TELETRAFFIC ANALYSIS FOR THE PERFORMANCE EVALUATION OF DE-ALLOCATION/RE-ALLOCATION STRATEGIES IN GSM/GPRS CELLULAR NETWORKS

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ABSTRACT

A teletraffic analysis for the performance evaluation of the joint use of Dynamic Resource Allocation (DRA), Channel De-Allocation (DAS), and Channel Re-Allocation (RAS) strategies in GSWGPRS networks is developed. In addition, an efficient DRA strategy with a link quality awareness policy, Channel De-Allocation and Re-Allocation policies as well as user prioritization (called DRA LA DAS RAS) is proposed. To the authors' knowledge, most related works have either studied Link Adaptation (LA) or Dynamic Resource Allocation (DRA) strategies as independent topics but have failed to address their combined effect on GSWGPRS systems. DRA LA DAS RAS uses both call degradation and call compensation techniques. Calls with the largest number of channels allocated and the worst link quality are degraded first. Conversely, calls with the lowest number of channels allocated and the best link quality are upgraded first. This allows upgraded calls to release resources more rapidly, making them readily available for new calls. Numerical results show that the proposed DRA LA DAS RAS strategy significantly improves system performance, i.e., up to 82% (74%) [37%] <27% < less blocking probability relative to the DRA (DRA LA with p=0.75) (DRA DAS) [DRA LA DAS with p=0.75] <DRA DAS RAS> strategy.

I. INTRODUCTION

In the literature, there are different techniques that improve radio resource management (RRM): link adaptation (LA), dynamic resource allocation (DRA), de-allocation/re-allocation schemes (DAS and RAS respectively), etc. [21]. Adaptive coding/spreading and adaptive modulation are referred to as link adaptation. LA techniques react on the channel quality to choose a suitable transmission mode including modulation, coding, or spreading. GSM/GPRS is able to operate with a choice of coding schemes appropriate to the prevailing signal to interference ratio (SIR). Four coding schemes, CS-1 to CS-4, are defined to code the GPRS radio link control data blocks [1]. Thus, the data rate per slot depends on the radio link quality. LA in GPRS allows for the selection of proper coding schemes based on channel conditions in order to cope with radio channel quality. Traditionally, system level analyses of mobile cellular systems with integrated voiceldata services have not

1 In packet data services, higher SIR implies that higher data rates can be provided by means of high order modulation and/or high coding rates (low redundancy) or low spreading gain. Generally, the SIR is larger in locations near the base station (BS) than in locations close to the cell's edge.

2 CS-4 is uncoded and CS-1 is based on a K-rate convolutional coding. CS-2 and CS-3 coding schemes are punctured versions of CS-1 with 213- and 3-rate coding, respectively.

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to the two coding schemes considered. The size and shape of the quality coverage zones depend on the propagation environment, coding scheme used, and on the required quality of service. In the GSWGPRS system considered, data users can be served with different transmission rates depending on their link quality. Data users with good quality link make use of CS-2; and data users with bad quality link make use of CS-1. A parameter, \( p \) [2-7], is used to represent the proportion of data users with good quality link using CS-2. The calculation of \( p \) considering shadowing is addressed in [7]. The throughput for data users depends on the coverage zone they traverse. However, due to the short packet length [2, 4, 9, 11], it is assumed that once a coding scheme is selected for the transmission of a temporary block flow (TBF), it remains in use until the end of the transmission. The general guidelines of the model presented in [19] are adopted to analyze the strategies here evaluated. The following assumptions allow the strategy presented to be cast in the framework of multidimensional birth and death processes. A multi-cellular system is considered where each cell has \( N_c \) channels for voice calls and GPRS packet sharing in a homogeneous GSWGPRS network. The new call arrival processes for voice and data follows Poisson processes. The new call arrival rate for voice (data) traffic is \( \lambda_{vo} (\lambda_d) \). The hand-off call arrival for voice traffic process is also considered to be Poisson with mean handoff arrival rate \( \lambda_h \). This handoff arrival rate is calculated by the iteration method described in [20] (i.e., the Erlang fixed point approach). As in [2, 4, 9], data users terminate their calls in the same coverage zones where they started them because of the short packet service time. Data packets require a number of resources between one resource, and a maximum \( M_D \). The ideal unencumbered service duration of a GPRS packet calls has an arbitrary distribution with mean \( 1/\mu_{SGW_CRS} \). The unencumbered GPRS packet call duration depends on the allocated bandwidth (resources). The unencumbered call duration for voice traffic is modeled by a negative exponential probability density function (pdf) with mean \( 1/\mu_v \). The cell dwell time (the time spent by a mobile station within a cell independent of being engaged in a call) is a random variable with a negative exponential pdf with mean \( 1/\eta \).

