by system level simulations using the Vienna LTE-Advanced (LTE-A) system level simulator [5], and the performance trends are discussed.

This paper is structured as follows: Section II describes the downlink resource allocation techniques. Section III defines the system model and introduces the Comparative Factor. Section IV presents the system level simulation results. Section V concludes the paper.

II. DOWNLINK RESOURCE SCHEDULING TECHNIQUES

The downlink scheduling RSTs can be summarised into two types, depending on the presence or absence of information about the channel: channel-independent scheduling (CIS) and channel-sensitive scheduling (CSS).

A. *Channel-independent scheduling strategy*

The CIS strategies were first introduced in wired networks and are based on the assumption of time invariant and errorfree transmission media, which makes them rather unrealistic. LTE networks typically use a combination of CIS and CSS downlink resource allocation techniques to improve system performance. In this paper two CIS downlink RSTs are used – ***Round Robin*** (RR) and ***Resource Fair*** (RF) [6].

B. Channel-sensitive scheduling strategy

When a CSS strategy is used the scheduler can estimate the channel quality experienced by each user. Since the CSS allocates resources via optimal algorithms in respect to the channel conditions, it can achieve a better performance compared to CIS techniques. Thus a channel-sensitive scheduler can meet the users' QoS requirements (QoS aware scheduling) or it may focus on excellent fairness among UEs (QoS unaware scheduling). In this work, three CSS strategy-based techniques are investigated – ***Maximum Throughput*** (mTP), ***Proportional Fair*** (PF) and ***Best Channel Quality Indicator*** (bCQI) [6].

III. System Model

A. Network layout

To compare the performance of different resource allocation strategies, a realistic indoor environment comprising different femtocell locations and numbers of users was employed. Simulations were conducted in indoor design, using the Realistic Indoor Environment Generator (RIEG) wall pattern method [7]. The arrangement of the walls was characterised by two basic parameters – *wall density* λ and *wall attenuation* ω. The wall density defines the length of the walls per square meter while the wall attenuation defines the impact of the walls on signal propagation.

The simulations were performed in a Region of Interest (RoI) with a set area η. When η is multiplied by the wall density λ, the *total length of walls* will be obtained $L_{sum} = \eta\,\lambda$. When the RoI area increases, the total length of walls will increase too, aiming to satisfy the required constant wall density λ. The system model of the investigated indoor wireless network provides a random deployment of femtocells equipped with omnidirectional antennae and employing the Closed Loop Spatial Multiplexing (CLSM) transmission mode. The indoor network environment layout is shown in Fig.1. The dots represent UEs, while the circles denote femtocells.

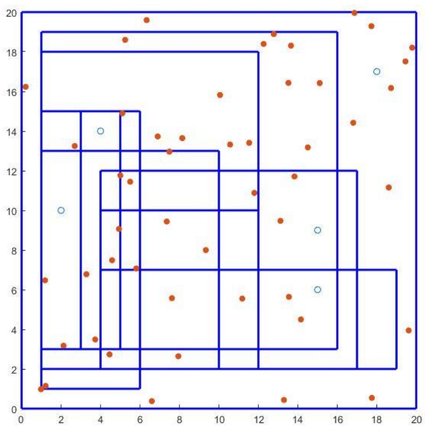

Figure 1. Indoor floor plan, modelled by RIEG

B. Comparative Factor

Different downlink scheduling RSTs can be better evaluated when a summative integrated assessment is applied. Its value will provide both general information about the usefulness of the competing algorithms and specific information about the level of particular performance parameters. Thus it will be possible to select the best downlink RST for use in an indoor environment.

The CF developed is a generalised metric that simultaneously takes into account four different indoor performance parameters – *normalised average user throughput*, *normalised average cell-edge user throughput*, *fairness* and *outage ratio*:

$$F = F_1 + F_2 + F_3 - F_4 \ . \tag{1}$$

To ensure a meaningful value of the CF, all four parameters are constituted to take values from 0 to 1. Hence, the CF will range from -1 to 3.

Normalised Average User Throughput (F_1): the UE data rate depends on the quality of the channel, numerically identified by the Signal-to-Interference ratio (SIR). Hence, a wide range of SIR received by the users results in high user throughput diversity. The impact of network topologies on users' throughput performance can be better comprehended when the *average user throughput* T_{avg} is considered:

$$T_{avg} = \frac{\sum_{k=1}^{N} T_k}{N} \ , \tag{2}$$

where T_k is the throughput of k-th user and N is the number of users. In order to transform (2) into a dimensionless ratio, the average user throughput T_{avg} is normalised against an experimentally obtained *reference user throughput* T_R. Experiments to deliver T_R were carried out for an indoor layout with only one femtocell, a free-of-walls RoI, and the corresponding number of users. As a result, the *normalised average user throughput* (F_1) parameter is as below:

$$F_1 = \frac{T_{avg}}{T_R} \ . \tag{3}$$

F_1 has its best value of 1 when the average user throughput is equal to the reference user throughput. The worst case occurs when obstacles are so numerous that the users' throughput becomes zero, i.e. $F_1 = 0$.

