Department of Electrical and Computer Engineering
Lisbon, Portugal

Department of Electronics and Information Technology
Warsaw, Poland

Multiservice Traffic Analysis in Mobile Broadband Systems

Krzysztof Marek Platek

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Under the supervision of:

Luis M. Correia

Department of Electrical and Computer Engineering

Instituto Superior Tecnico

Technical University of Lisbon

"It is dangerous to put limits on wireless"

Guglielmo Marconi (1932)

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List of Acronyms

AAL:	ATM Adaptation Layer
ABR:	Available Bit Rate
Asy:	Asymmetric
ATM:	Asynchronous Transmission Mode
BCC:	Business City Centre environment
BER:	Bit Error Rate
BPP:	Bernoulli Poisson Pascal process
CBR:	Constant Bit Rate
CC:	Conversational Class
CoS:	Class of Service
CS:	Circuit Switched
CSD:	Circuit Switched Data
DSL:	Digital Subscriber Line
DWDM:	Dense Wave Division Multiple Access
EDGE:	Enhanced Data for GSM Evolution
ETSI:	European Telecommunications Standards Institute
FCFS:	First Come First Served
FDD:	Frequency Division Duplex
FDMA:	Frequency Division Multiple Access
FIFO:	First In First Out
FTP:	File Transfer Protocol
GoS:	Grade of Service
GPRS:	General Packet Radio Service
GSM:	Global System for Mobile communications
HIMM:	High Interactive MultiMedia
HMM:	High MultiMedia
HSCSD:	High Speed Circuit Switched Data
IC:	Interactive Class
IEEE:	Institute of Electrical and Electronic Engineering
IMT-2000:	International Mobile Telecommunications 2000
IP:	Internet Protocol
IPP:	Interrupted Poisson Process

ITU:	International Telecommunication Union
MAC:	Medium Access Control
MBS:	Mobile Broadband Systems
MMM:	Medium MultiMedia
NRT:	Non Real Time
NTB:	Non Time Based
PDF:	Probability Density Function
PMF:	Probability Marginal Function
PS:	Packet Switched
QoS:	Quality of Service
ROA:	main Roads environment
RT:	Real Time
S:	Speech
SAP:	Service Access Point
SD:	Switched Data
SF:	Spreading Factor
SM:	Simple Messaging
STM:	Synchronous Transfer Mode
Sym:	Symmetric
TB:	Time Based
TCP:	Transmission Control Protocol
TD-CDMA:	Time Division-Code Division Multiple Access
TDD:	Time Division Duplex
TDMA:	Time Division Multiple Access
TV:	TeleVision
UBR:	Unspecified Bit Rate
UMTS:	Universal Mobile Telecommunication System
URB:	Urban environment
UTRA:	UMTS Terrestrial Radio Access
UTRAN:	UMTS Terrestrial Radio Access Network
VBR-NRT	Variable Bit Rate – Non Real Time
VBR-RT	Variable Bit Rate – Real Time
WCDMA:	Wideband Code Division Multiple Access
WWW:	World Wide Web

List of Symbols

α^{-1}	Time spent in On state
α_k	BPP process parameter
α_j	BPP process parameter
β^{-1}	Time spent in Off state
β_j	Activation rate of service component *j*
β_k	BPP process activation factor of application *k*
Δ	Velocity standard deviation
λ	Average number of calls generated by user per time unit (arrival rate)
$\lambda_{j\backslash k}$	Service component *j* used by application *k* arrival rate
$\lambda_j(n_j)$	Time after the next arrival of class *j* customer's arrival when the system is in state $N(t) = \boldsymbol{n}$
λ_k	Application *k* arrival rate
μ	Average service rate
μ_k	Average application *k* service rate
$\mu_{j\backslash k}$	Service component *j* used by application *k* service rate
η	The cell cross over rate
σ	Service time distribution variance
$\sigma[R_t]$	Standard deviation of interarrival time
τ	Call duration time when mobility is considered
τ_c	Channel occupancy time in a cell when mobility is considered
τ_h	Cell dwell time when mobility is considered
τ_n	Jump times

A	Total traffic intensity generated by system users
AF	Asymmetry factor
A_h	Traffic rate incoming from handover
a_j	Service component *j* data rates
A_k	Traffic generated per free user and for each application *k*
A_n	New arising in a cell traffic
A_u	Traffic intensity generated by user

b_k Data rates associated with application k

B_k Vector of steady states where k application arrive can not be granted

C Total number of system channels

c_1 Maximal load per user

D_v coefficient of variation

$E[R_t]$ Mean of interarrival time

f Fraction of active users

$f(v)$ Velocity probability density function

g Number of channels dedicated for guards

K Number of different applications

L Covered area length

L_q The average number of basic traffic units (ATM cells, IP frames) in the queue

L_u Every application data rate

M Total number of system users

M_v Markov process

M_n Markov chain

M_r Markov renewal process

$n_{j\backslash k}$ Average number of active service component j request

N_u Number of served users

$P(k)$ Probability of k system channels being busy

$p(n)$ State probability marginal function

P_b Probability of blocking

P_d Probability of call dropping

P_{hf} Probability of handover failure

p_k The probability that the system is in state S_k

$prop_k$ Proportion of application k users

R Coverage distance

R_t Interarrival time

S Area surface

T Average call holding time (average duration of call) generated by user

T_n Arrival instants

u Number of system users (terminals)

U Vector of active users of each application

u_j Number of users accessing to service component j

U_j	Total number of component j users
u_k	Number of users accessing to application k
U_k	Total number of application k users
V_{av}	Mobile terminals average velocity

1 *Introduction*

Mobile communications systems are becoming an important part of people everyday's life all around the world. Today's second generation (2G) cellular networks provide services to customers using mobile terminals through the use of advanced technologies. As 2G systems use digital technology, in contrast to the first generation ones, they are very successful world-wide in providing high quality voice services to users. Thanks to systems standardisation (e.g. GSM 900/1800 or IS 136) the ability to roam around the globe and communicate using handheld terminals became reality, hence customer pool is increasing faster than it was expected. Increasingly, those users will want to use a wireless access not only for voice communication. However these successful today 2G systems are limited in maximum data rate, thus the capabilities of cellular networks have to be improved. The High Speed Circuit Switched Data (HSCSD) and General Packet Radio Service (GPRS) are an actual user bit rate evolution in existing digital mobile networks that lead to high bandwidths, up to 470 kbit/s in Enhanced Data Rates for GSM Evolution (EDGE).

More advanced services than current voice and low data rate services are foreseen. Low and high definition video service components with high bandwidth demand are required for new arising multimedia services. According to the UMTS Forum, in 2010 about 60 % of traffic in Europe will be created by mobile multimedia applications. This is the background to the new third generation (3G) wireless systems demand. The bit rate up to 2 Mbit/s per user is assumed for the European 3G system – Universal Mobile Telecommunication System (UMTS). Nevertheless future multimedia services will range from low (~ 0.5 Mbit/s) to high user data rates (155 Mbit/s per user is foreseen). It is already well known that currently developed 3G systems are not able to fulfil these expectations, due not only to their bit rate but also to mobility limitations and packet switching (for high bit rate services) nature.

