Interference management for mixed services through power control and service-based power setting

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Abstract— **The efficient handling of radio resources is a crucial topic for the success of cellular systems. Since interference is the main capacity limiting factor, radio resource management techniques able to reduce/control interference can be of great utility to improve system capacity and QoS. In this work, we evaluate power control and service-based power setting as means to improve capacity of single and multi-service cellular networks. A complete system level simulator is used to assess the performance gains of these two techniques considering the voice service using the EFR and MR59-FR voice codecs and a WWW data service in a GSM/EDGE network. The capacity gains of power control applied to these services is characterized for single service scenarios. Mixed-service simulations are performed for different mixes of EFR and WWW users and mixes of EFR and MR59-FR users in order to assess the performance of SBPS, either alone or combined with power control. Finally, conclusions are drawn on the results presented for the evaluated scenarios.**

I. Introduction

The efficient handling of radio resources as to improve system QoS and capacity is a key requirement for the success of modern cellular systems in their continuous evolution towards 3G and 4G.

To improve capacity, tight frequency reuse patterns are usually implemented by these systems in combination with suitable techniques to reduce interference to acceptable levels. In this context, power assignment and control techniques, such as Power Control (PC) [1] and Service-based Power Setting (SBPS) [2]–[4], were shown to be adequate methods to manage interference and improve capacity while preserving QoS requirements.

Several works on PC considered static simulations and have shown that substantial capacity gains can be obtained by using PC, especially for the voice service (e.g., [5]). SBPS, on its turn, was used to balance the interference levels supported by different services and was shown to maximize combined service capacity. Moreover, both techniques can also be combined to implement interference balancing and provide maximum combined service capacity in multiple service environments [6].

In this work, we study the performance of these two techniques as means to manage interference and improve the capacity of cellular systems. The individual and combined performance of these techniques are investigated by using a dynamic system-level simulator considering voice and WWW services. The analyses considered a GSM/EDGE network with its most relevant aspects thoroughly modeled. Section II details the simulation model used in this work. Section III presents the obtained results and capacity figures. Finally, in section IV, some conclusions are drawn.

II. Simulation model

The simulations conducted in this work employed a dynamic system-level simulator previously described in [7], [8]. The simulator models the most relevant aspects of a GSM/EDGE radio access network. Both voice and WWW services are modeled in the simulator, as well as user mobility, propagation effects (path loss, log-normal spatially correlated shadow fading and fast fading). The most important GERAN features, such as link adaptation (LA), discontinuous transmission (DTX), measurement and reporting mechanisms, random frequency hopping and RLC/MAC protocol stack, are also thoroughly modeled.

In this study, both single and mixed-service scenarios were considered. The performance analyzes were first conducted for single service scenarios with and without power control. The SBPS performance was evaluated for mixed-service scenarios considering mixes of voice and data and mixes of speech services with different codecs. The performance evaluation of both techniques was carried out considering a macro-cellular environment implementing either a 1/3 or a 1/1 frequency reuse. Performance was assessed for pedestrian mobility only, where a random-walk mobility model with mean speed of 3km/h has been considered. Other mobility profiles were not evaluated due to the unavailability of suitable link-level results.

The most relevant simulation parameters employed in the simulations are listed in table I.

The power control algorithm employed in this work is a simple up/down algorithm. It performs one iteration at each 480ms, i.e., at each Slow Associated Control Channel (SACCH) multiframe period. The measurement and reporting mechanism model takes into account the delay associated with report transmission in the uplink and time-delay compensation is used to avoid instability, as described in [9].

Due to the link-to-system level interface used in the simulator, which maps directly Signal-to-Interference plus Noise figures to Frame Erasure Rates/Block Error Rates, the mean SINR of the radio blocks transmitted within the previous measurement report period is used instead of the standard link quality measurements of GERAN, i.e., RX_QUAL, MEAN_BEP and CV_BEP.

