# PERFORMANCE ANALYSIS OF GSM-GPRS NETWORK

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*Abstract – To provide Internet Services with much better utilization of frequency spectrum the General Packet Radio Service (GPRS) is integrated in a GSM network. However, some questions to arise about the network performance when these networks are integrated, once that they share the same radio resource of the air interface. Hence, on this article an analytic model is developed using the M/M/c/c queue, which is used to analyze the integrated GSM-GPRS network. That model is based on the voice services pre-emption over the Internet services to provide measures that inform the availability of radio resource, and this way, the throughput of the GPRS to any offered voice traffic profile on the GSM network.*

*Index terms: Network performance, GSM network, GPRS network, M/M/c/c queue.*

## I. INTRODUCTION

Among the main limitations showed by GSM to provide Internet services are the channel allocation for the whole call period, indirect Internet connection, low transmission rates what result on the billing based on the time that the channel is occupied, and the loss of approximately 50% of radio capacity during a data application. To solve these matters has created a new technology of packet-switched for providing Internet services on the GSM network, the General Packet Radio Service (GPRS) [1][2].

Once the GPRS is integrated on the GSM network, the radio resource is shared between them. So, what is the GPRS impact on the GSM network? To be more exactly, what is the impact of physical channels exclusively reserved for the GPRS channels to provide Internet service? This article shows some measures estimated from an analytic model, which are able to answer these questions and some others ones, such as the average number of on-demand channels and the average number of GPRS channels, the maximum average throughput and the average on-demand throughput. The utilized model is an M/M/c/c queue, which represents the radio interface of integrated GSM-GPRS network that it is the bottleneck of the system.

This article is organized as follow. On the section II is done a brief introduction about the GPRS, describing the main information used for the development of this article. On the section III is described the system model and the traffic model, and also are evaluated the measures used to analyze the performance of the GSM-GPRS network. On the section IV are showed and analyzed the results using the measures described on the last section. Finally, on the section V are done the final conclusions about the measures showed off on this article.

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## II. GENERAL PACKET RADIO SERVICE

The GPRS is a solution for Internet services and data services on the GSM networks. It provides packet-switched service, which means that the radio resources are only used when there are data transfers over the air interface. The benefits get by GPRS are the direct connection with the Internet, billing based on the information volume, shorter access time, higher data rates and a much better utilization of the radio resource. To integrate GPRS on the GSM network is necessary the utilization of a new node class, called GPRS Support Nodes (GSN). They are responsible to transfer data packets between mobile station and Packet Data Network (PDN). The Serving GSN (SGSN) is responsible for following functions: the delivery of data packets from and to mobile stations inside its service area, routing and transfer of data packets, management, authentication and billing. Another support node is the Gateway GSN (GGSN), which acts as an interface between PDN and GPRS network. It also makes the routing and transfer of data packets and billing [1][2]. MS is a user's equipment. The Base Transceiver Station (BTS) acts as an interface between GSM-GPRS network and the users. The Base Station Controller (BSC) monitors and controls lots of BTS. The Abis interface connects the BTS and the BSC. That link is dimensioned to carry 16 kbits/s [1][3]. The Fig. 1 shows the integrated GSM-GPRS network architecture.

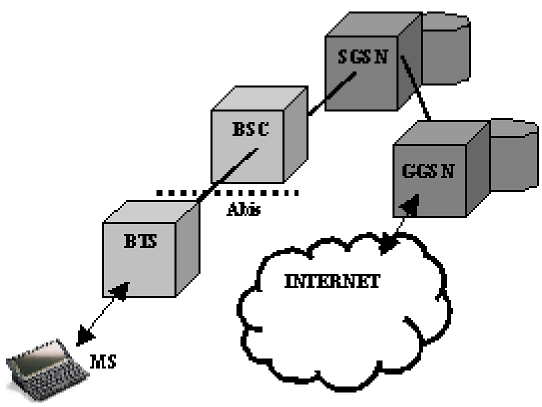


Fig. 1. Integrated GSM-GPRS network.

