Designing guard bands for minimal performance degradation

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***Abstract*— New spectrum is required for cellular systems including 3G, but such spectrum is hardly available. To find new spectrum, considerations have been given to reduce the existing guard bands. Such an approach would degrade the uplink/downlink performance of the incumbent cellular systems. The paper presents a method for estimating the degradation of the DL service considering only the receiver blocking mechanisms. Using Monte Carlo simulation, the coverage degradation of the incumbent cellular systems is evaluated for several RF parameters and traffic loading. It is shown that the overall degradation may be equated to less than 0.9% increase in outage.**

Cellular systems, Guard bands, Interference, Receiver blocking, Coverage degradation, Monte Carlo simulation

I. INTRODUCTION

Third generation (3G) wireless networks will need to deliver high speed, high capacity wireless data applications while simultaneously coping with an exponential growth in voice traffic. Meanwhile, the wireless communications industry is already faced with increasing competition, which puts additional emphasis on capacity, quality, and costs. Given the limited spectrum available for these new applications considerations have been given to reduce the existing guard bands.

The paper presents a method for estimating the degradation of the DL service considering only the receiver blocking mechanisms. Using Monte Carlo simulation, the coverage degradation of the incumbent cellular systems is evaluated for different RF parameters and traffic loading. It is shown that the overall degradation may be equated to less than 0.9% increase in outage.

The analysis is performed for the worst-case configuration, when base stations for both systems are collocated. Different scenarios are considered. Scenarios are characterized by: BTS configuration, number of radio links, models used for BTS to mobile and mobile to mobile propagation, blocking requirements (as per GSM05.05 standard) etc.

The paper is organized as follows. The second section describes the interference scenario. It is followed by a brief review the simulation algorithm. The performance indicators are derived in the fourth section, and are followed by simulation results. Finally, our conclusions are summarized.

II. INTERFERENCE SCENARIO

Instead of using a generic interference scenario, the paper will focus on a specific scenario, though hypothetical. The objective of the study below is to evaluate the possibility of accommodating a new PCS band (shortly G-band) within the current guard band between the PCS UL and DL bands (Fig. 1). Naturally, the radio services in the new radio band (G-band) do not have to degrade the performance of the incumbent PCS services.

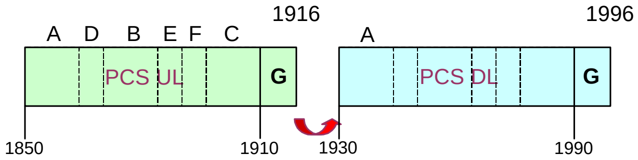

Figure 1. Hypothetical guard band reduction

It is further assumed that GSM technology is used by both the incumbent victim system (A-band) and the new radio services in the G-band. Thus, the receiver blocking of the mobile terminals operating in the A-band was identified as the major interference mechanisms for the selected scenario. Other mechanisms as spurious signals and intermodulation proved to be negligible. According to GSM 05.05 [2], the blocking level for A-band terminals is –26 dBm (in-band blocking).

The analysis is performed for the worst-case scenario, when base stations for both systems are collocated. Thus, on the cell fringe one may find G-band terminals using high transmit power levels next to A-band terminals receiving low level signals from BTS.

Several RF/technology parameters and traffic loading are considered. Scenarios are characterized by: BTS configuration (height, antenna gain), number of radio links, models used for BTS to mobile and mobile to mobile propagation, blocking requirements (as per GSM05.05 standard) etc. Details for each scenario are presented in section V. Scenarios are named to show their specific simulation parameters.

All scenarios use three-sector sites. Log-normal fading is added to the deterministic path loss figure derived from the propagation model. Terminals (A- or G-band) are connected using an ideal power control algorithm. Handoff is taken into account by connecting terminals to adjacent sites when a high path loss figure results for the main one.

A dual slope path loss model is used for calculating path loss from G-terminals to A terminals. If the distance between terminals is larger than a user specified value (δR) the path loss goes to 200 dB

Table I gives the parameters defining each simulation scenario. For all scenarios, the coverage objective is set to 90%.

