A Tunable Framework for Performance Evaluation of Spectrum Sharing in LTE Networks

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***Abstract*—Current spectrum allocation policies, imposing exclusive usage of a licensed operator, may lead to inefficient management and waste of resources. Spectrum sharing, i.e., usage by the same frequency band by multiple operators, can improve the efficiency of the allocation. We analyze a scenario where two mobile operators managing neighboring cells also share a fraction of their available spectrum and quantify the performance gain. To this end, we propose a framework based on the definition of the Interference Suppression Ratio, which models effects such as beamforming or directional antennas. Depending on its value, mutual interference among the operators is reduced and sharing gains can be achieved. We implemented this framework in the well known open-source simulator ns-3 and we ran a parametric analysis of the impacting factors, including noise and cell radius. Simulation results confirm that significant gains can be achieved in terms of network capacity and throughput, provided that the Interference Suppression Ratio is above a given value.**

***Index Terms*—Spectrum Sharing; wireless networks; radio resource allocation; cellular systems; Long Term Evolution; beamforming; network planning.**

I. INTRODUCTION

In the last few years, a widespread diffusion of mobile phones and the appearance of novel applications for multimedia communications and the mobile Internet have caused a great demand for wireless connectivity all over the world.

Very recently, a possible solution to address these issues has been identified in *cooperation* among multiple agents of the network allocation, i.e., operators and users, even belonging to different networks and systems. In this paper we will focus on wireless cellular networks, with specific reference to the downlink of Long Term Evolution (LTE) of the Universal Mobile Telecommunication System (UMTS) [1]. In our context, cooperation can take place between multiple operators, which normally operate on exclusive frequency bands, through share access to the spectrum, resulting in what is called *spectrum sharing*.

Spectrum sharing may be *orthogonal*, meaning that access to the shared resources by either operator automatically excludes the other one, or *non orthogonal*, where the operators are allowed to use the same transmission frequency resource simultaneously. In the latter case, we aim at achieving an efficient usage of the available bandwidth and improving the performance in terms of capacity and throughput by means of increased spatial and frequency diversity. Therefore, we can perform non orthogonal sharing only if the interference is below a predetermined threshold. In fact, when users are allocated simultaneously on the same frequency, the inter-cell interference must be coordinated, e.g., through the use of multiple antennas and proper mitigation technique, such as beamforming [7]. The EU-funded project SAPHYRE [6] explicitly aimed at assessing the potential gains deriving from cooperation among the operators in resource allocation for cellular networks; in this context, spectrum sharing is identified as an extremely promising solution. Although the problem of interference channels and spectrum sharing have been addressed in several papers [5], and few of them have considered the scenario of inter-cell spectrum sharing was considered only in few of them, and even fewer papers have focused on multi-operator networks. The interest in this area increased during the last few years, involving not only researchers, but also telecommunication companies and regulatory bodies. The exact characterization of these techniques in a network-wide scenario may be extremely challenging, especially when evaluating the performance of a beamforming system involving dozens of users. In this paper, we decided to keep a more general and modular approach, which can be used in a network simulator. Therefore, we abstract all the physical layer effects by considering the Signal-to-Interference-plus-Noise Ratio (SINR) to be regulated by a parameter that we call Interference Suppression Ratio (ISR). Moreover, we exploit this definition into the spectrum sharing framework [4] of ns-3, a well-know open source and modular network simulator widely used by the scientific community. Then, we evaluate the system performance to demonstrate the advantages of non orthogonal spectrum sharing when compared to exclusive resource usage.