The GPRS provides point-to-point services and point-to-multipoint services, SMS and non-standardized services [2].

In the context of this article, the most important point inside of GSM-GPRS architecture is the air interface (physical layer), once it investigates the behavior of radio resource during the network running. On the air interface is done a blending of FDMA-TDMA for multiple access. Two frequency bands of 25 MHz are utilized; one for uplink and another one for downlink. Each one of these bands is divided into 124 frequency channels with 200kHz of width. Each one of these frequency channels is also divided into eight time slot, which make a TDMA frame of 4.613 ms. This way, the duration of each time slot is 576.9µs. The recurrence of one time slot defines a physical channel. The physical channel used to carry GPRS traffic is called Packet Data Channel (PDCH) [1].

The physical channel allocation for GSM is unlike from the PDCH. Belonging to the circuit-switched technology, GSM allocates its physical channel for the whole call period. On the contrary, being GPRS a packet-switched technology, the PDCH is allocated only when there are data transfers over the air interface, so that strategy optimizes the utilization of the radio resource [1][4]. The same PDCH can be shared with others users, which is called statistical multiplexing [1]. The number of allocated PDCH depends on the traffic demand in the cell. As well as the available physical channels GSM can be allocated as on-demand PDCH what improves the quality of service. Nevertheless they are de-allocated when a voice call arrives on the systems, because the highest priority of the voice service over GPRS services [1][3][4].

Four coding schemes can be used on the GPRS to guarantee the integrity of transmitted data, these are: CS-1, CS-2, CS-3 and CS-4. In order to avoid re-dimensioning the Abis interface (see fig.1) is advice the CS-2 coding scheme that carries 13.4 kbits/s per time slot. When the eight time slots are being used, it is reached data rates of 107.2 kbits/s. In fact, due to the statistical multiplexing, the available bits rate is less than it. The CS-3 coding scheme provides data rates of 15.6 kbits per time slot, but with all added overhead this data rates exceeds 16 kbits/s, which is the capacity of the Abis interface [1][3].

## III. TRAFFIC ANALYSIS

### *A. SYSTEM MODEL*

Each BTS of the integrated GSM-GPRS network receives $N$ physical channel, where $N_{GPRS}$ are allocated as PDCH, and the remainder, $N_{GSM} = N\text{-}N_{GPRS}$ are either allocated to GSM or to on-demand PDHC, like mentioned on the last section. The system has a buffer, which stores the IP packets when all physical channels are busy. The behavior of the IP packets and its impact on the systems does not take into account on this article.

*1) VOICE PRE-EMPTION:* Pre-emption is a kind of priority, which permits that clients enter in the service as soon as it has arrived [6]. Because of that, the GSM calls are immediately attended [3][4].

### *B. TRAFFIC MODEL*

The showed model on this article represents the air interface of a single cell, which belongs the integrated GSM-GPRS network. The GSM voice calls are lead to circuit-switched while the GPRS data packets are lead to packet-switched. Like it has been assumption on the literature, the GSM calls arrive according to Poisson Process with rate $l_{GSM}$. The GPRS arrived process is also Poissonian with rate $l_{GPRS}$. These two processes are independent at each other. The call duration is exponentially distributed with mean value $1/m_{GSM}$ , where $m_{GSM}$ is a GSM voice call departure rate [4][5][7].