TABLE I. SCENARIO PARAMETERS

Par.	Val		Note
*Ra		m	Cell radius PCS-A band
*Rg		m	Cell radius PCS-G band
DR	15	m	Boundary for UL G-interference
*PL model		#	1 COST231-Hata Metropolitan 2 COST231-Hata Suburban 3 Dual Slope V1
Hm	1.5	m	Height of mobile terminal antenna
*BinSize		m	
CmA	-102	dBm	Sensitivity for A-band terminal (receiver mode) GSM
*PmaxG		dBm	BTS max Tx power, PCS-A system
FG	1916	MHz	Ul-link frequency for G-band terminals
*Io		dBm	Blocking level @ reference sensitivity
Site			
Sector			
X		m	x coordinate for site
Y		m	y coordinate for site
σ	8	dB	Log-normal standard deviation
Pmax		dBm	Maximum BTS transmit power calculated based on PL model, cell radius and desired coverage
*RLA		#	Number of radio links for band-A PCS cellular system—incumbent
*RLG		#	Number of radio links for band-G cellular system—co-located
*hB		m	BTS antenna height
Fc	1900	MHz	DL frequency for PCS-A cellular
CmG	-102	dBm	Sensitivity for G-band terminal (receiver mode)
*Ga		dBi	RxTx antenna gains and BTS losses for PS-A links
*Gg		dBi	RxTx antenna gains and BTS losses for PS-G links

III. SIMULATION ALGORITHM

200 or more snapshots are collected for each simulation run for having a sufficiently large statistic. Terminals are randomly spread (uniform distribution) within the coverage area of the network and path loss figures (including log-normal fading) are associated to each of them. Figure 2 shows the incumbent A- (black) and G-band (red) terminals within a 120-degree sector of the main server. G-band terminals outside the sector are also including.

Two path loss models are considered: COST231 Hata for macro-cells, and dual slope for micro-cells. The dual slope model uses a break distance derived from the BTS and mobile antenna height..

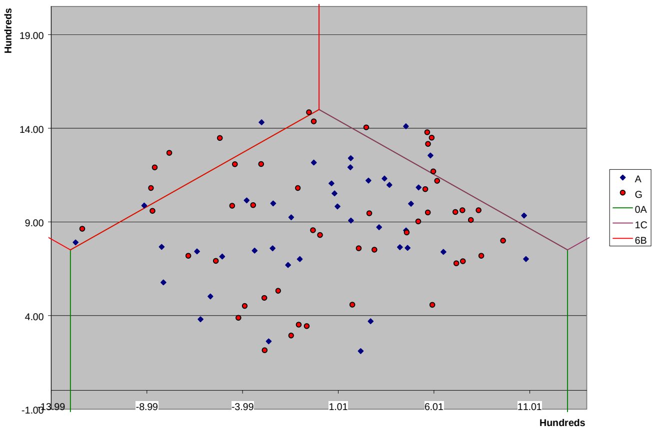

Figure 2. Hypothetical guard band reduction

For every location within the coverage area, the BTS with the minimum path loss to that location (excluding shadowing) represents the best server. Assuming ideal power control, terminals are connected (or not) according to the path loss figure (including shadowing) and maximum BTS transmit power. A-band terminals, which do not connect to the best server (BTS), will try to communicate with adjacent servers. A terminal is qualified disconnected if it cannot reach any of its neighboring cells. The following counters are related to the connectivity process

- *Nu*, number of terminals attempting to connect to the main server
- ·*Nnc*, number of disconnected terminals

G-band terminals are always connected to the location's best server. Power control is used to determine the UL transmit power, which never exceeds the power class limit. Such an approach will provide conservative results.

For each connected A--band terminal, the G-band terminals within a given distance range (δR) are registered. For a non-zero outcome, the A-band terminal is counted as aggressed and the total G-band power (*Ik*) at its antenna connector is evaluated. The total G-band power (blocking power) for user *k* (*Ik*) is given by the equation

$$I_k = \sum_i P_i^{UL} - PL_{ki} \tag{1}$$

where P_i^{UL} is the transmitted power for the i^{th} G-band terminal, and PL_{ki} is the path loss from terminal *k* (A-band) to terminal *i* (G-band). A dual slope path loss model is used for mobile to mobile path loss modeling.

Aggressed terminals will use power control for overcoming the blocking power. If the DL transmit power adjustment will give a figure exceeding the BTS power limits, the terminal is counted as non-surviving G-band blocking.

A. Trace back simulation

For eliminating the randomness while evaluating performance sensitivity to BTS/terminals RF configuration only (no changes in the environment or traffic), a trace-back feature was implemented. Trace back is also useful for “what if” analysis. Trace back preservers the user distribution and propagation losses (including log-normal fading) from a previous simulation scenario, and re-calculates the performance indicators given the new RF configurations. Trace back cannot be used for simulation scenarios where the number of traffic channels or the sector radius is changed.