The future fourth generation Mobile Broadband System (MBS) concept is basically to extend mobile users access to Broadband Integrated Services of Digital Networking (B-ISDN) that will exist in future fixed networks, Figure 1.1. Around ten years from now, MBS will play an important role in the mobile telecommunications market, mainly in large city centres and urban areas where the highest demand is foreseen, while 3G systems are dedicated to provide service to anyone, anytime, anywhere. Fourth generation MBS is also assumed to support several services used simultaneously by the same user with the maximal bit rate up to 155 Mbit/s. Some today's assumptions for MBS are presented in Table 1.1.

Future applications must be considered differently in network planning and evolution process from today's simple voice services. The GSM Association is expecting a high grade of asymmetry between uplink and downlink for data based applications, with much higher capacity needed for downlink. Due to the expected new system users behaviour while they are using new services, teletraffic engineers should provide new models allowing communication networks to be planned and systems to be designed more efficiently and economically, as well as to meet a good performance. The Erlang B model for predicting blocking and Erlang C model for predicting delay are still used extensively by teletraffic engineers in their daily work while these formulas are not useful for multiservice modelling in Broadband networks. New models have to be created and developed, which together with a deep understanding of the technology and good applications characteristic can allow planning and dimensioning of future network with all its phenomena.

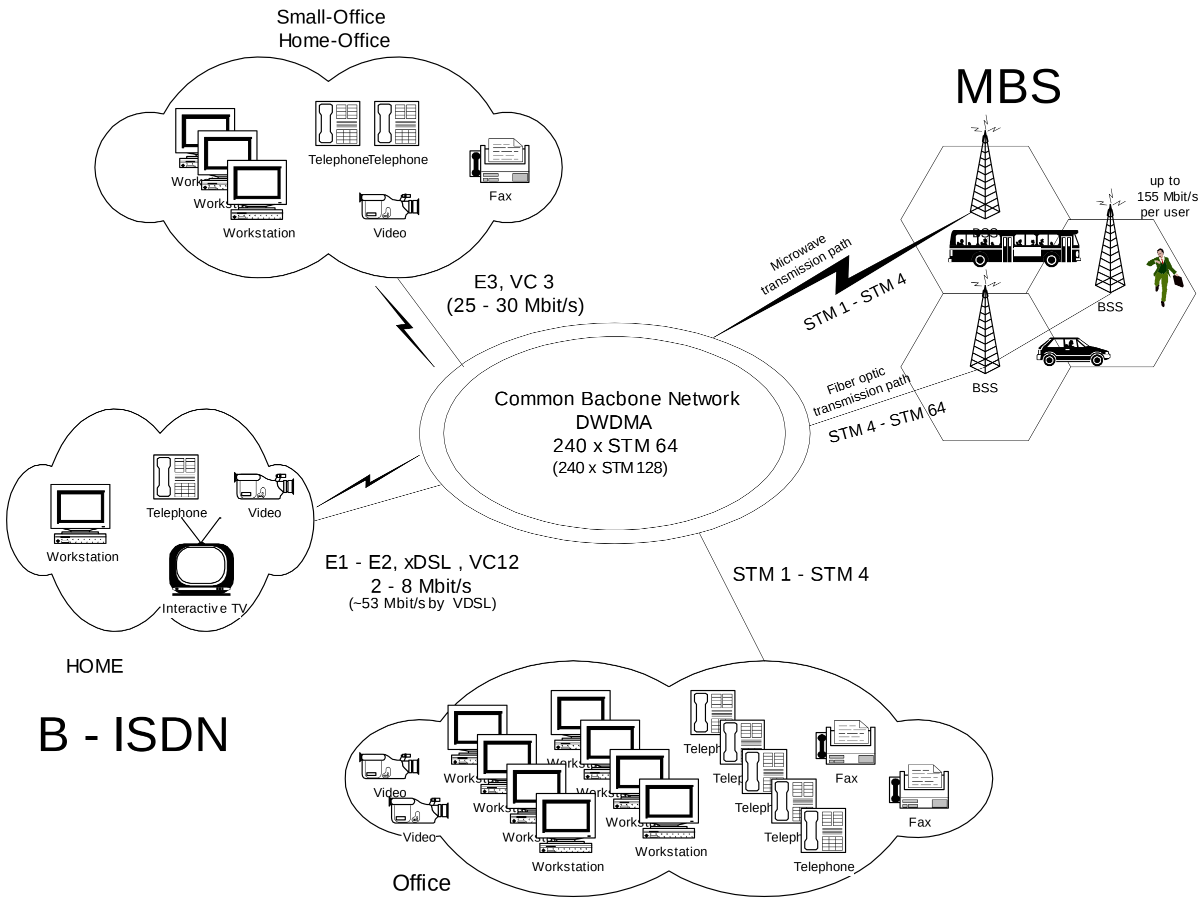


Figure 1.1 Mobile Broadband System as extension to B-ISDN.

Table 1.1 MBS objectives.

Owner/operator	Public and private system
Environment	Indoor and outdoor for all specified applications
Services/data rates	ATM cell transfer capability with user data rates up to 155 Mbit/s
Infrastructure	Cellular system consisting of mobile stations, base stations comprising transceivers, controller, and interworking units
Mobility	More than 100 km/h
Coverage	Large cities and business areas
Range	Up to 1 km, depending on antenna and frequency
Channel access	FDMA/TDMA frame structure
Frequency Bands: Medium Range MBS Short Range MBS	 39.5 – 40.5 and 42.5 – 43.5 GHz 62.0 – 63.0 and 65.0 – 66.0 GHz
Modulation	Polyvalence QPSK (4 QPSK or 16 QPSK)

Structure of the Report

This report concerns the analysis of multiservice traffic in future Mobile Broadband Systems, where different types and classes of services are assumed using the same network. and the same pool of resources. Different scenarios and environments with associated different users behaviours are considered. Some teletraffic theory is presented as well. The structure of the report is as follows.

In Chapter 2 one can find the classification of broadband services according to ITU-T I.211 Recommendation. Fixed networks Broadband ISDN services and applications are presented as well as current and future mobile networks applications. Mobile networks evolution in terms of user bit rate is analysed as well.

Chapter 3 is dedicated to theoretical traffic models. Some classical models for fixed networks are presented in order of better understanding the ones that are deployed for mobile network performance analysis. Packet switching data networks simple models are also included. In the last step models for multiservice traffic networks analysis are described.

In Chapter 4 the Mobile Broadband System's approach is done in terms of future applications. User's behaviour while using future applications in different environments is extensively analysed and some performance evaluations are presented to the reader. Different duplexing solutions (TDD or FDD) and their advantages and weakness are discussed of this chapter as well.

Chapter 5 provides the reader with the main conclusions achieved during this work. Some proposals for further research are also included.

2 *Broadband Services & Applications*

2.1 Broadband Services Classification

Today's market competition leads to the operators need of delivering new services, and to make their network more attractive to customers. In these times of fast Internet growth, people are interested in multimedia and E-commerce. Introducing new services has to be taken into account as well as their new requirements (bandwidth, delivery time, etc.). To make the future traffic analysis more effective, some characterisation parameters of the new applications have to be identified. Future MBS services and applications are based on new B-ISDN services, although it is too early to specify the overall vision of MBS using today's technology as a reference point. Nevertheless a first approach of 4G systems and their applications can be already done.