### *C. PERFORMANCE MEASURES*

Due to the GSM voice call pre-emption, the behavior of the GSM voice call can be modeled by M/M/c/c queue, where $c = N_{GSM}$. Hence, the blocking probability of this service is given by Erlang's B formula. The carried voice traffic $T_{RAF}$, which means the utilization of physical channels to a given offered traffic is described by the average number of calls in that queue. Hence, $T_{RAF}$ is [4][7]:

$$T_{RAF} = E[n] = \sum_{n=1}^{N_{GSM}} n.p(n)\,, \tag{1}$$

where $p(n)$ is a steady-state probability of the M/M/c/c queue, which is given by [6]:

$$p(n) = \frac{\dfrac{\left(\dfrac{l_{GSM}}{m_{GSM}}\right)^{n}}{n!}}{\displaystyle\sum_{i=0}^{N_{GSM}} \left(\dfrac{l_{GSM}}{m_{GSM}}\right)^{i}} \quad ,(0 \le n \le N_{GSM})\,. \tag{2}$$

The average number of channels that can be allocated on-demand to GPRS $CH_{OD}$, is given by the average number of channels that are not being used by GSM. Hence, $CH_{OD}$ is:

$$CH_{OD} = N_{GSM} - \sum_{n=1}^{N_{GSM}} n.p(n) \ \ , \tag{3}$$

$$CH_{OD} = N_{GSM} - T_{RAF}\,. \tag{4}$$

The average number of channels that can be allocated to GPRS $CH_{MAX}$, is given by every possible channels used to carry the GPRS traffic, on others words, dedicated channels plus on-demand channels. Hence, $CH_{MAX}$ is:

$$CH_{MAX} = N_{GPRS} + CH_{OD} \tag{5}$$

$$CH_{MAX} = N - T_{RAF} \,. \qquad (6)$$

Using the measures (4) and (6) is possible to compute two measures of the utmost importance to analyze the performance of the integrated GSM-GPRS network. The first one is the maximum average throughput $TH_{MAX}$ over determined amount of offered voice traffic. That measure is given by the $CH_{MAX}$ times the used coding scheme data rate. This article works with CS-2, so that $TH_{MAX}$ is:

$$TH_{MAX} = 13.4 \times CH_{MAX} \ (kbits/s) \,. \qquad (7)$$

The second measure is the average on-demand throughput $TH_{OD}$. Like (7), that measure is given by:

$$TH_{OD} = 13.4 \times CH_{OD} \ (kbits/s) \,. \qquad (8)$$

## IV. RESULTS

The table I shows the parameters used to analyze the integrated GSM-GPRS network. They are divided into two models, these are: Integrated GSM-GPRS network model and the Traffic model.

TABLE I - PARAMETERS USED TO ANALYZE THE NETWORK

| MODEL | PARAMETERS | VALUE |
|---|---|---|
| INTEGRATED GSM-GPRS NETWORK MODEL | Number of physical channels ($N$) | 20 |
| | Number of PDCH ($N_{GPRS}$) | (0,1,2,4) |
| | Transfer rate for a single PDCH (CS-2) | 13.4 kbits/s |
| TRAFFIC MODEL | Percentage of users GSM | 95% |
| | Percentage of users GPRS | 5% |
| | Mean time of GSM call duration $T_{GSM}$ | 2 min |
| | GSM/GPRS call arrival rate ($l = l_{GSM} + l_{GPRS}$) | 0.0 – 0.56 call/s |

To simulate the network are utilized four network configurations, these are: 0-PDCH, 1-PDCH, 2-PDCH and 4-PDCH. This way, it is possible to investigate what is the impact of allocate some physical channels as PDCH. As mentioned before, the utilized coding scheme is CS-2. The call arrival rate is increased to study what is its impact on the network. The percentage of GSM users is 95%, while the percentage of GPRS users is just 5% [4]. The mean time of GSM call duration is about 2mim [3][8]. The total number of physical channels is 20.

Fig. 2 plots the voice blocking probability by means of Erlang's B formula. It can be observed that after about 0.3 call/s the voice blocking probability is approximately the same to every network configurations 0-PDCH, 1-PDCH, 2-PDCH and 4-PDCH. It means that the allocation of some physical channels like PDCH does not have a considerable impact on the network performance after a determined value of offered traffic.

