A Comparative Factor Evaluation of Downlink Resource Allocation Algorithms in Indoor Communication Environments

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Abstract – **In this paper a new comparative factor (CF) is developed and used to compare several classic downlink resource allocation algorithms (RAAs) in indoor wireless environments, simulated by means of the Realistic Indoor Environment Generator (RIEG). The CF components' values are analysed for five different downlink RAAs studied across different numbers of users.**

Keywords – **Resource allocation algorithms; Small cells; Indoor communication environment; Comparative factor.**

I. Introduction

As a result of urbanisation, a large percentage of current mobile traffic takes place in indoor environments, where many obstacles impact signal propagation and thereby deteriorate the users' Quality of Service (QoS). Today's consumers are interested not only in the variety and availability of services, but also in coverage and data rates. A consistent, predictable, trouble-free indoor environment would contribute to ensuring an adequate QoS for users.

Small cells are an inexpensive and elegant approach to improving wireless indoor coverage, due to their flexible distribution and low transmission power. The throughput of an item of user equipment (UE) is affected by many factors, including the distance from the serving transmitter, the availability of a multipath environment, applied multiple antenna techniques, as well as resource allocation algorithms (RAAs). RAAs for wireless communication has been an active research area in recent years, due to the rapidly-increasing demands on data rates which has led to a large growth in traffic [1]. Many publications have compared different resource allocation scheduling algorithms in heterogeneous networks, comprising macro- and small-cells. However, the comparison has been mainly in terms of average UE throughput and "fairness". Thus the number of outages and the throughput of cell-edge users have not been considered. Another flaw in the studies so far relates to the simulations themselves and it is that the network models and chosen simulation parameters are insufficiently realistic [1], [2].

Since each algorithm for the distribution of available resources has pros and cons, the intelligent solution logically involves the development of a mixed scheduler design. The *proportional fair* algorithm, often regarded as the optimal choice, strikes a balance between system fairness and throughput. A combination of *proportional fair* and *maximum throughput* algorithms may maximise system throughput with guaranteed fairness for users [3], [4].

In order to provide an excellent indoor QoS in line with users' needs, telecommunication service providers need to apply RAAs that ensure a high average user throughput (particularly for cell-edge users), good fairness with regard to radio resource distribution, and lack of outages. The balance between the above parameters is highly important in indoor environments (offices, shopping centres, markets, et al), since the traffic demands are higher and the signal propagation is deteriorated. In this work we develop and introduce a CF that comprises the above-mentioned performance parameters and use it to compare five resource allocation algorithms in several indoor scenarios. Thus a particular RAA can be recommended depending on the number of the users and femtocells.

Experimental results are carried out by the Vienna LTE-Advanced (LTE-A) system level simulator [5]. Since femtocells are often deployed in a network by clients they are usually spread in an uncontrolled manner, which does not help the efficient performance of the network. An adequate location of the femtocells in line with the specifics of the indoor environment, as well as usage of appropriate downlink resource allocation algorithms, will contribute to a better coverage and data rate for the users, thus improving the QoS.

The paper is organised as follows: Section II describes the downlink resource allocation algorithms. Section III presents the system model of the indoor environment and introduces the comparative factor. Section IV discusses the system level simulation results, and Section V concludes the paper.

II. Downlink Resource Allocation Algorithms

The scheduling RAAs can be summarised into two types, each following a different strategy: channel-independent scheduling (CIS) and channel-dependent scheduling (CDS).

The CIS strategy can never provide an optimal solution in a wireless network, due to the lack of information about the channel conditions. On the other hand, the CDS strategy is based on optimal algorithms and can thus achieve a better performance by allocating resources, since it has information about the channel quality.

A. Channel-independent scheduling strategies

The CIS strategy was first introduced in wired networks and is based on the assumption of time-invariant and error-free

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transmission media. Since this is unrealistic for LTE networks, it is typically used in combination with the CDS strategy to improve system performance. In this publication two algorithms based on the CIS strategy are discussed: ***Round Robin*** (RR) and ***Resource Fair*** (RF).

The RR algorithm allocates resources to each UE, without taking into account the channel quality or data rate.

At first, UEs are queued at random, with each new UE joining the end of the queue. All available resources are assigned to the first UE in the queue, any unused resources then becoming available for the next UE and so on until the queue does not contain any UEs requesting resources.

The RF algorithm distributes resources equally among all UEs, with the goal of achieving the maximum total rate for all UEs while simultaneously ensuring fairness in regard to the number of resource blocks allocated to each UE.

B. Channel-dependent scheduling strategies

The CDS strategy allocates resources via optimal algorithms in respect to the channel conditions. In this paper, three CDS strategy-based algorithms are investigated – ***Maximum Throughput*** (MT), ***Proportional Fair*** (PF) and ***Best Channel Quality Indicator*** (CQI).