The classification of broadband services and applications for fixed B-ISDN is done according to the ITU-T I.211 Recommendation [VeCo00]. An application is defined as a task that requires communication of one or more information streams, between two or more parties that are geographically separated, being characterised by the main attributes, and also by traffic and communications characteristics. A set of applications with similar characteristics, or even a single application, can be classified as a service if they have a common set of characteristics. The application characteristics mainly consider delivery and bandwidth requirements.

Delivery Requirements

Communications can be either unidirectional or bi-directional. The bi-directional ones can be either symmetric (Sym) or asymmetric (Asy). For example, an usual telephone call is a symmetric application, while Internet browsing is clearly an asymmetric one (only commands are transmitted in the reverse link direction). An example of an unidirectional application is TV broadcasting. Time based (TB) information must be presented at specific instants to convey its meaning, i.e., time is an integral part of the information to be communicated or the information has a time component; typical time based types of information are video, audio and animation, while non time based (NTB) information includes images, graphics and text. An application can include both time based and non time based components. When an application involves multiple streams of information, synchronisation among them is an important issue [Kwok95].

Regarding to delivery requirements an application can be defined either as real time (RT) or a non real time (NRT) one. A real time application is one that requires information delivery for immediate consumption, in contrast to non real time applications, in which information can be stored temporarily at the receiving points (their buffers) for later consumption. For example, a telephone conversation is considered a real-time application, while sending electronic mail is a non real-time one [Kwok95]. In other words, users that communicate via a real-time application must be present at the same time. Classes of delivery are presented in Table 2.1.

Table 2.1 Example of applications with different information types and delivery requirements (extracted from [Kwok95]).

	Real Time Delivery	Non Real Time Delivery
Time Based Information	Video conferencing, telephony	Video clip transfer
Non Time Based Information	Image browsing	Electronic mail

The bandwidth requirements of an application (in each direction) are typically specified in terms of peak and average bandwidth. For Constant Bit Rate applications, the peak and average bandwidths are the same [Kwok95]. Special mechanisms and protocols are dedicated to protect delivery, bandwidth and quality requirements called Quality of Service Controls.

Quality of Service Control

Quality of Service (QoS) generally can be described as a parameter responsible for customer satisfaction. Traditional services are characterised on a point-to-point connection basis by giving fixed limits for network performance parameters such the bit rate, bit error rate (packet error rate), delay and jitters. Traditional networks have been Circuit Switched with fixed capacity and deterministic delay or Packet Switched with Variable Bit Rate and unpredictable delay by storing data in buffers. QoS parameter for these networks, like maximum allowable bit error rate and delay time, are controlled by continuous measuring. New services, in particular multimedia and broadband ones, require variable bandwidth and techniques like point-to-multipoint connections. Communication requirements for such services have to be defined by a sophisticated QoS framework, which has to be included in future network's architecture bearing in mind the following aspects:

- full end to end connection;
- service quality requirements can change in time, even during session.

Therefore a QoS parameter control framework has to include:

- end to end QoS negotiation as set up time (admission control);
- policing to ensure that users are not violating negotiated QoS parameter (user parameter control);
- monitoring to ensure that negotiated QoS levels are being maintained by the service provider.

Classification

The description of B-ISDN services and applications is organised according to ITU-T I.211 Recommendation. The work of [VeCo00] is used in what follows. Basic components are: audio, video and data, Figure 2.1.

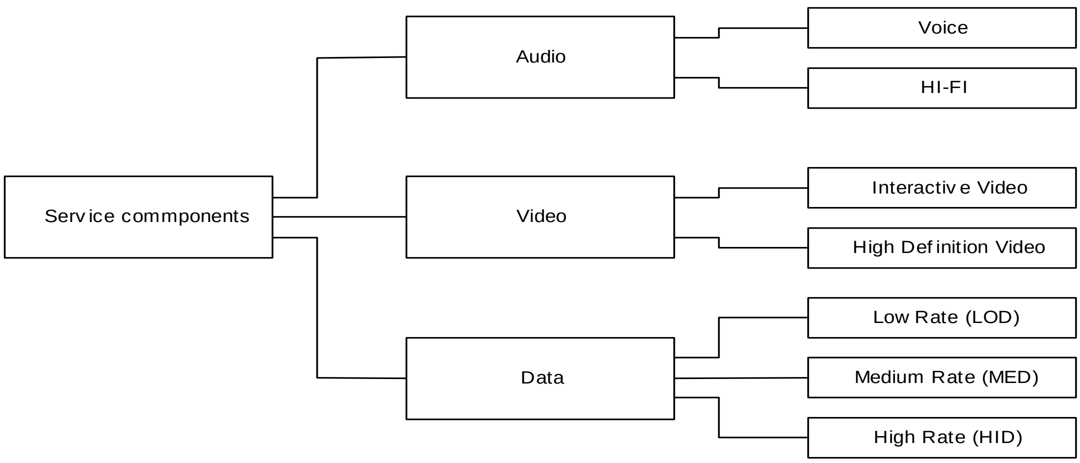


Figure 2.1 Basic service components (extracted from [VeCo00]).

According to ITU-T I.211, services can be classified as interactive or distribution ones, Figure 2.2. Interactive services are those in which there is a two-way exchange of information between subscribers or between a subscriber and a service provider, including the following three different categories: conversational, messaging and retrieval. Distribution services are the ones whose information transfer is primarily one-way, from service provider to subscriber, including broadcast services, where the user has no control over the presentation of the information, and cyclical services, which allow the user some measure of presentation control.

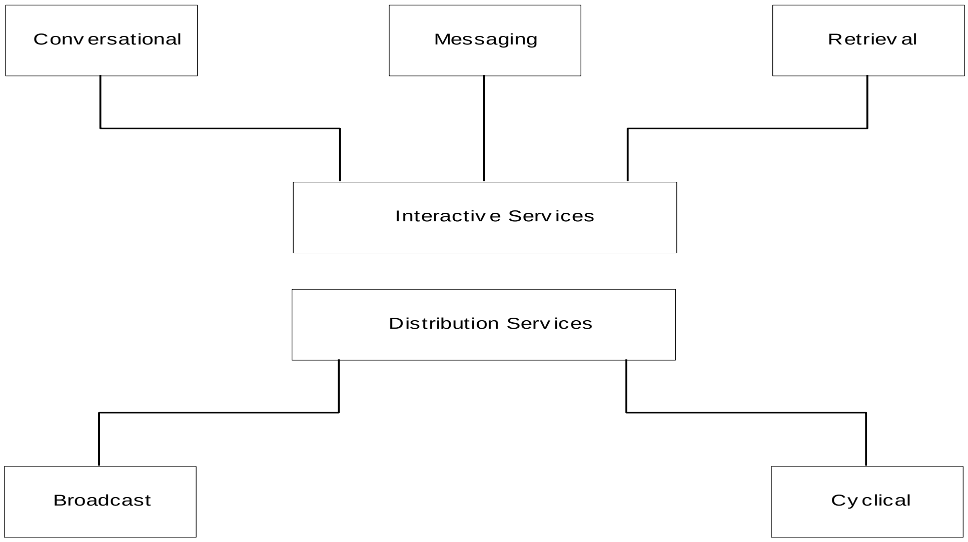


Figure 2.2 Classification of services according to ITU-T I.211 (extracted from [VeCo00]).