II. SYSTEM MODEL

Our reference scenario involves two adjacent LTE Base Stations (BSs) managed by different operators that are serving two groups of users in the same geographical region. The operators have the opportunity to share, partially or totally, their spectra, as shown in Fig. 1, here $\mathcal{Q}$ is the set of all sub-channels for the downlink, equally divided between the two BSs, and $s \in (0, 1)$ represents the sharing percentage. The spectrum is divided into groups of adjacent sub-carriers, called sub-channels; a private subchannel can be accessed by a single user whereas a shared one can be accessed by one users

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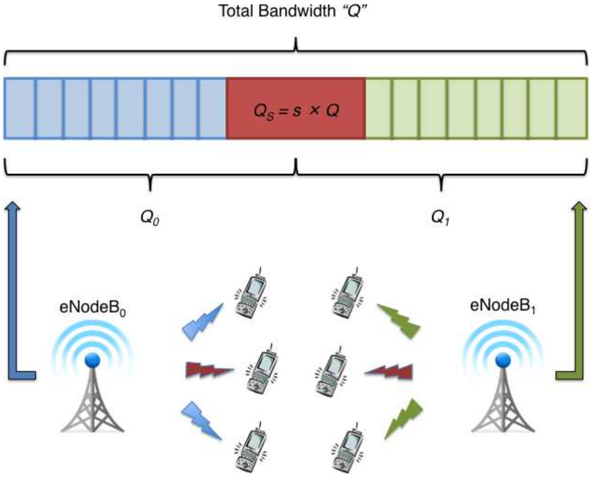

Fig. 1. Adopted scenario

per operator, depending on the scheduling algorithm used.

Non orthogonal sharing introduces the problem of inter-operator interference. The signal received by each UE is affected by the transmission toward other users that are sharing the same time-frequency resource. The SINR perceived by the users is degraded with respect to the no-sharing case, where access to the resource is mutually exclusive and the inter-operator interference is zero. This effect can be reduced, or entirely cancelled, by using linear precoding beamforming techniques that are able to reduce the interference but that at the same time decrease the useful power level received by the UEs. If SNR_{nsh} is the SINR in the no-sharing case and $SINR_{sh}$ is the SINR in the non orthogonal sharing case, we can re-evaluate the performance of spectrum sharing by considering the same indicators of the case without sharing and doing the following replacement

$$SNR_{nsh} = \frac{P_S}{\sigma^2} \implies SINR_{sh} = \frac{P_Q}{\sigma^2 + P_I} \qquad (1)$$

where P_S is the useful power in the no-sharing case, P_Q is the useful power in the non orthogonal sharing case, P_I the inter-operator interference and σ^2 is the noise power.

To summarize the SINR user degradation experienced in the no-sharing case, we introduce the parameter ISR $\in (0, 1)$, defined as:

$$ISR = \frac{SINR_{sh}}{SNR_{nsh}} . \qquad (2)$$

As will be shown next, the definition of the ISR enables a compact, low-complex representation of all PHY layer effects to be considered in the network performance evaluation. Actually, the evaluation becomes quite flexible, as the impact of beamforming procedures and user selection mechanisms can be translated into the proper ISR value.

III. NUMERICAL RESULTS

To assess the performance of the ISR parameter we run a simulation campaign extending the version presented in [2] of the well known Network Simulator 3 (ns-3) [3]. In our version, the resource allocation scheduling depends on the type of channel, namely private or shared. For private channels, a "max throughput" policy is implemented, i.e., all the resources are allocated to these users with the highest Channel Quality Indicator (CQI). Users without a resource assignment are allocated in the shared pool. Here the pairwise allocation that maximizes the throughput sum is made. The SNR perceived by the users in the shared resource pool are then perturbed according with to ISR.

The scenario consists of two eNBs spaced by 50 m and 40 UEs for each eNB, uniformly distributed within the associated eNB coverage area. The other main system parameters are reported in Table I.