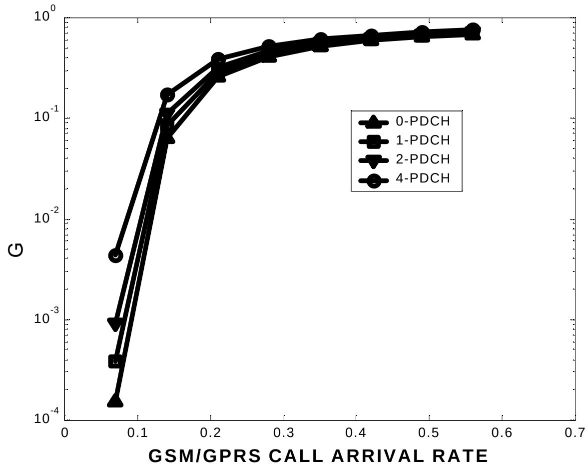


Fig. 2. Blocking probability.

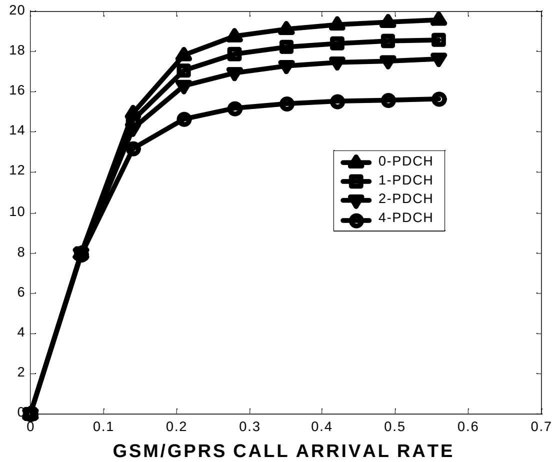


Fig. 3. Carried Traffic.

Fig. 3 shows that increasing the voice traffic on the network, more physical channels are used, being the configuration with 0-PDCH that more to carry the offered traffic. This increasing of voice traffic on the GSM network to decrease the number of available on-demand channels to Internet service on the GPRS network, due to the voice pre-emption over the GPRS services. This way, as it presents on fig. 4, the average number of on-demand channels approaches zero to the four network configurations, when the offered traffic approaches 0.56chall/s, which is the maximum traffic load. So to large traffic values, the unique available channels to Internet services on the GPRS network are the reserved ones, as it presents on the fig. 5. This way, the employment of physical channels allocate permanently as PDCH is fundamental to provide Internet services with quality.

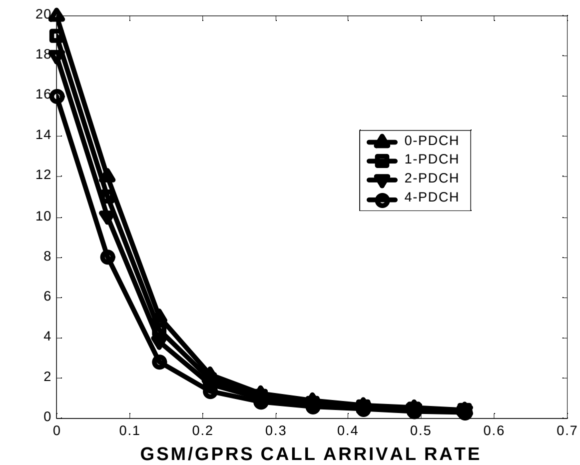


Fig. 4. Average number of on-demand channels.