Conversational Services provide the means for bi-directional dialogue communication with bi-directional, real-time (not store and forward), end-to-end information transfer between two users, or between a user and a service provider host. The flow of information may be bi-directional symmetric or bi-directional asymmetric, and in some specific cases (e.g., video surveillance) the flow of information may be unidirectional.

Messaging Services offer user-to-user communication between individual users via storage units with store and forward, mailbox, and/or message-handling (e.g., information editing, processing and conversion) functions. In contrast to conversational services, messaging services are non real-time. Hence, they place lesser demands on the network and do not require that both users be available at the same time.

Retrieval Services provide the user with the capability to retrieve information stored in information centres that is, in general, available for public use. This information is sent to the user on demand only, with the possibility of being retrieved on an individual basis, i.e., the time at which an information sequence is started is under the control of the user. Examples are broadband retrieval services for film, high resolution image, audio information and archival information. An analogous narrowband service is videotext.

Broadcast Services provide a continuous flow of information, which is distributed from a central source to an unlimited number of authorised retrievers connected to the network. Each user can access this flow of information, but has no control over it; in particular, the user cannot control the starting time or order the presentation of the broadcasted information. All users simply tap into the flow of information. Depending on the instant of time the user accesses as the information may not be presented from the beginning.

The most common examples of this service are broadcast of television and audio programmes.

Cyclical services allow distributing information from a central source to a large number of users. However, the information is provided as a sequence of information entities (e.g., frames) with cyclical repetition. So the user has the ability of individual access to the cyclical distributed information, and can control start and order of presentation. Due to cyclical repetition, the information entities, selected by user, will always be presented from the beginning. Delivery and bandwidth requirements for new B-ISDN applications are presented in Table 2.2.

Table 2.2 B-ISDN applications and their requirements (extracted from [VeCo00]).

Broadband Services – Retrieval	**Applications**	**Time Dependency**	**Delivery Requirements**	**Transmission Data Rate [kbit/s]**
Broadband Videotext	Videotext (Including Moving Pictures) Tele Education Tele Software E-commerce Tele Advertising News Retrieval Multimedia Library Retrieve of Encyclopaedia Entries Tourist Information	TB NTB TB TB	RT	64 – 10 000
Video Retrieval Service MPEG 1	Entertainment Purpose Remote Educational and Training	TB	RT / NRT (for file download)	1 000 – 2 000
Video Retrieval Service MPEG 2	Entertainment Purpose Remote Educational and Training	TB		4 000 – 10 000
Video Browsing	Entertainment of Business Purpose	TB	RT	2 000 – 40 000
High Resolution Image Retrieval Service	Entertainment Purposes Remote Educational and Training Professional Image Communications Medical Image Communications	NTB	RT / NRT	10 000 – 100 000
Data Retrieval Service	Tele Software Remote Educational and Training Remote Database Access Large File Download Mixed Media Document Remote Procedure Call	NTB	RT/ NRT	400 – 10 000
Multimedia Retrieval Service	Urban Guidance Public Transport Information Assistance in Travel	TB	RT/ NRT	2 000 – 4 000

Table 2.2 B-ISDN applications and their requirements (cont.).

Broadband Services – Messaging	**Applications**	**Time Dependency**	**Delivery Requirements**	**Transmission Data Rate [kbit/s]**
Electronic Mail / Paging	Paging Visual E-mail (with attachments)	NTB	RT	9.6 – 1 500
Video / Image Mail	Audio / Video Mailbox	TB	NRT	1 000 – 4000
Voice Mail	Electronic Mailbox Service for Voice	TB	NRT	16 – 64
Multimedia Mail	Electronic Mailbox Service for Voice Multimedia	TB	NRT	1 000 – 4 000

Table 2.2 B-ISDN applications and their requirements (cont.).

Broadband Services – Conversational	Applications	Time Dependency	Delivery Requirem ents	Transmission Data Rate [kbit/s]
Broadband High Definition Videotelephony	Tele Education E-commerce Tele-advertising	TB	RT	64 – 2 000
Broadband Videoconference	Tele Education E-commerce Tele-advertising	TB	RT	2 000 – 8 000 UL 750 DL 2 250
ISDN Videoconference	Tele Education E-commerce Tele-advertising	TB	RT	384
Video Surveillance	Building Security Traffic Monitoring Mobile Video Surveillance	TB	RT	750 – 2 250
Audio/Video Information Transmission Service	TV Signal Transfer Audio/Video Dialogue Mobile HDTV outside Broadcast Contribution of Information	TB	RT	2 000 – 8 000 (with MPEG 2) up to 34 000 (without MPEG 2)
Multiple Sound Programme Signals	High Quality Voice Multi Lingual Commentary Multiple Programmes Channel	TB	RT	128 (MP3 Compressed) 3 070 (8 channels Hi-Fi Stereo)
High Speed Unrestricted Information Transmission Service	High Speed Data Transfer - LAN Interconnection - MAN Interconnection - Computers Interconnection	NTB	NRT/RT	1 500 – 100 000
	Wireless LAN Interconnection Transfer of Video Information	TB		128 – 150 000
	Still Image Transfer Multi Rate Interactive Computer Industrial Wireless LAN CAD/CAM/CAE	NTB		25 000
	Business Communications			1 500 – 100 000
High Volume File Transfer Service	Data File Transfer (FTP) Program Downloading	NTB	RT	64 – 1 500 2 000
High Speed Tele-action	Real Time Control Telemetry Alarms Remote Terminal	TB	RT	2 – 20
High Speed Tele Fax	User to User Transfer of Text, Images, Drawings etc	TB	RT	64
High Resolution Image Communication Service	Professional Images Medical Images Remote Games Tele-robotics	TB/ NTB	RT	10 000 – 100 000
Mixed Document Communications Service	Desktop Multimedia Multimedia Conferencing Interactive Multimedia Real Time Desktop Multimedia	TB	RT	1 000 – 2 000
	Document Storage System Mobile Emergency Services Mobile Repair Assistance Mobile Tele Working			2 000 – 8 000
	Freight and Fleet Management High Speed Trains			UL 100 DL 500

Table 2.2 B-ISDN applications and their requirements (cont.).

Broadband Services – Cyclical	Applications	Time Dependency	Delivery Requirem ents	Transmission Data Rate [kbit/s]
Full Channel Broadcast Videography	Remote Education and Training Tele Advertising News Distribution	TB	NRT	2 000 – 34 000 (with Video)
	Tele Software	NTB		
	E-newspaper	TB		
Cabeltext (timely and frequently requested information)	E-newspaper	NTB	NRT	2 000 – 34 000 (with Video)
	In House Information Systems for Trade Fairs, Hotels and Hospitals	NT/ NTB		

Table 2.2 B-ISDN applications and their requirements (cont.).