Parameter	Value
1-st sub-channel frequency	2110 MHz
Downlink Channel Bandwidth	5 MHz
Sub-Carrier Bandwidth	15 kHz
Doppler Frequency	60 Hz
Resource block bandwidth	180 kHz
Resource block carriers	12
Resource block OFDM symbols	7
BS downlink TX power	43 dBm
Noise spectral density	-174 dBm/Hz
Macroscopic Pathloss (distance R)	$128.1 + (37.6 \cdot \log(R))dB$
Shadow fading	log-normal
Multipath fading	Jakes (6-12 scatterers)
Wall penetration loss	10 dB
Frame duration	10 ms
TTI (sub-frame duration)	1 ms
Cell coverage	5 km
Cell distance	50 m
Number of UEs per BS	40

TABLE I
MAIN SYSTEM PARAMETER

The results obtained are expressed in terms of throughput, which represents the average sum data rates delivered to all UEs. For non orthogonal sharing, throughput increases with respect to the no-sharing case when a certain ISR threshold has been exceeded and when noise power is sufficiently low. Clearly, if the system is noise limited, rather than interference limited, there is no improvement in coordinating interference. Fig. 2 shows that the asymptotic case when the ISR is equal to 1, i.e., perfect interference cancellation, and the BSs share all of their spectra, is the best case, the gain is even higher than 100% due to increased multi-user diversity. However, it is worth noting that the curves are sufficiently flat so that significant gains are achieved even when these conditions are not met. Moreover, the results show that it is always better to have a full, i.e., 100% sharing of the available frequencies. This may not be possible due to internal policy requirements of the operators; nevertheless, the larger the fraction of shared spectrum, the better.

Then, we compare the previous results with the performance obtained by applying feasible beamforming techniques in a Multiple-Input-Single-Output (MISO) 2×1 full sharing LTE system. The main system parameters used in the simulation are reported in Table I but in this case only two UEs, positioned at 1.5 km from the BS, are involved in the communication. We

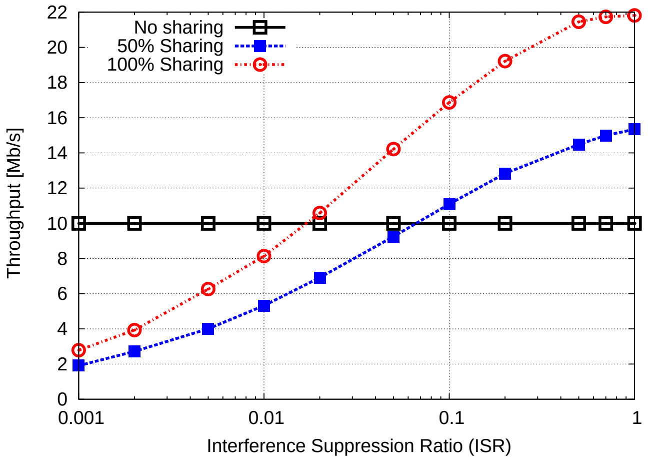

Fig. 2. Total sum throughput varying ISR parameter.

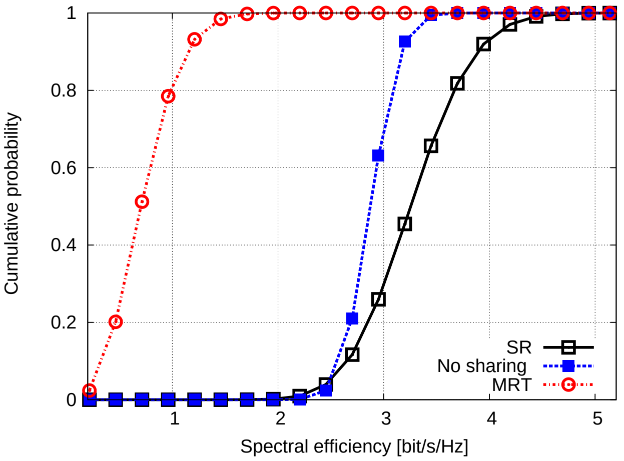

Fig. 3. Spectrum sharing gain for different beamforming techniques

considered two different linear precoding beamforming techniques: the Maximum Ratio Transmission technique (MRT) and the Sum Rate technique (SR).