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TABLE I

SIMULATION PARAMETERS

Characteristic	Value
System	
Bandwidth	2.4Mhz
Frequency of operation	2GHz
Cell layout	sectorized
Sector radius	500m
Frequency reuse	1/3, 1/1
Link direction	Downlink only
# of transceivers/sector	12
Mobile station type	single-slot
Simulation and traffic	
# of calls/sessions simulated	at least 10000 per service
Traffic types	EFR voice, MR59-FR voice, WWW data
Mean voice call length	120s
Mean voice activity	≈60%
WWW traffic model	see [8]
Mobility profile	Pedestrian 3km/h
Propagation	
Path-loss model	$128.15 + 37.6log_{10}(d)$dB
Log-normal shadow standard deviation	6dB
Shadow decorrelation distance	110m
Fast-fading	modeled in the link-level
Power control	
Maximum transmission power	35dBm
Minimum transmission power	5dBm
Power levels	discrete in steps of 2dB
Frequency of actuation	1 iteration at each 480ms
Target SINR Γ_t	18dB (voice) / 35dB (WWW)
Power control algorithm	Up/down

This model, however, can be easily related to other models using standard link quality measurements and an up/down PC algorithm.

In this work, voice capacity is defined as the voice load, in Erl/MHz/cell, at which 95% of the users verify a mean Frame Erasure Rate (FER) lower than a pre-defined threshold. We adopted as QoS requirement a mean FER of 1% and 0.6% for EFR and MR59-FR voice users, respectively. In other words, a user is satisfied if he verifies the mean FER target during his call. The more restrictive mean FER threshold for MR59-FR stems from the fact that its voice quality may be slightly worse than that of EFR. AMR rate adaptation was not simulated in this study.

Data capacity, similarly, is defined as the data load, in bps/Hz/cell, at which 90% of the users verify an average packet throughput of, at least, 10kbps per time-slot.

In mixed service scenarios the requirements of all services must be fulfilled simultaneously. All considered mobile stations are single-slot.

III. SIMULATION RESULTS

Single service simulations were initially performed in order to determine the capacity limits of each service. Since SBPS is intended for mixed scenarios, only power control has been considered for single service simulations.

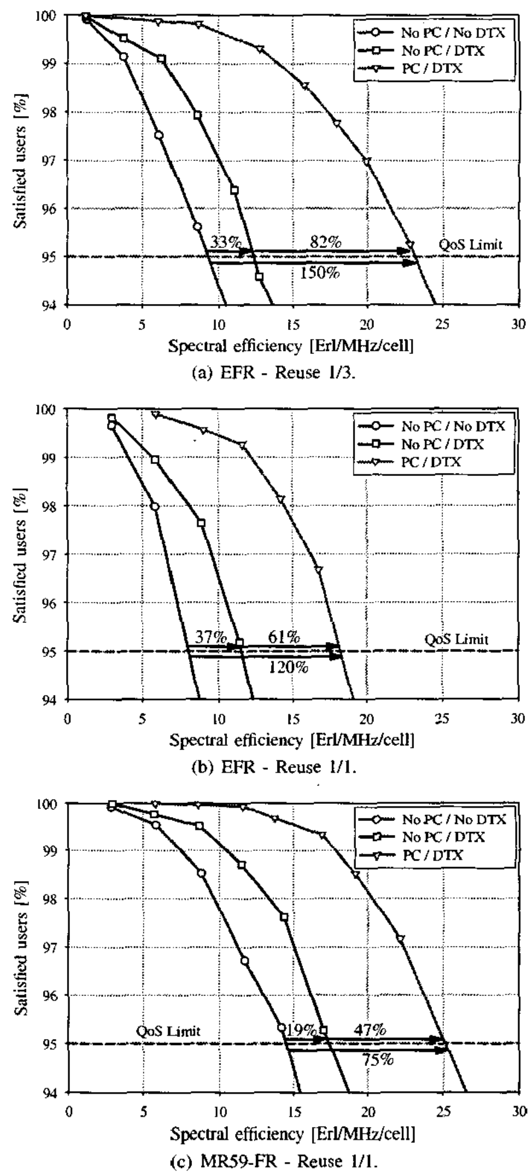


Fig. 1. Power control performance for voice services.

A. Power control performance for voice services

In order to obtain performance curves for power control, simulations were conducted by increasing the offered load of each service until its QoS limit was reached. Figure 1 shows the performance of power control for EFR and MR59-FR with reuses 1/3 and 1/1.

It can be seen that power control provides system capacity gains to voice services up to 82%/150% while maintaining QoS requirements. Its well-known abilities of using only the minimum transmission power required and adapting to channel variations are specially useful to reduce interference levels in the system and improve capacity. The achievable gains are all indicated in figure 1, where DTX gains are also presented for illustration purposes.