Broadband Services – Broadcast	**Applications**	**Time Dependency**	**Delivery Requirements**	**Transmission Data Rate [kbit/s]**
High – Speed Unrestricted Digital Information Distribution Services	Distribution of Unrestricted Data	NTB	NRT	1 000 – 140 000
Document Distribution Service	Electronic Newspaper Electronic Publishing	NTB	NRT	1 000 – 10 000
Broadband Video Information Distribution Service	Distribution of Audio/Video Signals	TB	RT	2 000 – 40 000
Existing Quality TV Distribution Service (NTSC, PAL, SECAM)	TV Programme Distribution	TB	RT	3 000 – 10 000 (compressed) 15 000 – 44 000 (without compression)
Extended Quality TV Distribution Service (enhanced and high quality TV distribution)	TV Programme Distribution	TB	RT	> 15 000
HDTV Service	TV Programme Distribution	TB	RT	~ 20 000
Pay TV (pay-per-view, pay-per-channel)	TV Programme Distribution	TB	RT	3 000 – 40 000

2.2 Mobile Systems and Applications Evolution

Today's cellular systems are designed to achieve 90-95% coverage for voice users. The explosive growth of Internet and the continued dramatic increase in demand for all types of wireless services (voice, data and video) are supplying the demand with increasing capacity requirements. Higher data rates have to be delivered to mobile network subscribers for supporting new services (e.g. multimedia services, which provide concurrent video, high quality voice and data to support advanced applications). Higher data rates will enable a broader range of services compared to those provided in the currently deployed cellular systems. Forecasted data traffic growth for mobile networks is presented on Figure 2.3, where one can find the present trends of demand for transmission capacity for data traffic.

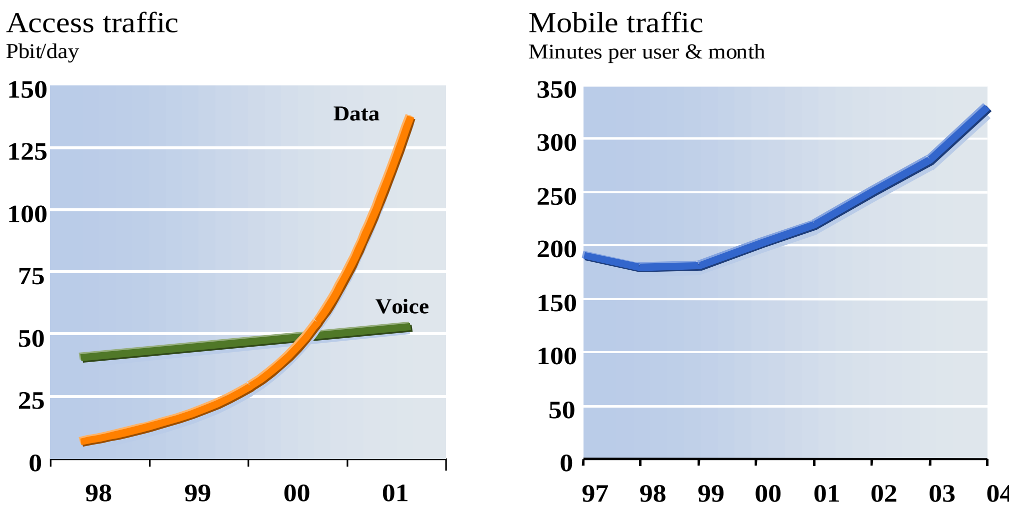


Figure 2.3 Forecasted traffic growth of data in mobile networks as function of time, extracted from [Beck00].

It is well known that in existing systems user bit rates extension is the main target of telecommunication operators. The evolution of digital cellular systems is presented in Figure 2.4.

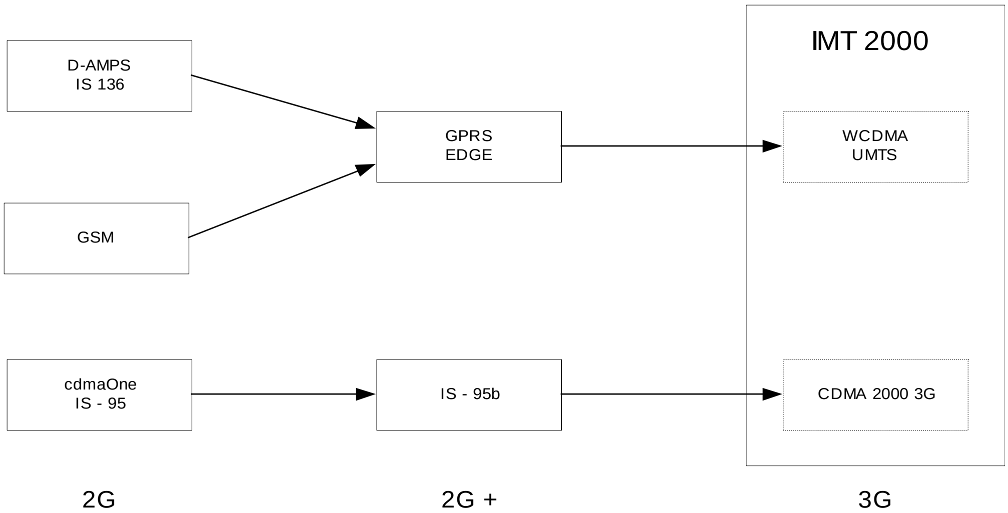


Figure 2.4 Mobile Systems Evolution.

Today's switching systems called support Circuit Switching data communication, while the future ones are oriented to Packet Switching. The differences are presented in Figure 2.5: while for Circuit Switching there is a connection open all-way full time, Packet Switching includes partial connection, i.e., part-time.

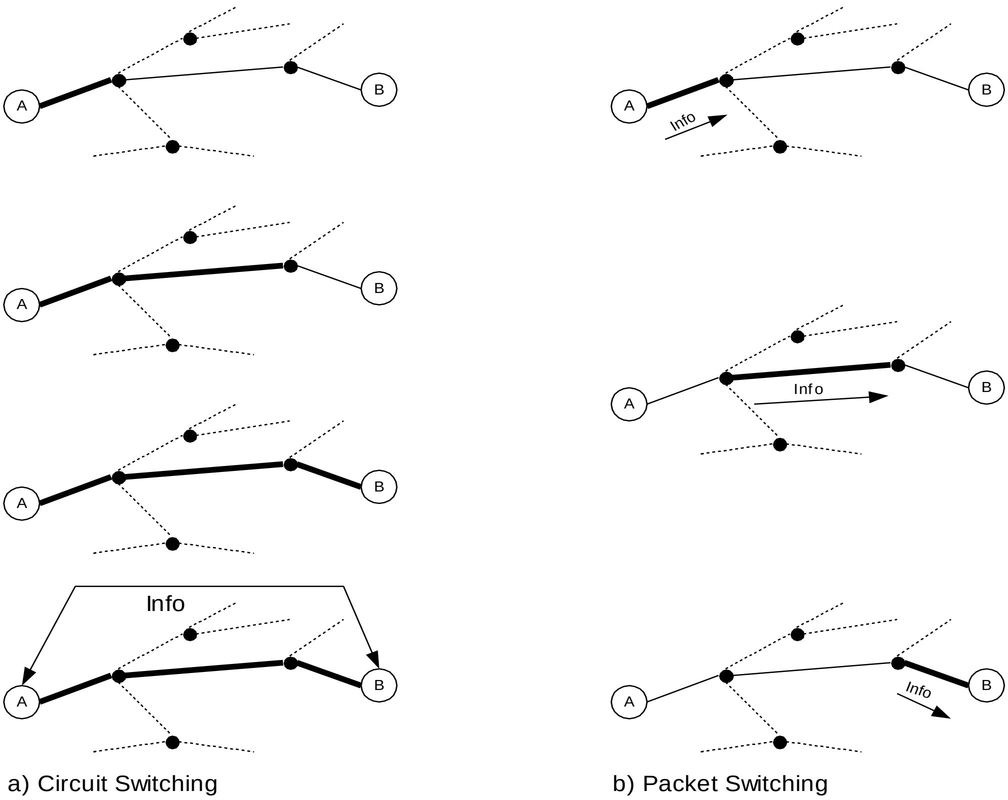


Figure 2.5 Comparison of Circuit Switched and Packet Switched modes.