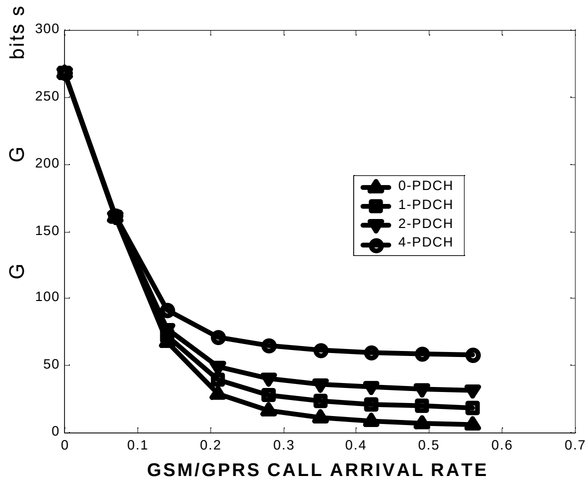


Fig. 6. Maximum average throughput

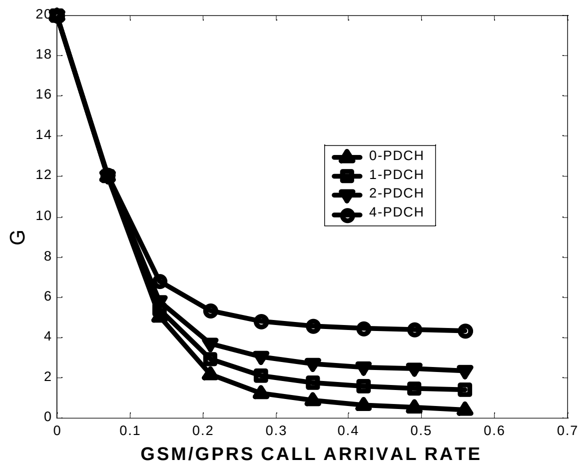


Fig. 5. Average number of GPRS channels.

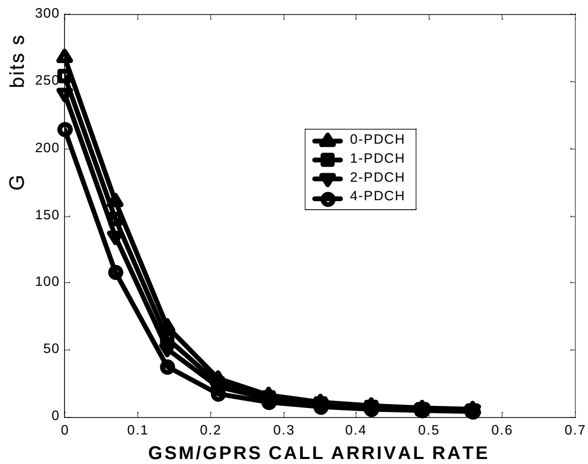


Fig. 7. Average on-demand throughput

The fig. 6 and fig. 7 respectively, holds the last analysis to show that the throughput is only guaranteed with the employment of physical channels allocate permanently as PDCH. It can be noticed on the fig. 6, that for 0.56 call/s the network gets to offer with the 4-PDCH, 2-PDCH, 1-PDCH configurations, the maximum average throughput of 57.85 kbits/s, 31.77 kbits/s, 18.75 kbits/s, respectively. On the contrary, on configuration 0-PDCH the maximum average throughput is 5.74 kbits/s, what is so low.

On that same offered traffic value, as it presented on the fig. 7, the averages on-demand throughput are 4.25 kbits/s, 4.97 kbits/s, 5.35 kbits/s and 5.74 kbits/s to configurations of 4-PDCH, 2-PDCH, 1-PDCH and 0-PDCH, respectively. It shows that the network does not get to provide the Internet service with the desired QoS only with these kinds of channels.

Although an analysis of IP packets were necessary to know exactly their impact on the network. The fig. 6 and fig. 7 show how much throughput the GPRS channels get at most to carry over a given offer of voice traffic, which still governs the network behavior [7].