Due to its robustness, the MR59-FR voice service is blocking limited when considering a 1/3 reuse. In the 1/1 reuse, it becomes interference limited while EFR is interference limited in both reuses. From figures 1(a) and 1(b), one can see that the EFR performance is poor in the 1/1 reuse and that its performance with PC in the 1/3 reuse is comparable to that of MR59-FR in reuse 1/1.

When considering a network where EFR and MR59-FR users are present, one can select the best reuse to be implemented according to the fraction of users of each codec. The more EFR users present in the network, the more suitable the 1/3 reuse, and conversely the reuse 1/1. However, if a 1/3 reuse is selected, the network capacity will not be maximized, since interference-limited systems show, in general, higher capacities than blocking-limited systems. Moreover, the SBPS power offset intended to reduce the amount of interference caused by the more robust service (MR59-FR) over the less robust service (EFR) cannot be easily calculated for blocking limited systems, since MR59-FR supports even more interference than the maximum interference level admitted by the network using a 1/3 reuse.

Therefore, for mixed service simulations considering EFR and MR59-FR voice services, an interference-limited scenario implementing a 1/1 frequency reuse will be considered in section III-C when evaluating the performance of SBPS.

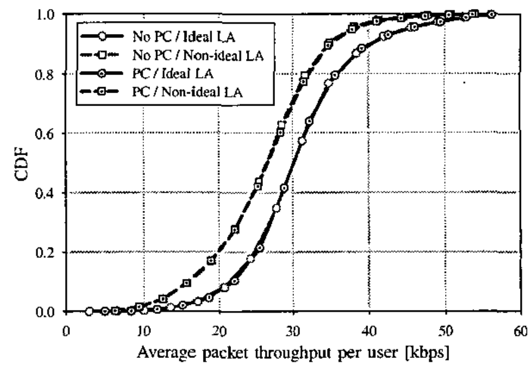
B. Power control performance for the WWW service

The same methodology used in the previous section was applied to the WWW service. Due to the bursty nature of WWW traffic, power control does not improve significantly data system capacity. This fact is illustrated in figure 2(a) for a fixed offered load while figure 2(b) shows the performance of the WWW service using non-ideal LA without power control for the 1/3 and 1/1 reuses.

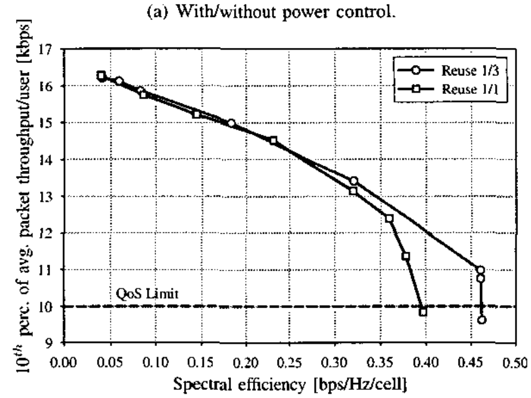
For the WWW service, the target SINR was set to 35dB in order to avoid competition between the LA mechanism and power control, as in [10]. This selection gives LA, which is intended to adapt the modulation and coding scheme according to channel conditions, priority over power control. For packet data services in GERAN, this is a requirement stated in the standards [11]. Additionally, we also evaluated the performance of PC considering ideal and non-ideal LA for illustrative purposes. In ideal LA, modulation and coding scheme (MCS) selection is performed for each radio block based on the SINR. For the non-ideal case, selection is done at each 480ms based on the mean SINR of the period. In both cases, power control did not improve data capacity, as can be observed in figure 2(a).

C. Service based power setting performance

Nowadays cellular networks are able to offer a diversified set of radio services to its customers. This multi-service nature imposes to these systems additional engineering problems



(a) With/without power control.



(b) Without power control.