Examples of systems allowing Circuit Switching mode in their pure version, with the respective data rates are presented in Table 2.3.

Table 2.3 Phase 2 user available bandwidth.

System	Peak Data Rates [kbit/s]
GSM	9.6
IS – 136	9.6
IS – 95	9.6 (Rate set 1) 14.4 (Rate set 2)

The first enhancement made for the GSM network is High Speed Circuit Switched Data (HSCSD). HSCSD is only an association of up to four channels (time slots) in one common data string, hence it can provide up to 38.4 kbit/s (in [EN7499] one can find 64 kbit/s as a future solution, assuming 16 kbit/s per time-slot). Circuit Switched connection should be chosen for continuous time applications and notification, the former because of its sensitivity to connection delays, and the latter because of its almost constant bandwidth.

The next enhancement for improving data rates after HSCSD is General Packet Radio Service (GPRS). In Packet Switched communications the network delivers a packet with data when the need arises. Thus, for the air interface, one radio channel can be shared among several users simultaneously. When a user generates a data packet the network forwards it to its addressee on the first available channel. Since data traffic often consists of bursts of data, radio channels will be used efficiently. In TDMA higher data rates are achieved by combining up to eight (for GSM) physical channels (time slots). Rate improvement in CDMA systems is achieved through a combination of variable spreading, coding and code aggregation. In the IS-95 system each high-speed data user is assigned one to eight codes. The specified maximum data rates are presented in Table 2.4.

Table 2.4 Phase 2+ user available bandwidth.

System	Peak Data Rate [kbit/s]
GSM GPRS GMSK mod. GSM EDGE 8 PSK mod.	160.0 473.6
IS – 136 GPRS π/4 DQPSK mod. (3 slot throughput) 8 PSK mod. (3 slot throughput)	30.0 45.0
IS – 95 B Rate set 2	115.2

GPRS Packet Data applications are [EN7499]: E-mail, World Wide Web browsing, File transfer (FTP), Point of sale (credit cards readers), Database searches, Two-way messaging (Internet chats), Telemetry (meters readers), Dispatch services (police, courier, taxi, etc.)

Third Generation (3G)

Wideband Code Division Multiple Access (WCDMA) is chosen as one of the air interface technologies to meet the future requirements of next generation wireless communication services. Packet and Circuit Switched services can be freely mixed, with variable bandwidths, and delivered simultaneously to the same user, with specific quality levels. Bandwidth requirements for a user can be changed during a session. This is achieved in a spectrum efficient WCDMA wireless access. As for 3G main goals, the following can be considered:

- support for several simultaneous connection;
- national and international Roaming;
- capable of handling Packet and Circuit Switched services, as well as asymmetric data transmission;
- co-existence and interconnection with satellite based services.

Peak data rates for 3G are presented in Table 2.5.

Table 2.5 Phase 3 user available data rates (extracted from [NaBK00]).

System	Bandwidth [MHz]	Spreading factor	Peak Data Rate [kbit/s]
WCDMA/UMTS	5	64 16 8 4 4	12.2 64.0 144.0 384.0 2048.0
cdma2000	5 (convolutional code rate: 1/3)	128 64 32 16 8 4 2	9.6 19.2 38.4 76.8 153.6 307.2 614.4

The UMTS market comprises a wide area of applications that can be converted into six main service classes, Table 2.6. The first three classes of services are seen as logical extensions of the 2G mobile market, being supported by Circuit Switching, while the last three are addressing the new UMTS multimedia market, being supported by Packet Switching, except High Interactive Multimedia, which is also supported by Circuit Switching.

Table 2.6 UMTS applications and their peak bit rates (extracted from [VeCo00]).

Application	Peak Bit Rate [kbit/s]	Service Class
Simple Voice Services Teleconferencing Voicemail	16	Speech
SMS and Paging E-mail Delivery Broadcast and Public Information Messaging Ordering/Payment (simple electronic commerce)	14	Simple Messaging
Low Speed Dial-Up LAN Access Internet/Intranet Access FAX	14	Switched Data
LAN and Internet/Intranet Access Application Sharing Interactive Games Lottery and Betting Services Broadcast and Public Information Messaging Simple Online Shopping and Banking (E-commerce)	384	Medium Multimedia
Fast LAN and Internet/Intranet Access Video Clips on Demand Audio Clips on Demand Online Shopping	2 000	High Multimedia
Videotelephony and Videoconferencing Collaborative Working and Tele-Presence	128	High Interactive Multimedia

Fourth Generation (4G)

The fourth generation Mobile Broadband System (MBS) will be deployed in urban and business (exhibitions halls, offices, downtown) areas, where the highest demand will occur. A reason for 4G coverage limitations is the huge path loss due to the high working frequency (40 and 60 GHz), and also coming from rain attenuation and gas absorption. The goal of MBS is to increase drastically mobile networks capacity and their services spectrum. Nevertheless, it does not mean the nightfall of 3G systems, i.e., 4G and 3G systems will work simultaneously, fulfilling each other hole: low user bit rates and short available services list of 3G and small coverage of 4G. The main advantage of MBS is that it supports several services simultaneously, over the same platform, for different, or even the same user(s). The MBS concept is graphically presented in Figure 2.6. Owing to the diversity of characteristics of the services to be supported, different requirements arise for resource usage, each application being supported by these services having access to various service components or bearers. Depending on the mixture of applications and service components being active simultaneously different user bandwidths will be requested. Two 2 GHz bands are assumed to be capable to serve to the customer all applications with good GoS. In order to prepare first system approach some marketing analysis has been done and some future MBS applications can be foreseen today. Examples of them are presented in Table 2.7.