TABLE II- VALUES OF AVERAGE THROUGHPUT

| CONFIGURATION | $TH_{MAX}$ (kbits/s) | $TH_{OD}$ (kbits/s) |
|---|---|---|
| 0-PDCH | 11.46 | 11.46 |
| 1-PDCH | 23.89 | 10.49 |
| 2-PDCH | 36.39 | 9.59 |
| 4-PDCH | 61.56 | 7.96 |

The table II presents the values of the maximum average throughput and the average on-demand throughput of data transmission to 0.35 call/s. If it is considerable 15 GPRS users on the network, and a it is desired a QoS profile of 3.5 kbits/s per user, so that just the 4-PDCH configuration will get to satisfy this specification reaching 4.0 kbits per user when the offered traffic is 0.35 call/s. It takes a place because for this value of offered traffic the maximum average throughput is 61.56 kbits/s, as it is showed on table II. The other ones configurations will degrade a QoS.

On the table II, to the same offered traffic, the average on-demand throughput is 11.4 kbits/s to 0-PDCH, which is the configuration that shows highest on-demand throughput. It results on 0.76 kbits/s per user what is so low value. Then, just the on-demand channels do not get to provide sufficient throughput to satisfy de QoS.

This way, the showed measures on this article are import to Network designers who aim to analyze the available resources that must be used to provide Internet services over the integrated GSM-GPRS, and to dimension them according to the available throughput to carry the Internet traffic with a desired QoS.

## V. CONCLUSION

On this article were showed measures that can be used to analyze the performance of the integrated GSM-GPRS network based on the voice service pre-emption over the Internet services. Through of presented outcome, it was possible to notice that physical channel permanently allocated as PDCH can guarantee the quality of the provided Internet service by GPRS network. Then, with these measures the GSM-GPRS network designers can calculate how many PDCH must be employed to provide the Internet services.

The showed model also provides information about the amount of available radio resource, and then the maximum average throughput and the average on-demand throughput, which are important to design of such integrated network.

## ACKNOWLEDGMENTS

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## REFERENCES

[1] C. Bettstetter , H. J. Vogel and J. Eberspacher , "GSM Phase 2+. General Packet Radio Services GPRS: architecture, protocols and air interface", IEEE Communications Surveys, Third Quarter 1999, vol. 2 no. 3.

[2] P. Chengyuan, "General Packet Radio Services (GPRS)".

[3] H. Gudding, " Capacity Analysis of GPRS, white paper", Norwegian University of Science and Tecnology, Department of Telematic, 2000

[4] C. Lindemann and A. Thümmler, "Performance Analysis of the General Packet Radio Service", University of Dortmund, Department of Computer Science, Germany, 2001.

[5] M. Rajaratnam and F. Takawira, "A single Cell model for the performance analysis of the radio layer in the GSM phase 2+ (GPRS) Networks under voice and data traffic", University of Natal, South Africa, 2001.

[6] D. Gross and C. M. Harris, "Fundamentals of Queueing Theory", John Wiley & Sons, 1974.

[7] I. Katzela and M. Naghshineh, "Channel Assignment Schemes for Celular Mobile Telecommunications Systems: A Comprehensive Survey", IEEE Personal Communications, June 1999.

[8] M. Mahdavi and R. Tafazolli , "Analysis of integrated voice and data for GPRS", 3G mobile communications technologies, conference publication, No 471, 2000.

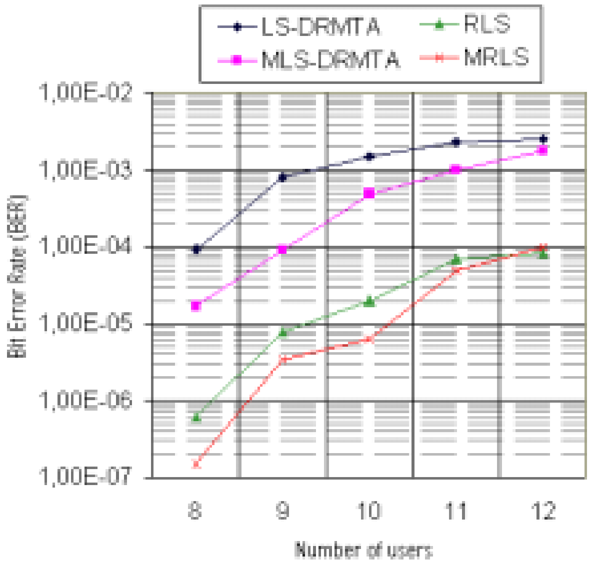


Fig. 5. Bit Error Rate (BER) in function of the number of users, using a linear array of 8 elements spaced of λ/2, with the presence of three multipaths of the signal of interest and $E_b/N_o$= 8 dB, for algorithms LS-DRMTA, MLS-DRMTA, RLS and MRLS.