IV. PERFORMANCE INDICATORS

The information provided by each snapshot is used for updating the following performance indicators

- Aggression probability (P_a)
- Surviving probability (P_s)
- Coverage degradation (P_d)
- Average blocking signal strength (I)

The aggression probability gives an indication on the blocking likelihood. The surviving probability indicates the average number of terminals facing blocking and continuing to preserve the link quality, taking advantage of the power control mechanisms. P_a and P_s cannot fully describe the changes in the performance of the incumbent system. The coverage degradation has to be used for that purpose. The average blocking signal power gives and indication on the required DL power increase required for preserving the link.

A. Aggression probability

The aggression (blocking) probability is defined as the ratio between the total number[1] of aggression instances (N_a) and the total number of connected terminals

$$P_a = \mathbf{E}\left\{\frac{N_a}{N_u - N_{nc}}\right\} \tag{2}$$

where, $\mathbf{E}\{\}$ stands for statistical average. The simulation proves that P_a depends on the sector size and number of terminals per sector. For a fixed number of terminals, P_a depends on the cellular geometry mainly. For a cellular system with very good coverage (> 90%) $P_a \approx P'_a = \mathrm{E}\left\{ {N_a}/{N_u} \right\}$

B. Surviving probability

The surviving probability is defined as the ration between the number of instances when an aggressed terminal “survived” and the total number of aggressions.

$$P_s = \mathrm{E}\left\{\frac{N_s}{N_a}\right\} \tag{3}$$

For environments with identical P_a, a higher P_s will indicate a network configuration with better resistance to G-band blocking. G-band base stations, with high antenna gains, are expected to generate less blocking interference in the incumbent A-system.

C. Coverage degradation

The coverage degradation is the comprehensive performance indicator, and is derived form the service availability P_{ser}. The service availability is defined as the number of terminals connected and surviving G-band blocking divided by the total number of terminals.

$$\begin{aligned} P_{ser} &= \mathbf{E}\left\{\frac{N_u - N_{nc} - N_a + N_s}{N_a}\right\} = \\ &= P_c - P'_a \cdot (1 - P_s) \end{aligned} \tag{4}$$

where $P'_a = \mathrm{E}\{N_a / N_u\}$, and P_c represents the original cellular radio coverage. The equation shows how the G-band system reduces the original coverage through aggression. This reduction is defined as the coverage degradation P_d

$$P_d = P'_a \cdot (1 - P_s) \tag{5}$$

The coverage degradation combines the two previous indicators, P_a and P_s, showing their contribution to the global performance. As expected, the larger P_s the smaller the coverage degradation would be.

D. Average blocking power

For each aggression instance, the total blocking power (I_k) is calculated. The average blocking power (I) averages the blocking powers for all the aggression instances.

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[1] In the definitions above, counters (Nu, Nnc, Na, Ns, etc) represent figures aggregated over all the snapshots.

$$I = \mathbf{E}\left\{ \frac{1}{N_a} \sum_{k=1}^{N_a} I_k \right\} \qquad (6)$$

V. SIMULATION RESULTS

Simulation results are named to show their specific simulation parameters. Thus, R15h30g14CM-RL35 indicates a sector radius of 15 hundred meters, 30 m BTS antenna height, 14 dBi BTS gain and losses, Cost 231 Hata Metropolitan propagation model, and 35 radio links (traffic channels). The parameters not included in the name keep their default values. The next sub-sections show the sensitivity of the performance indicators to the most important parameters of the interference scenario.

A. *Cell radius and propagation model sensitivity*

The first objective is to evaluate the changes of the performance indicators with the sector radius and the propagation model. Radii from 500m to 4200 meters are considered. A dual slope propagation model is used for radii up to 1000m (micro-cell). For larger radii (macro-cell), the COST 231 Hata model (metropolitan) is used.

Both P_a and P_s go down when increasing the sector radius. The largest coverage degradation 0.8% appears at 1500 meters, but it reduces to 0.1% for 4200 meters. The average blocking power (*I*) has a peak at 3000m. The limited range for I is explained by the selection of 15 m for the boundary of G-interference.