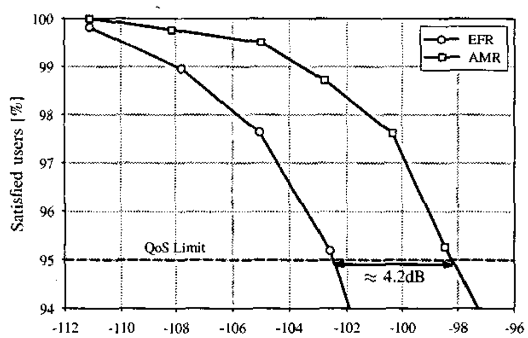
Fig. 2. Performance of the WWW service with/without power control and ideal/non-ideal link adaptation.

when compared to the single service scenario of older cellular systems.

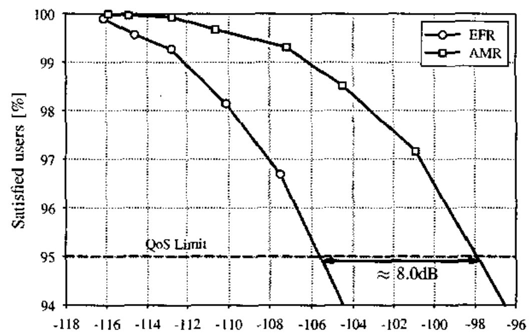
Each service usually has specific QoS requirements and properties, which can make it more or less robust against interference. In [6], the concept of interference balancing through the use of power offsets is used as a form of maximizing the combined service capacity of the systems.

Since in multi-service scenarios the multiple QoS requirements must be met, if a service is less robust to interference, it will limit the fraction of other services that the system is capable of supporting, thus limiting the capacity of the whole system. The idea behind the SBPS technique presented in [2]–[4] is to balance the interference among services in a way that the interference of the more robust services over the less robust ones is reduced and all QoS limits are met simultaneously.

This interference reduction is implemented by SBPS through power offsets, which reduce the maximum power that can be used by the more robust services. This reduction in the interference works as an exchange of QoS among the services, i.e., the excess quality verified by the more robust services is reduced by lowering their transmission powers and traded by an increase in the QoS of the less robust services, resulting in a higher combined service capacity. This interference balancing,

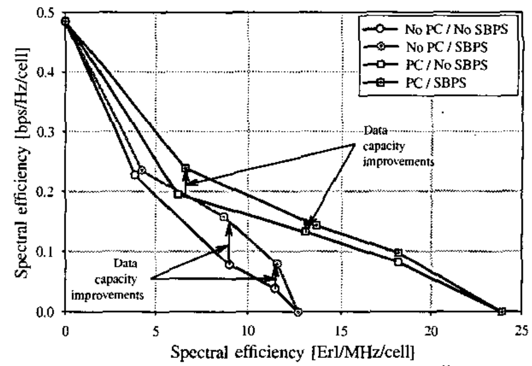


(a) EFR + MR59-FR - Without PC.

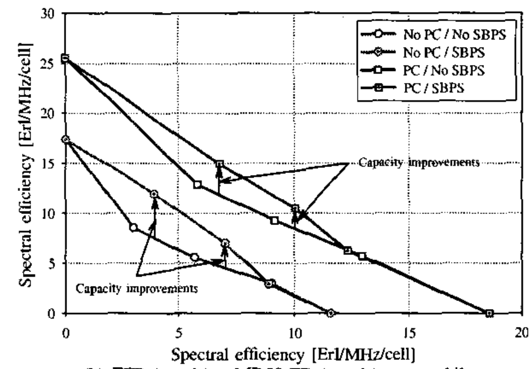


(b) EFR + MR59-FR - With PC.

Fig. 3. Power control performance for voice services in 1/1 reuse.



(a) EFR (x axis) + WWW (y axis) - reuse 1/3.



(b) EFR (x axis) + MR59-FR (y axis) - reuse 1/1.

Fig. 4. Power control performance for voice services.

with all services meeting their QoS limits together, leads to the maximum combined service capacity, as demonstrated in [6].

In scenarios where the capacity of each service depends only on the average amount of interference, but not of its nature, the SBPS offsets can be calculated by estimating the average interference level supported by each service. This estimation can be derived as the average of the interference verified by each user in the system during the whole single service simulation.

This affirmative shall be valid as long as we are employing random frequency hopping with a large enough number of hopping frequencies (12), i.e., due to the interference averaging ability of random frequency hopping, the average interference level supported by each service will not vary with the service mix. Neither will it depend on the traffic nature.