The addition of all the signals increased of white gaussian noise then was submitted to the adaptive antenna array, controlled for the different algorithms in simulation. The output of the array was compared with the random sequence of bits of the interest user and calculated thus the BER for each situation

For the analysis of Fig. 5, perceives that the algorithms presented in this work (MLS-DRMTA and MRLS) are capable to surpass traditional algorithms LS-DRMTA and RLS when is considered as measured of performance the BER

# IV. CONCLUSIONS AND PROPOSALS OF FUTURE WORKS

In this paper we propose two new algorithms for adaptive antennas, which allows the array to receive all desired signal's multipaths and are presented diagrams of irradiation with the adaptive algorithms considered in this work (MLS-DRMTA and MRLS) and with the adaptive algorithms traditional originals (LS-DRMTA and RLS). After that, the new algorithms had been compared with the traditional algorithms using as performance index the bit error rate (BER). It was clearly, that the algorithms considered in this work surpass (according to metric used) the traditional algorithms of which had been generated.

In development of this work, and after the attainment of some results, some ideas if had presented as sufficiently interesting for accomplishment of new works.

They follow some topics that could be explored:

(i) Influence of the variation of the class and the size of the pseudo-random codes in the features of convergence of the algorithms.
(ii) Search of modifications in the algorithms to found the best selectivity of the irradiation diagrams.
(iii) Simulation of the algorithms for different geometries of array of the presented ones in this work.
(iv) Comparisons of the algorithms MRLS and MLS-DRMTA with the algorithms RLS and LS-DRMTA for different value of $E_b/N_o$.
(v) Analysis of the influence of the variation of the amplitude and the delays of propagation of the multipaths of the signal of interest in the performance of the considered algorithms.
(vi) Analysis of the viability of the application of the methods and results of the adaptive antenna arrays destined to the transmission.

## ACKNOWLEDGMENTS

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## REFERENCES

[1] Zhigang Rong, "Simulations of adaptive array algorithms for CDMA systems." M.S. thesis, Virginia Tech, Blacksburg, VA, September 1996
[2] Z. Rhong and T. S. Rappaport, "Simulation of multitarget adaptive algorithms for wireless CDMA systems," *Proc. IEEE Vehicular Technology Conf.,* April 1996.
[3] Josephi C. Liberti, Jr. and Theodore S. Rappaport, *Smart Antennas for Wireless Communications*. New York: Prentice Hall, 1999.
[4] R. T. Compton, Jr., *Adaptive Antennas – Concepts and Performance*. New Jersey: Prentice Hall, 1988.
[5] C. S. Beigthler, D. T. Philips, and D. J. Wilde, *Foundations of Optimizations,* Prentice Hall, Englewood Cliffs, New Jersey, 1979.
[6] B.H. Khalaj, A. Paultaj, and T. Kailath, "Antenna Arrays for CDMA Systems with Multipath," 1993 *IEEE Military Comm. Conf.,* pp. 624-628, Boston, MA, Oct. 1993.
[7] B.H. Khalaj, A. Paultaj, and T. Kailath, "2D RAKE receivers for CDMA cellular systems," *Proc. IEEE Globecom,* pp. 395-399, 1994.
[8] R. Price, P.E. Green, Jr., "A Communication Technique for Multipath Channels," *Proc. IRE,* 46:555-570, March 1958.
[9] Simon Haykin, *Communication Systems*. New Baskerville: John Willey & Sons, Inc., 1994.