### III. PROPOSED DYNAMIC RESOURCE ALLOCATION STRATEGY

This section presents the dynamic resource allocation strategy used in the analysis. The strategy can be seen as a combination of DRA, a LA aware policy, prioritized DAS, and prioritized RAS. This strategy will be called DRA LA DAS RAS. In DRA LA DAS RAS, prioritized call degradation (DAS) and prioritized compensation (RAS) is used for rate degradation and compensation, respectively, of the GPRS packets. In this way, no calls with high (low) priority are degraded (compensated) if calls with low (high) priority can be degraded (compensated). When a GPRS packet (voice call) arrives, if there are enough resources available, the call is allocated the maximum number of resources \( M_D \) (one resource for voice calls). On the other hand, if the number of resources available in the cell is less than the maximum number of resources required, then prioritized degradation of calls in progress is carried out to release resources for the new GPRS packet (or GSM voice call). The priority order of decreasing importance considered is as follows: voice calls, data packets using CS-2, and data packets using CS-1. The main idea is to keep packet transmission with good link quality with the largest number of resources possible; in order to reduce resource holding time. In this way there will be more resources available for new packet transmission or new voice calls.

Degradation of a GPRS data call in progress exists only when a call operates with more resources than the minimum required. Priority degradation (compensation) of ongoing calls occurs in the following three ways:

When the number of resources available is less than the maximum required for the incoming call, calls with lower priority, are degraded with the ultimate goal of providing the largest number of resources required (\( M_D \) for GPRS packet; one for GSM voice calls) or the largest number of resources possible. If the first condition is met, the call arrival will be assigned \( M_D \) resources to the incoming data service request (one resource to the incoming voice service request). If the second condition is met instead, degradation process continues for data service requests with the admission policy. On the other hand, if the second condition is met for voice service requests, the incoming voice request is blocked or dropped.

If degradation of calls with lower priority does not provide the incoming data request with the \( M_D \) resources required, then degradation of calls with the same priority is carried out. The primary objective in this admission policy is providing the incoming call with at least one resource and sharing as equally as possible the number of available resources among calls with the same priority as the incoming request. Degradation of calls with the same priority takes place until there are enough resources for the incoming call, or until all active calls with the same priority are degraded to one resource. If the first condition is met, the incoming data call is accepted sharing as equally as possible the number of resources available for calls with the same priority. If the second condition is met, then further degradation of calls with higher priority is necessary.

If the updated number of resources available after degrading calls with lower priority and the same priority than the incoming data call is not enough to provide at least one resource required; then, degradation of data calls with higher priority takes place with the purpose of freeing at least one resource. Hence, data calls are degraded until the one resource is free or all data calls with higher priority are degraded to one. If the first instance is met, the data call arrival will be accepted.

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4 The ideas here presented can be easily extended for the case where the four coding schemes are used.

5 The Poisson hand-off arrival model is an assumption widely accepted in the literature because it gives acceptable results and keeps mathematical tractability. The handoff call arrival process generated by a single cell is clearly not Poisson. However, the combined process from the six different neighboring cells can be adequately approximated by a Poisson process [20].

6 This strategy is based in FRAQoS, presented in [17-19], but LA has not been considered in previous works. Then, the proposed strategy, mathematical model, and performance evaluation results shown in this paper differ considerably from those presented in [17-19].

7 Degradation only applies to GPRS packet calls; due to that GSM voice calls possess the highest priority, besides they have assigned only one resource.
with the minimum number of resources required. If the second condition is met instead, the incoming data call is blocked.

The compensation process is triggered by a (voice or data) call departure and it consists of the re-allocation of resources released to data call which quality may be improved. Prioritized compensation takes into account call’s priority, the compensation process of a data call ends with the allocation of the $M_D$ resources required. High priority GPRS packet calls are compensated first, then low priority GPRS packet calls. If there are more than enough resources to compensate all high priority GPRS packets calls, compensation process continues with low priority GPRS packet calls. On the contrary, if there are not enough resources to compensate all high priority calls resource available for high priority GPRS packet calls are shared in the most equally manner. A similar process occurs in low priority compensation.