Scenario	R [m]	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R15h30g14CM-RL35 Model= 1 COST231-Hata Metropolitan	1500	1.36	41.05	0.80	-15.23
R30h30g14CM-RL35 Model= 1 COST231-Hata Metropolitan	3000	0.27	42.10	0.15	-13.68
R42h30g14CM-RL35 Model= 1 COST231-Hata Metropolitan	4200	0.14	25.00	0.10	-14.65

Micro-cells show larger figures for Pa and Ps in comparison with the macro-cell environments. For 500 meters radius P_a is 11.37% and goes down to 2.79% for 1000m.

Scenario	R [m]	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R05h06g14DS-RL35 Model= 3 Dual Slope V1	500	11.37	94.72	0.59	-29.36
R08h06g14DS-RL35 Model= 3 Dual Slope V1	800	4.38	90.19	0.42	-25.99
R10h06g14DS-RL35 Model= 3 Dual Slope V1	1000	2.79	85.36	0.40	-23.37

The 500 m micro-cell has the highest P_s figure (94.7%). The high P_s can be explained by the low terminal transmit power when close to the base station. The low terminal transmit power is shown by the low average blocking power that has a range from –29dBm to –23 dBm.

B. *G-band BTS antenna gain*

The analysis uses the trace back feature and is performed only to the 1500 m macro-cell environment. The BTS antenna gain for the A-band system is 14 dB. The table below summarizes the results.

Scenario	Gg [dB]	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R15h30g14CM-RL35	14	1.567	47.826	0.816	-15.261
R15h30g18CM-RL35	18	1.622	53.781	0.748	-16.639
R15h30g22CM-RL35	22	1.622	63.025	0.598	-18.323

The transmit power of the G-band terminals goes down when the BTS antenna gain is increased from 14 do 22 dBi. This results in a reduced average blocking power (*I*) and an increased *Ps*. Accordingly, the coverage degradation reduces from 0.816% to 0.598%. Thus, G-band antenna gain can be used as a simple method for controlling the coverage degradation. The minor changes of P_a result from the inaccuracy of controlling the RF coverage.

C. *Traffic load*

The objective of the following simulations is to find out the sensitivity of the performance indicators to the traffic load. Three cell types are considered: low traffic cell with 7 traffic channels (TCH), medium traffic cell with 18 TCH and high traffic cell with 35 TCH. Three scenarios are investigated: equal traffic in both systems (RLA=RLG), unequal traffic with RLA fixed to 35, and unequal traffic with RLA fixed to 18.

When both systems use the same number of radio links (RLA=RLG), simulations confirm that the larger the number of traffic channels (radio links) the larger the coverage degradation. Degradation is not higher than 0.435%.

Scenario	RLA= RLG	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R15h30g14CM-RL7	7	0.47	57.14	0.20	-14.64
R15h30g14CM-RL18	18	0.61	78.26	0.13	-14.03
R15h30g14CM-RL35	35	1.58	72.41	0.43	-13.19

The second traffic load scenario considers RLA=35, while the G-band system goes from 7 TCH to 35 TCH. The coverage degradation reduces ten times (from 0.43% to 0.04%) when the number of traffic channels in the G-band sectors (RLG) reduces from 35 to 7.

Scenario	RLG [#]	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R15h30g14CM-RLA35RLG7	7	0.34	87.99	0.04	-14.84

R15h30g14CM-RLA35RLG18	18	0.62	78.26	0.13	-13.30
R15h30g14CM-RLA35RLG35	35	1.51	72.41	0.43	-13.18

The third traffic load scenario (RLA-18) gives similar results with a reduced dynamic for the coverage degradation

Scenario	RLG [#]	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R15h30g14CM-RLA18RLG7	7	0.265	80.000	0.052	-12.943
R15h30g14CM-RLA18RLG18	18	0.608	78.260	0.132	-14.028
R15h30g14CM-RLA18RLG35	35	1.481	75.000	0.370	-13.029

D. *G-band terminal power class*

Future GSM systems are expected to be optimized for reducing the handset transmit power. The following simulations are defined for identifying the sensitivity of the performance indicators to the G-band terminal power class (*PmaxG*). Again, the trace back feature is applied to the 1500 m macro-cell environment. The maximum transmit power is changed from 10 dBm to 30 dBm.