The first approach, MRT, uses linear preconding beamforming matrices that maximize the transmission rate when no interference is perceived by the users. Since this technique does not include any kind of collaboration, it achieves a Nash Equilibrium, i.e. the best result for each user individually, from a selfish standpoint. However, its global performance, i.e., considering the two users jointly, is inefficient due to the high mutual interference. Conversely, in SR, the linear precoding beamforming matrices are computed to achieve the Pareto Optimal operation point that achieves the best sum rate. This operation point is one point of the upper-right boundary (Pareto Boundary) of the region that collects all ratetuples that can be achievable simultaneously by the users under a certain set of transmit-power constraints. So a point on the Pareto Boundary consists of rate tuples at which it is impossible to increase the rates of some users without decreasing the rate of at least one of the other users [8].

Fig. 3 compares the performance of the no-sharing approach with that provided by full sharing, where the multi-user mode is obtained by using the beamforming techniques described previously. As expected, the MRT system performs poorly in terms of spectral efficiency with a significant loss respect to the no-sharing setting. On the other hand, the SR system outperforms the MRT system and provides some improvement compared to the no-sharing scenario.

Comparing the gains achieved in the sharing cases, it can be seen how the MRT technique corresponds to a value of ISR around 0.002, while the SR technique corresponds to a value of ISR between 0.02 and 0.05. We expect that a higher value of ISR can be achieved using a smart selection of the users that consider the conditions of the channel and the beamforming technique used. In any event, this confirms our assumption that suppression ratios of 5% or higher are feasible for practical systems, thus implying that the gains achievable by non orthogonal sharing are realistic.

IV. CONCLUSIONS

In this paper we have proposed a modular framework based on the definition of an ISR parameter to evaluate the spectrum sharing performance. Numerical results show that *non orthogonal spectrum sharing* leads to considerable gains, in spite of the presence of inter-cell interference that degrades the SINR perceived by the users as long as some interference suppression techniques, such as beamforming or multiple-input-multiple-output transmission, are available. This means that the ISR parameter must be sufficiently high in order to have practical gains. However, we quantified the ISR range of actual beamforming techniques and we found that these values are in line with our simulation report. Moreover, for complexity reasons our estimates are conservative, as we did not exploit any user selection mechanism that could push the ISR even further. Thus, non-orthogonal spectrum sharing appears as a way to extend current network planning paradigms that can improve the performance of future communication networks.

REFERENCES

[1] *LTE physical layer*, TS 36.201 (V9.1.0), 3GPP, 2010.

[2] L. Anchora, M. Mezzavilla, L. Badia, M. Zorzi, ”A performance evaluation tool for spectrum sharing in multi-operator LTE networks”, *Computer Communications*, Vol. 35, pp. 2218-2226, Nov. 2012.

[3] *NS-3 simulator*. Available: http://www.nsnam.org/.

[4] http://code.nsnam.org/lanchora/ns-3-lte-SpectrumSharing.

[5] R. Etkin, A. Parekh, D. Tse, ”Spectrum sharing for unlicensed bands,” *IEEE Journal on Selected Areas in Communications*, vol. 25, no. 3, pp. 517-528, April 2007.

[6] E. A. Jorswieck, L. Badia, T. Fahldieck, D. Gesbert, S. Gustafsson, M. Haardt, K. M. Ho, E. Karipidis, A. Kortke, E. G. Larsson, H. Mark, M. Nawrocki, R. Piesiewicz, F. Römer, M. Schubert, J. Sykora, P. Trommelen, B. van den Ende, M. Zorzi, ”Resource sharing in wireless networks: The SAPHYRE approach,” *Future Network and Mobile Summit 2010*, pp. 1-8, 2010.

[7] R. Mochaourab, E. A. Jorswieck, ”Optimal Beamforming in Interference Networks with Perfect Local Channel Information”, *IEEE Transactions on Signal Processing*, vol. 59, no. 3, pp. 1128-1141, March 2011.

[8] E. A. Jorswieck, E. G. Larsson, and D. Danev, ”Complete Characterization of the Pareto Boundary for the MISO Interference Channel”, *IEEE Transaction on Signal Processing*, vol. 56, no. 10, pp. 5292-5296, Oct. 2008.