Normalised Average Cell-edge User Throughput (F_2): at the edge of the cell the signal is weakest and inter-cell interference further degrades the overall network performance and in particular reduces the user throughput. Therefore, to achieve all-over network coverage for mobile users and to avoid call-drops during cell handover it is imperative to maintain a minimum throughput at the edge of the cell. The *average cell edge-user throughput* T_{avg_edge} is defined as the 5th percentile of the user throughput empirical cumulative distribution function (ECDF). By analogy to F_1, the cell-edge user throughput is normalised against the *reference throughput of cell-edge users* T_{R_edge}, experimentally delivered as the reference user throughput T_R. Hence, the *normalised average cell-edge user throughput* F_2 is as follows:

$$F_2 = \frac{T_{avg\_edge}}{T_{R\_edge}}. \quad (4)$$

Since the reference throughputs are used to determine the maximum value of throughputs, as with F_1, F_2 also ranges from 0 to 1 and has its best value equal to 1.

Fairness (F_3): UEs expect to receive bandwidth fairly, thus improving the QoS. Hence, fairness is an attribute of the resource sharing and allocation techniques. The consequence of an unfair resource allocation between different users may lead to resource starvation, resource wastage or redundant allocation. The parameter *fairness* F_3 attains its maximum value of 1 when resources are distributed equally, regardless of the needs of individual users. This is also called Jain's Fairness Index (JFI):

$$F_3 = \frac{\left[\sum_{k=1}^{N} T_k\right]^2}{N\sum_{k=1}^{N} T_k^2}. \quad (5)$$

Outage ratio (F_4): represents the ratio of the number of users with outages N_{out} to the total number of users N:

$$F_4 = \frac{N_{out}}{N}. \quad (6)$$

Clearly, the best value of F_4 is achieved when there are no users with outages (F_4=0), while the worst (F_4=1) occurs when all users have outages.

The CF can be considered as a way of analysing the overall QoS. The CF increases due to an increase in throughput or user fairness and a decrease in the number of outages. This results in better overall performance for the users.

IV. System-Level Simulation Results

A. Simulation Setup

The experiments were carried out using a constant number of 5 femtocells and different numbers of users (10, 20, 30, and 100). Each of the 100 simulations conducted took place with a different location of the femtocells. The RIEG wall layout was used to model an acceptably realistic floor plan. No particular traffic model and user throughput requirements were considered and the lack of interference from BSs is assumed. The aim was for every user to maximise its CF. The numerical values of the simulation parameters are given in Table I.

B. Results Analysis

The peak and mean values of the CF for the five scheduling downlink RSTs and for different numbers of users are shown in Fig. 2. The peak value of the CF for each downlink RST is achieved for the best location of the femtocells for the corresponding number of users.

TABLE I. Simulation Parameters

Parameter	*Value*
Frequency	2.14 GHz
Bandwidth	20 MHz
Number of resource blocks (RB)	100
Transmission mode	CLSM
Femtocell transmitter power	1 W
Number of users	10 - 100
Number of femtocells	5
Wall density	0.2 m^{-2}
Wall attenuation	10 dB
Simulation area size (ROI)	20m x 20m
Reference area size (ROI)	8m x 10m

The RR, PF and RF algorithms reach higher values of the CF as a result of a good balance between throughput and fairness among the users. The curves of these three downlink RSTs are monotonically smooth due to the excellent fairness. The PF algorithm shows the best performance, regardless of the number of UEs, and achieves a balance between the CF components and hence the best QoS. The PF and RF are the fairest algorithms since their goal is to maximize cell-edge users' throughput. The increase in the peak CF when the number of UEs increases is caused by a decrease in the fairness, especially for the PF algorithm. This increase is due to the reduction of cell-edge user throughput, which is itself dependent on the diminution of the system resources, which remain constant despite the number of UEs.

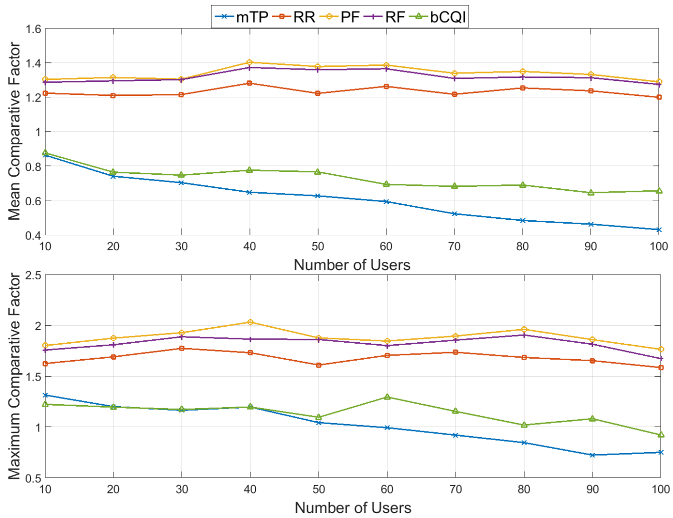

Figure 2. Mean and peak CF for various number of users

Alternatively, the mTP and bCQI algorithms attempt to maximise the user throughput while giving less weight to fairness and the number of outages. Thus the values of the CFs for these two RSTs decrease, especially when the number of users increases, since the amount of available resources per user reduces.