The MT algorithm achieves maximum throughput thanks to the multiuser diversity of the system. Primarily, UEs' reports about channel quality indicators are considered in order to identify the data rate of a sub-channel for the UEs. Thus UEs can be ranked as having good or bad channel quality, resources accordingly being allocated to users so that each one achieves the highest possible throughput in their identified sub-channel on the basis of the signal-to-noise ratio (SNR). The aim of the MT algorithm is only to maximise the throughput and it attains this by assigning the resources in an unfair manner.

Fairness is improved when the PF algorithm is applied and the average throughput is preserved, i.e. efficiency is retained. A priority function is calculated as a ratio of the instantaneous to average throughput and is used to prioritise the UEs. The highest priority user is allocated resources, thereafter the priority function is re-calculated and another UE get the highest rank. The algorithm repeats until either all UEs' needs are satisfied or the resources are exhausted.

The idea behind the Best CQI algorithm is to assign resources to the UE with the best radio-link environment. In order to calculate the CQI, UEs and the base station (BS) exchange signals. In the downlink direction, the BS transmits reference signals to the UEs. These downlink pilots help the UEs to calculate the CQI, which is fed back to the BS to identify the best CQI. The higher the value of the CQI, the better the quality of the channel.

III. SYSTEM MODEL

A. Indoor wireless network layout

To compare the performance of different resource allocation strategies a realistic indoor environment comprising different numbers of small cells (femtocells) and users is employed. Simulations are conducted in indoor design, using the wall layout method named Realistic Indoor Environment Generator (RIEG) [6]. The RIEG method distributes rectangles, thus modelling a floorplan with many rooms and corridors. The arrangement of the walls is 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 are 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* L_{sum} will be obtained:

$$L_{sum} = \eta\lambda\,. \tag{1}$$

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 lack of interference from BSs is assumed.

The indoor network environment layout is shown in Fig.1. The dots represent UEs, while the circles denote femtocells (transmitters). The model excludes the possibility of a UE or a transmitter being located exactly in a wall.

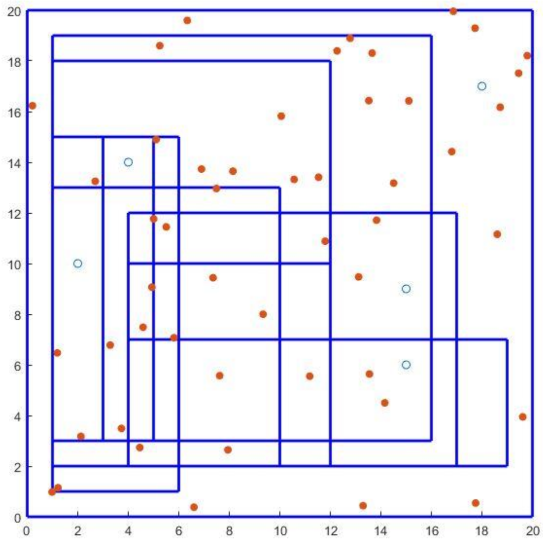

Fig. 1. Indoor wireless network environment layout based on the RIEG wall layout method

B. The Comparative Factor

Different scheduling RAAs 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 RAA for use in an indoor environment.

In this work we propose a CF, which is a generalised metric, and simultaneously takes into account four different indoor performance parameters – *normalised average user throughput*, *normalised average cell-edge user throughput*, *fairness* and *outage ratio*:

$$F = F_1 + F_2 + F_3 - F_4 \,. \qquad (2)$$

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 UEs 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:

$$T_{avg} = \frac{\sum_{k=1}^{N} T_k}{N} \,, \qquad (3)$$

where T_k is the throughput of k-th user, and N is the number of users.

In order to transform (3) 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 are 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 follows:

$$F_1 = \frac{T_{avg}}{T_R} \,. \qquad (4)$$

F_1 ranges from 0 to 1, and its best value is 1 when the average user throughput is equal to the reference user throughput. The worst case ($F_1 = 0$) occurs when obstacles are so numerous that the users' throughput becomes zero.

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 UE 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:

$$F_2 = \frac{T_{avg\_edge}}{T_{R\_edge}} \,. \qquad (5)$$

Since the reference throughputs are used to determine the maximum value of throughputs, like 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 UEs 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. It is defined as:

$$F_3 = \frac{\left[\sum_{k=1}^{N} T_k\right]^2}{N \sum_{k=1}^{N} T_k^2} \,. \qquad (6)$$

Outage ratio (F_4):

The *outage ratio* represents the ratio of the number of users with outages N_{out} to the total number of users N:

$$F_4 = \frac{N_{out}}{N} \,. \qquad (7)$$

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 Simulations and Analysis of the Results

A. Simulation setup

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

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
Number of simulations	100
Simulation time	0.1 s
Wall density	0.2 m^{-2}
Wall attenuation	10 dB
Simulation area size (RoI)	20 m x 20 m
Reference area size (RoI)	8 m x 10 m

B. Experimental results analysis

The maximum values of the CF for the five scheduling RAAs and for different numbers of users are shown in Fig. 2. The RR, PF and RF algorithms provide a good coverage according to the corresponding CF values. The PF algorithm shows best performance, despite the number of users and achieves a balance between the CF components and hence the best QoS.