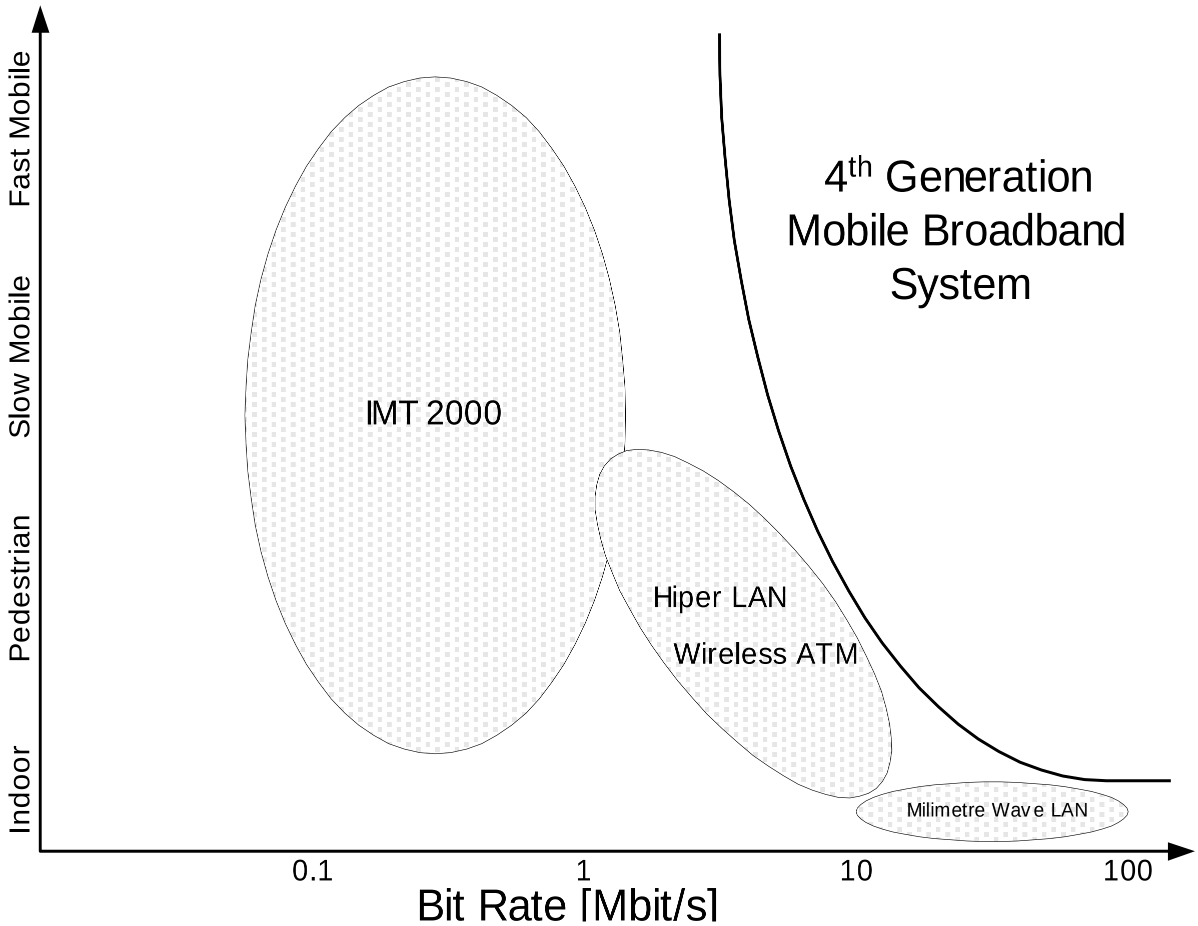


Figure 2.6 Systems evolution toward MBS.

Table 2.7 MBS applications and bandwidths (extracted from [VeCo00]).

	Application	Data Rate [kbit/s]
Low MBS	ISDN Videoconference (Tele-advertising)	384
	Data File Transfer (ftp)	384
	Desktop Multimedia(Web browsing)	384
	Broadband Videotext (E-commerce)	384
Wideband	Monitoring	500
	Configuration Data	600
	E-mailbox for Multimedia	1 500
	Remote Procedure Call	1 500
	HD Videotelephony (Tele-education)	2 000
	Mobile Tele-working	2 000
	Assistance in Travel	2 000
	City Guidance	2 000
	Mobile Video Surveillance	2 000
	Tourist information	2 000
	E-newspaper	2 000
	Video Multi-point Monitoring	2 000
Broadband	Freight and Fleet management	2 200
	Mobile Repair Assistance	2 400
	Multimedia Library	2 400
	Mobile Emergency Services	2 800
	TV-programme (MPEG 2)	8 000
	High BW Video, Multipoint Monitoring	8 000
	Professional Images	8 000
	HDTV Outside Broadcast	8 000
	Control Data	21 000
	Wireless LAN Interconnection 10Base.x 100Base.x	10 000 100 000

The B-ISDN introduction into the market is delayed and it is not easy to forecast now all the future customer's needs or applications and their behaviour while using them. It is also important to stress that MBS is not completely identified in terms of mobility, but a maximum user bit rate of 155 Mbit/s is assumed for the time being.

3 *Traffic theory basis*

3.1 Introduction

Telecommunication systems use trunks to accommodate a large number of users in limited transmission abilities. The concept of trunking allows a large number of users to share the relatively small number of channels in a chosen area by providing each user access to resources on demand, from a pool of available channels. Trunking exploits the statistical behaviour of users and calls so that a fixed number of channels may accommodate a large, random user community. Probability theory is used to calculate the requirements for resources and their utilisation.

3.2 Intensity and Units of Traffic

Traffic intensity is measured in Erlang, the name of the Danish mathematician, who found telephone traffic theory. Using the Erlang formula, the calculation of traffic generated by one user can be defined as follows [Yaco93]:

$$A_u = \frac{\lambda_u}{\mu_u} \quad [\text{Erlang}] \tag{3.1}$$

$$\mu_u = \frac{1}{T} \quad [s^{-1}] \tag{3.2}$$

where:

λ – Average number of calls generated by user per time unit

T – Average call holding time (average duration of call) generated by user

μ – Average service rate

Hence, typically it is represented as follows:

$$A_u = \frac{\lambda \cdot T}{3600} \quad [\text{Erlang}] \tag{3.3}$$

From this, the total traffic in a chosen area is calculated by summing the traffic generated by each system user in the considered area:

$$A = \sum_{u=0}^{N_u} A_u \quad [\text{Erlang}] \tag{3.4}$$

where:

N_u – number of served users

Congestion time is the period of time during which all channels available in the system are busy. Thus new incoming calls will be denied. In that case, the following relation exists for the set of available channels:

$$c_n = 1 \text{ Erlang} \tag{3.5}$$

where:

c_n – maximal traffic from the independent channel n

Hence, the total traffic offered by one channel is less or equal to 1 Erlang.

3.3 Birth & Death Process

Let S_k denote the state of the system when the number of busy channels is k. In the Markov chain model transitions are only allowed between neighbouring states, hence transition from S_k to S_{k+1} implies that a new channel will get busy with rate λ_k, and transition from S_k to S_{k-1} implies channel releasing with rate μ_k , Figure 3.1[Yaco93].

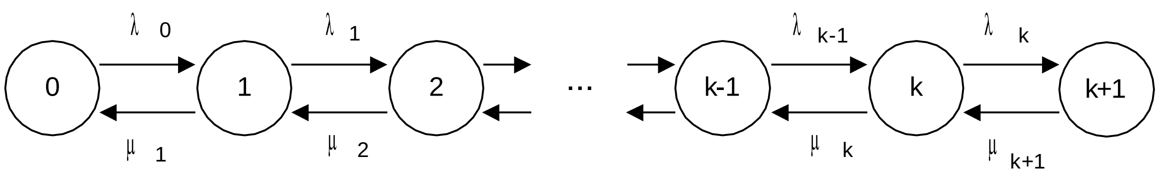


Figure 3.1 State transition diagram for one dimensional birth death process.