IV. TELETRAFFIC ANALYSIS

The system performance is evaluated by means of a multidimensional birth and death process. A homogenous case is assumed where all cells are statistically identical. Hence the overall system performance can be analyzed by focusing on only one given cell. The teletraffic analysis for DRA LA DAS RAS is as follows. Let us denote the state of a given cell as:

$$K = [k_v, k_{dCS-1}, k_{dCS-2}]$$  (1)

where $k_v$ represents the number of voice active users and $k_{dCS-1}$ and $k_{dCS-2}$ represents the number of active data users with bad (CS-1) and good (CS-2) link quality, respectively. The effective voice offered traffic per cell is given by:

$$\lambda_v = \frac{\lambda_v}{\mu_v + \eta_v}$$  (2)

The data offered traffic in the different quality zones is given by:

$$a_{dCS-1} = \frac{(1 - p) \lambda_d}{\mu_{dCS-1}}, \quad a_{dCS-2} = \frac{p \cdot \lambda_d}{\mu_{dCS-2}}$$  (3)

The unencumbered GPRS packet call duration is calculated using the iterating process shown in [19], and it is given by:

$$\frac{1}{\mu_{dCS-i}} = \frac{M_D}{B_{avg,CS-i} \cdot \mu_{max,CS-i}}$$  (4)

The parameter $B_{avg,CS-i}$ is the average number of resources allocated to GPRS calls using CS-i scheme, and it is computed in an iterative way [19], using (5)

For the DRA LA DAS RAS described in the previous section, the steady state probability distribution has product form given by:

$$P(K) = \frac{\alpha_v \cdot \alpha_{dCS-1} \cdot \alpha_{dCS-2}}{k_v! \cdot k_{dCS-1}! \cdot k_{dCS-2}!} \sum_{\{k_{dCS-1}, k_{dCS-2} \leq N_c, k_{dCS-1}+k_{dCS-2}=0\}} P(K)$$  (6)

The voice new call blocking ($P_{bv}$), handoff failure ($P_h$) probabilities and the GPRS packet blocking probability ($P_{bd}$) are given by:

$$P_{bv} = P_h = P_{bd} = \sum_{\{k_{dCS-1}, k_{dCS-2} \leq N_c\}} P(K)$$  (7)

The forced termination probability for GSM voice calls ($P_f$) is given by [20]:

$$P_f = \frac{P_f}{\mu_v + \eta_v + P_h}$$  (8)

The outgoing inter-cell handoff rate for GSM voice calls ($\lambda_h$) is given by [20]:

$$\lambda_h = \frac{\eta_v (1 - P_{h}) \lambda_v}{\mu_v + \eta_v P_h}$$  (9)

The average GPRS packet transmission time ($T_p$) is given by:

$$T_p = \frac{\sum_{\{k_{dCS-1}, k_{dCS-2} \leq N_c\}} (k_{dCS-1} + k_{dCS-2}) \cdot P(K)}{\lambda_d \cdot (1 - P_{bd})}$$  (10)

* A potential problem for prioritized DAS and prioritized RAS is that some users not directly benefiting from these mechanisms will experience smaller data rates. However, all data users indirectly benefit and enjoy reduced blocking probabilities.
V. Numerical Results

This section presents numerical results. For comparative purposes, the system performance of six different dynamic resource allocation strategies is evaluated in terms of the GSM voice call blocking and forced termination probabilities, GPRS packet dropping probability, average GPRS packet transmission time, and average number of resource allocated to GPRS packets using a bad (good) quality link. The dynamic resource allocation strategies evaluated are DRA, DRA DAS, and DRA DAS RAS strategies with/without LA.9 In the numerical evaluation, it is assumed that $N_c = 7$, $M_D = 2$, $1/\mu = 900$ s, $1/\mu_s = 180$ s, $p = \{0.25, 0.5, \text{and} 0.75\}$, $1/\mu_{\text{max}, \text{CS-2}} = 4/(3 M_D)$ s, $1/\mu_{\text{max}, \text{CS-1}} = 2/(M_D)$ s. Since the intention is to study the performance of the strategies proposed and their effect on data services, a fixed voice traffic of 2.15747 Erlangs is assumed. (This produces a blocking probability $0.5\%$ when there is no data traffic). Figures 1-4 show the performance of the strategies for different proportion $p$ of packets with good quality link. Figure 1 shows the blocking probability for new voice calls, GPRS packets and voice handoff attempts failure versus the data arrival rate. It is observed that the use of LA decreases the blocking probabilities. This is due to the fact that calls with good quality links experience higher data rates which results in faster transmission times and faster channel release times. The figure shows an increment of blocking probability with a decrease in the proportion of packets using a good quality link. This is due to the lower channel utilization caused by the use of robust coding schemes to overcome bad channel conditions and their inherent low transmission rate. DAS reduces the blocking probability by degrading ongoing calls to assign de-allocated resources to arriving calls. Re-allocation of recently available resources10 to GPRS packet calls increases their transmission rate. So, resource holding time is in turn reduced, producing resources available for new incoming calls. Then the synergies of DRA, LA, DAS, and RAS techniques cause a lower blocking probability than the pure use of these techniques separately. The behavior and tendencies for forced termination and blocking probability for voice calls are similar; due to the lack of space the results are not shown. In Figure 2 the average number of resources allocated to GPRS calls using good quality link (CS-2) is shown plotted versus GPRS packet arrival rate. From this figure it is observed that DRA LA DAS RAS allocates a higher average number of resources to GPRS packet calls with good quality links (CS-2) than the other strategies without RAS. This is caused by the prioritized degradation process, which degrades GPRS calls using CS-1 scheme first. This behavior can be observed from Figure 3, where the average number of resources allocated to GPRS packet calls with bad quality links plotted versus GPRS packet arrival rate is showed. Note that the re-allocation scheme process gives a higher average number of resources allocated to GPRS packet calls with CS-1 when the packet arrival rate is low and the opposite is true. This is in agreement with the expected behavior of the prioritized de-allocation scheme.