Fig. 3 depicts the values of the peak CF indoor performance parameters for 40 and 80 users. It is worthwhile comparing the two scenarios since 1) the highest value for the peak CF is achieved for the PF downlink RST for 40 users (Fig.2), and 2) when the number of users doubles, the resources available and the average area per user halve.

The best three downlink RSTs (RR, PF and RF), according to the CF, succeed in coping with the decreased amount of system resources by performing an intelligent allocation. They endeavour to minimise the outages (F_4) and at the same time to balance the other three indoor performance parameters. The normalised average user throughput F_1 and the fairness F_3 are the main contributors to the peak CF value, as shown in Fig. 3. The RR, PF and RF algorithms give significant consideration to cell-edge user throughput, F_2, which is a substantial indoor performance parameter. The users located in the periphery of the cell are most affected by the indoor interference due to their proximity to the interfering transmitting devices and their remoteness from the serving transmitter. The effect of the walls as obstacles should also not be overlooked. On the other hand, the mTP and bCQI downlink RSTs maximise the normalised average user throughput F_1 and completely disregard the average cell-edge user throughput F_2. The increase of the F_1 parameter is due to the increased number of outages, i.e. the outage ratio F_4. The mTP and bCQI algorithms allocate resources to users with the best channel quality, thus compromising the fairness and the cell-edge users' QoS. A big difference between the throughputs of different users is typical for these two downlink RSTs.

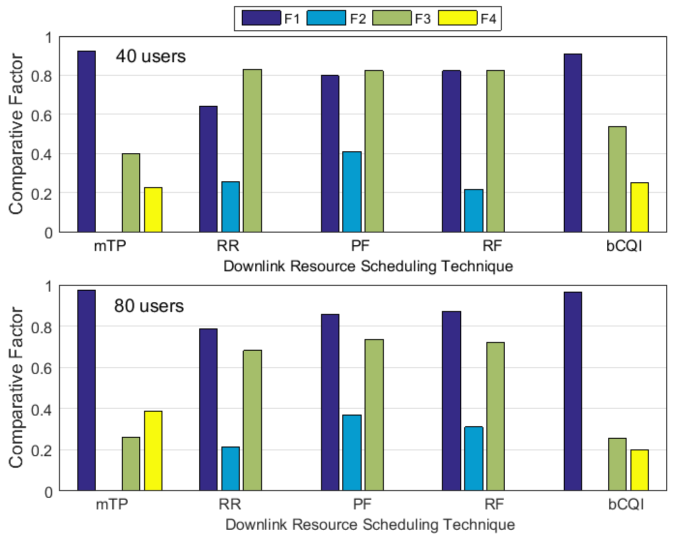

Figure 3. Peak CF components' values for 40 and 80 users

The slight increase or decrease in the value of a parameter can be compensated for by another parameter constituting the CF. In this context, the proposed CF is affected even by small changes in the location of the femtocells and alters its value depending on the specifics of the investigated indoor environment. Thus a generalised metric, such as the introduced CF, can show the flexibility of the different downlink RSTs.

In determining the maximum values of the CF, the number of simulations performed is of great importance. The locations of femtocells have a huge impact on the results and, at times, increasing the number of users does not have the anticipated negative impact on overall performance. This is because an optimal location of the femtocells is found which reduces or even neutralises the negative impact of the increased number of UEs and the consequent logical reduction of the resources.

V. Conclusion

In order to overcome the narrow scope of the most commonly-used indoor resource scheduling techniques, a more aggregated assessment is offered, entitled Comparative Factor. Summarising four different indoor performance parameters, the CF evaluates downlink RSTs in a complex, multi-faceted and flexible manner. After the CF is analytically introduced, it is experimentally studied for a varying number of users and a fixed number of differently located femtocells in an indoor wireless environment simulated via RIEG. The simulation results for the peak CF show the best possible location of the femtocells for a certain number of UEs when a particular RST is applied.

A detailed analysis of the indoor performance parameters which constitute the CF clearly shows the pros and cons of different resource allocating algorithms and offers ideas for both their improvement and cooperative usage. A limited amount of assumptions for the simulation process, an increased number of simulations and a highly realistically-modelled indoor environment would assist in reaching a more precise assessment of the CF value, which is a metric to determine the level of the QoS.

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