Measures of the average interference level and fraction of satisfied users are produced for each load simulated in the single service scenarios of the previous sections. Next, these measures are used to compose average interference versus fraction of satisfied users curves, in order to determine at which interference level the QoS limit is reached for each service. Finally, the SBPS offset is calculated as the difference between the average interference levels supported by each service, as exemplified in figure 3 for the 1/1 reuse and the EFR and MR59-FR voice services with and without power control.

As soon as the power offsets were calculated using the methodology described, we simulated some service mixes in order to measure the efficiency of SBPS in both power-controlled and non-power-controlled scenarios. This procedure was performed for mixes of EFR voice users and WWW data users in a 1/3 reuse and for mixes of EFR and MR59-FR voice users in a 1/1 reuse. In both cases, we are dealing with interference limited scenarios.

Figure 4 shows the results obtained for the referred service mixes.

It can be observed from figure 4 that SBPS can provide substantial capacity gains, as indicated by the arrows. SBPS allows the EFR voice service to support higher fractions of WWW and MR59-FR services, as long as the interference generated by these services be reduced by the power offsets.

In the EFR + WWW scenarios, the application of an SBPS offset of 4dB leads to improvements in the supported data capacity up to 117% (without power control). In this case, however, we observed that the QoS limits of the services were not reached simultaneously and, despite the power offset, WWW users still verified QoS values above the minimum required, which can be seen in table II. This table shows QoS and capacity figures for different service mixes.

TABLE II

SBPS CAPACITY GAINS FOR EFR + WWW SERVICE MIXES.

Without PC			With PC		
EFR FER [%]	WWW rate [kbps]	Capacity gain [%]	EFR FER [%]	WWW rate [kbps]	Capacity gain [%]
0.59	11.20	11	0.80	9.74	26
0.99	10.20	88	0.97	10.90	13
1.04	15.45	117	1.01	10.16	20

TABLE III

SBPS CAPACITY GAINS FOR EFR + MR59-FR SERVICE MIXES.

Without PC			With PC		
EFR satisf. [%]	MR59-FR satisf. [%]	Capacity gain [%]	EFR satisf. [%]	MR59-FR satisf. [%]	Capacity gain [%]
95.68	95.22	64	97.26	94.79	28
94.81	94.89	55	96.75	94.42	25
95.30	94.88	-5	97.07	94.49	-1

When power control was applied to the voice service, we noticed that EFR and WWW QoS limits were reached nearly together after applying SBPS. However, the data capacity improvements verified in the service mixes were smaller, staying around 20-25%. We concluded that the bursty nature of WWW traffic and the influence of power control affect interference distributions and reduce the achievable SBPS gains. Moreover, in the power-controlled case, power control already compensates for a fraction of the interference of the WWW service, thus limiting the relative gains that could be provided by SBPS.

In the EFR + MR59-FR scenarios without power control, SBPS also provided significative capacity gains, allowing for increases of up to 64% in the MR59-FR offered load for some service mixes. In the power-controlled case, similarly to what happened with EFR + WWW mixes, SBPS provided smaller gains. However, interference was more unbalanced when power control was considered, as indicated by the fractions of satisfied users of EFR and MR59-FR shown in table III.

In this case, the impact of power control over the interference distribution was more noticeable, since both services use power control. They actively compete for radio resources and a single offset of 8dB applied to the MR59-FR voice service becomes less effective to balance interference. Additionally, power control already counteracts interference and the relative gains achievable by SBPS are consequently reduced.

IV. CONCLUSIONS

In this work, we evaluated the performance of power control and service-based power setting applied to single and mixed-service scenarios in a GSM/EDGE network. We confirmed that power control can provide substantial capacity gains to the voice service (up to 150%), but not to the WWW service, possibly due to the bursty nature of this kind of traffic. In the mixed-service evaluations, SBPS provided significant capacity gains (up to 117%) when power control was not employed. However, when power control was activated, the SBPS performance was affected and the achieved gains were strongly reduced (to 20-30%). We indicate the effect of power control on the interference distribution as one of the factors responsible for the reduction of the SBPS gains when PC is applied to both services. Power control may affect interference distributions and, consequently, the effectiveness of using a single power offset for all mixes and load configurations may be reduced, even when using random frequency hopping. For this case, it may be necessary to dynamically adjust the power offsets.

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