Table 1. Blocking probability reduction for each strategy analyzed relative to DRA (@ 0.9 packets/sec)

<table>
<thead>
<tr>
<th>Strategy</th>
<th>Blocking Probability</th>
<th>Reduction (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>DRA</td>
<td>0.09969</td>
<td>-</td>
</tr>
<tr>
<td>DRA LA p=0.25</td>
<td>0.08965</td>
<td>10.07</td>
</tr>
<tr>
<td>DRA LA p=0.5</td>
<td>0.07981</td>
<td>19.94</td>
</tr>
<tr>
<td>DRA LA p=0.75</td>
<td>0.07017</td>
<td>29.61</td>
</tr>
<tr>
<td>DRA DAS</td>
<td>0.0427</td>
<td>57.16</td>
</tr>
<tr>
<td>DRA LA DAS p=0.25</td>
<td>0.03757</td>
<td>62.31</td>
</tr>
<tr>
<td>DRA LA DAS p=0.5</td>
<td>0.03277</td>
<td>67.12</td>
</tr>
<tr>
<td>DRA LA DAS p=0.75</td>
<td>0.02831</td>
<td>71.60</td>
</tr>
<tr>
<td>DRA DAS RAS</td>
<td>0.02451</td>
<td>75.41</td>
</tr>
<tr>
<td>DRA LA DAS RAS p=0.25</td>
<td>0.02220</td>
<td>77.73</td>
</tr>
<tr>
<td>DRA LA DAS RAS p=0.5</td>
<td>0.01995</td>
<td>79.98</td>
</tr>
<tr>
<td>DRA LA DAS RAS p=0.75</td>
<td>0.01776</td>
<td>82.18</td>
</tr>
</tbody>
</table>

The aforementioned performance is caused by the low transmission time achieved by the combination of the DRA strategies with de-allocation and re-allocation schemes. From Figure 4, that plots GPRS packet transmission time versus GPRS data packet arrival rate, it can be observed that LA techniques reduce transmission time for GPRS packets; while, due to its nature, DAS increase it. Then, the combination of these techniques (LA + DAS) with RAS further reduces the transmission time of GPRS packets. In order to compare capacity gain, the blocking probability reduction for each strategy is compared to that resulted from the use of DRA only, as shown in Table 1. The joint effect of all the strategies DRA LA DAS RAS with $p=0.75$ reduces the blocking probability up to $82\%$ (74%) [58%] [37%] <27%> relative to the DRA (D M LA with $p=0.75$) [D M DAS] [D M LA DAS with $p=0.75$] <DRA DAS RAS> strategy.

VI. Conclusions and Future Work

In this paper several techniques for resource allocation have been studied. In particular, the synergies between dynamic resource allocation with de-allocation/re-allocation scheme and link adaptation have been evaluated. Numerical results show that link adaptation increases the system capacity and performance by decreasing blocking probability. In addition, prioritized DAS RAS strategy shows a lower blocking probability and higher good quality link channel utilization; meanwhile the combined use of DRA LA DAS RAS can reduce blocking probability up to $82\%$ (74%) [58%] [37%] <27%> relative to the DRA (D M LA with $p=0.75$) [D M DAS] [D M LA DAS with $p=0.75$] <DRA DAS RAS> strategy. As future work, others compensation/degradation prioritization orders may be tried and compared; with the intention of find the best prioritization order according to system's conditions and QoS constraints.

REFERENCES

The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC’07)