The RF and RR algorithms achieve monotonically smooth curves due to their excellent fairness. The increased number of UEs and the reducing amount of the available resources per user affect the performance of the MT and Best CQI algorithms to the greatest extent. The increased number of cell-edge users leads to a significant reduction in the value of the CF, when throughput maximisation is desired. The maximum of the CF for each scheduling RAA is achieved in the best location of the femtocell for the corresponding number of users.

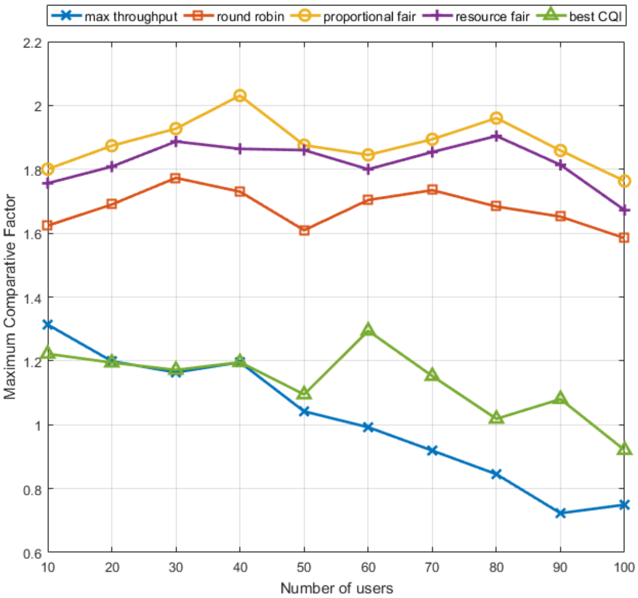

Fig. 2. Maximum Comparative Factor as a function of the number of users

The values of the four indoor performance parameters of the CF for different numbers of users is depicted in Fig. 3.

The MT and the Best CQI RAAs contribute most to accomplishing an excellent normalised average throughput (F_1). The parameter F_2, which refers to the cell-edge users' QoS, shows that it is poor and that outages are often observed. The PF RAA behaves similarly to the RF and RR algorithms in respect to the parameters F_1, F_3 and F_4.

A clearly-defined goal of next-generation networks is to provide an excellent level of mobile services to users located at the periphery of the cell. The RF and RR algorithms based on the channel-independent strategy are easier to implement and control due to the lack of channel information. For this reason, they are often preferred over the PF RAA.

V. Conclusion

In this paper a Comparative Factor comprising four performance parameters has been proposed to compare five scheduling RAAs. The experiments conducted demonstrate that the PF algorithm achieves the maximum values of the CF for any number of users, thus providing the best QoS. The contribution of each component of the CF for the assessment of the most often-used RAAs is experimentally evaluated. Future work may focus on the investigation of scenarios when specific traffic models are also considered. The CF can be used not only for comparison of scheduling RAAs but also for different issues that affect the users' QoS.

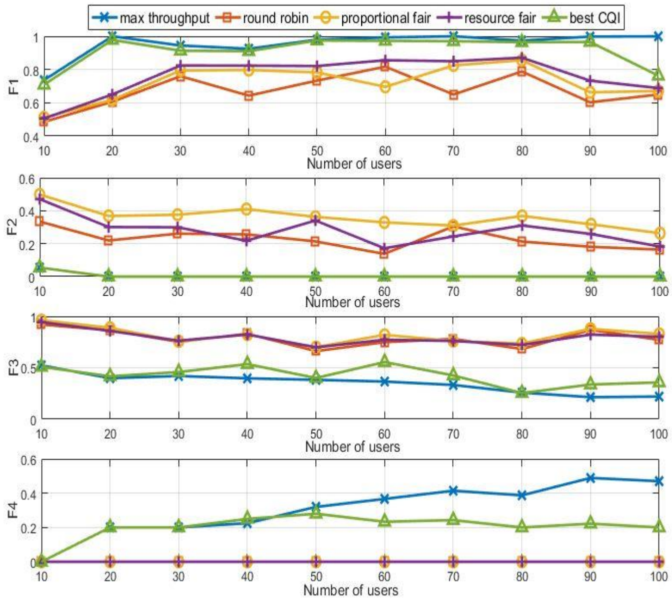

Fig. 3. Comparative Factor components for different number of users

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