Scenario	PmaxG [dBm]	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R15h30g14CM-RL35PG10	10	1.62	85.71	0.23	-23.42
R15h30g14CM-RL35PG20	20	1.62	61.34	0.62	-18.91
R15h30g14CM-RL35PG25	25	1.62	56.30	0.70	-16.91
R15h30g14CM-RL35PG30	30	1.62	47.05	0.85	-15.28

As expected, the average blocking power becomes smaller when decreasing the G-band terminal maximum transmitted power. Accordingly, P_s increases minimizing coverage degradation For example, P_d falls from 0.867% to 0.231% when *PmaxG* becomes 10 dBm instead of 30 dBm. The terminal power class should be considered as an approach for controlling the coverage degradation when deploying G-band systems.

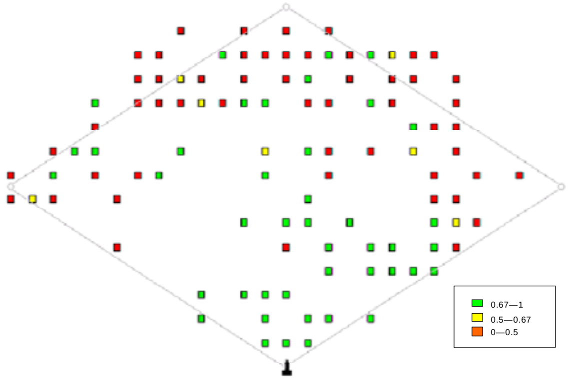
E. *Blocking characteristics (Io)*

The blocking characteristics do no change the aggression probability and the average blocking signal. For the same blocking power, terminals with a better blocking characteristic (higher *Io*) survive easier. Thus, for the same average blocking power, P_s increases and P_d decreases as terminals have better blocking characteristics. Simulations show that the degradation of the incumbent GSM system is very sensitive to the terminals' blocking characteristic; therefore, this figure has to be carefully considered.

Scenario	Io [dBm]	Pa [%]	Ps [%]	Pd [%]	I [dBm]
R15h30g14CM-RL35Io-26	-26	1.57	87.06	0.20	-15.52
R15h30g14CM-RL35Io-31	-31	1.57	62.93	0.58	-15.52

F. *Performance distribution within the cell*

Bin statistics are used to view the distribution of the performance indicators within the cell. The plot below shows *Ps* distribution within a 120 degree 1500 m sector. Because only aggressed terminals are included in the analysis, the white islands on the plot must be regarded as regions where aggression never happened for the simulation run. The legend indicates P_s ranges. On the average, bins close to the sector fringe have lower P_s figures than bins close to the base station.



The red points close to the base station represent outcomes when G-band and A-band terminals are very close to each other. Such instances would be avoided in real situations considering the natural mobile user instinct of moving out of areas with poor reception quality.

VI. CONCLUSIONS

The paper presents the approaches and results of evaluating the performance of incumbent GSM cellular systems in the PCS band in the presence of interference (blocking) from GSM mobiles operating in a hypothetical new band (G-band) created within the current PCS UL-DL guard band. The most important parameters are the aggression (or blocking) and surviving probabilities, the average interference (blocking) power per aggression and the coverage degradation.

The comprehensive parameter for assessing the change in the performance of the incumbent cellular system is the coverage degradation. It describes the service failure due to G-band blocking. The service degradation due to receiver blocking may be regarded as extra coverage degradation. If this extra degradation is less than 1% of the original coverage objective, one may conclude that the G-band deployment would preserve the performance of the incumbent GSM network.

For any of the defined simulation scenarios, the coverage degradation never exceeds 0.9%. Thus, the preliminary study of reducing the PCS guard band for accommodating new GSM services, in the worst case, would reduce an original coverage of 90% to 89.1%. By carefully deploying G-band GSM services, degradation can be further reduced below 0.2%.

The largest degradation happens for the heavily loaded (35 traffic channels) medium cell size (1500m) with low G-band BTS antenna gain and height. Very important is the fact that degradation manifests mainly at cell fringes, when base stations do not have enough power margins to overcome the blocking signals.

Mechanisms for reducing the coverage degradation were investigated also. For the given interference scenario, any technology that would require less transmit power for G-band terminals would have a positive impact on the coverage degradation. The simplest immediate approach is to use high gain BTS antennas or smart antennas. Simulations performed show an increase from 47.83% to 63.03% in the surviving probability when the BTS antenna gain increases from 14 dBi to 22 dBi respectively. Similarly, P_s goes up to 85.71% if the maximum terminal Tx power is limited to 10 dBm instead of 30 dBm.

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