Let p_k be the probability that the system is in state S_k at time t (k represents the number of system channels being busy). Inspecting Figure 3.1, the probability of reaching state S_k can be represented as:

$$S_k = [\lambda_{k-1}\, p_{k-1} + \mu_{k+1}\, p_{k+1}]\, dt \tag{3.6}$$

and the probability of departing from state S_k is given by:

$$S_k = (\lambda_k + \mu_k) dt\, p_k \tag{3.7}$$

By differentiation one obtains the equilibrium equation

$$\lambda_{k-1} p_{k-1} + \mu_{k+1} p_{k+1} = (\lambda_k + \mu_k) p_k \qquad k \geq 0 \tag{3.8}$$

where:

$p_{-1} = 0$ (less then 0 channels cannot be allocated)

$\mu_0 = 0$

$\lambda_{-1} = 0$

Equation 3.8 shows that, in equilibrium, the rate of flow into the state S_k equals the rate of flow out of S_k. By writing equation above sequentially, for k = 0,1,2,..., and observing that the probabilities p_k sum to unity, one obtains the following solution for the set of equations:

$$p_k = p_0 \prod_{i=0}^{k-1} \frac{\lambda_i}{\mu_{i+1}} \tag{3.9}$$

where:

$$p_0 = \left[1 + \sum_{k=1}^{\infty} \prod_{i=0}^{k-1} \frac{\lambda_i}{\mu_{i+1}} \right]^{-1} \tag{3.10}$$

If one has a total of C channels in the system and considering $\mu_i = i\mu$, where μ is the service rate, p_C corresponds to the Erlang B equation.

Grade of Service

The grade of service (GOS) is defined as the probability of call failure due to transmission congestion and it is very often called *Blocking Probability*. Looking to the Markov chain model, time congestion is the proportion of time when, for C available in system channels, transitions terminate at state S_C. All calls will fail if GOS = 1 and all calls will pass if GOS = 0. Typical values are:

- $0.005 < GOS < 0.008$ for fixed networks (depends on operator marketing demands);
- $GOS = 0.02$ for mobile networks.

3.4 Basic Aspects of Traffic Modelling

3.4.1 Bursty and Renewal Traffic

A recurrent theme relating to traffic in broadband networks is traffic burstiness exhibited by key services such as compressed video, file transfer, etc., Figure 3.2. Burstiness is present in a traffic process if arrival instants T_n look like visual clusters, that is, interarrival times R_t tend to give rise to runs of several relatively short interarrival times followed by a relatively long one. The two simplest measures of burstiness take into account only first-order properties of traffic (they are each a function of interarrival times R_t). The first one is the ratio of peak rate to mean rate – a very crude measure, which also has to shortcoming of dependence on the interval length utilised for rate measurement. A more elaborate measurement of burstiness is the coefficient of variation, defined as the ratio of standard deviation to mean of interarrival times [FrMe94] $D_v = \sigma[R_t]/E[R_t]$.

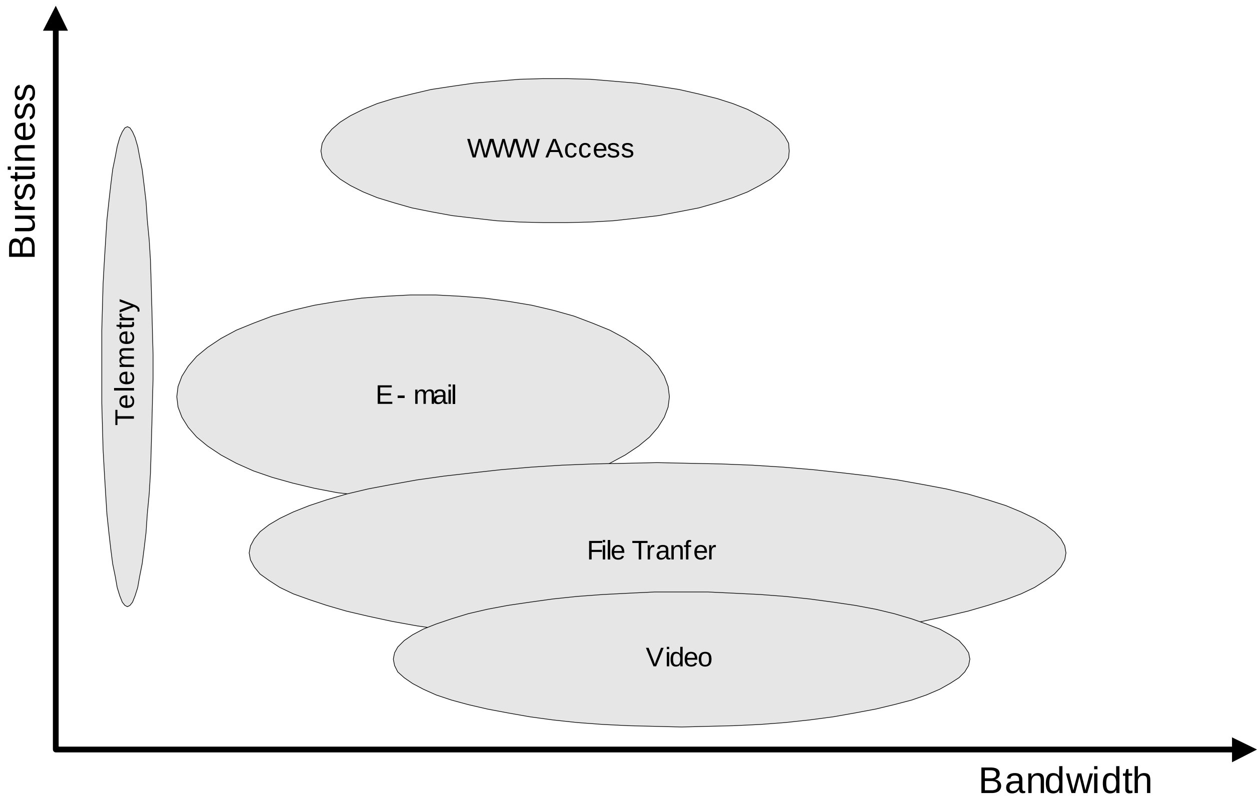


Figure 3.2 Areas of bursty and bandwidth consuming by applications extracted from [EN7499].

In the renewal traffic process, the interarrivals times R_t are independent and identically distributed, and their distribution is allowed to be general. Unfortunately, with few exceptions, the superposition of independent renewal processes does not yield a renewal process. Queuing models have almost routinely assumed a renewal-offered traffic. Renewal processes modelling is generally based on autocorrelation of interarrivals times R_t. The autocorrelation function in Renewal Traffic Models is used to capture temporal dependence in time series, for example to make an approach of traffic bursts. Bursty traffic is expected to dominate broadband networks, and when offered to a queuing system, it gives rise to much worse performance (such as mean waiting times) as compared to renewal traffic (which lacks temporal dependence). Consequently, models that capture the autocorrelated nature of traffic are essential for predicting the performance of emerging broadband networks.

3.4.2 Poisson Process

A Poisson process can be characterised as a renewal process whose interarrival times R_t are exponentially distributed with rate parameter λ and probability Prob$\{R_t \leq t\}$=1– exp(-λt). Poisson processes enjoy some elegant analytical properties. First, the superposition of independent Poisson processes result in a new Poisson process whose rate is the sum of the component rates, Figure 3.3.

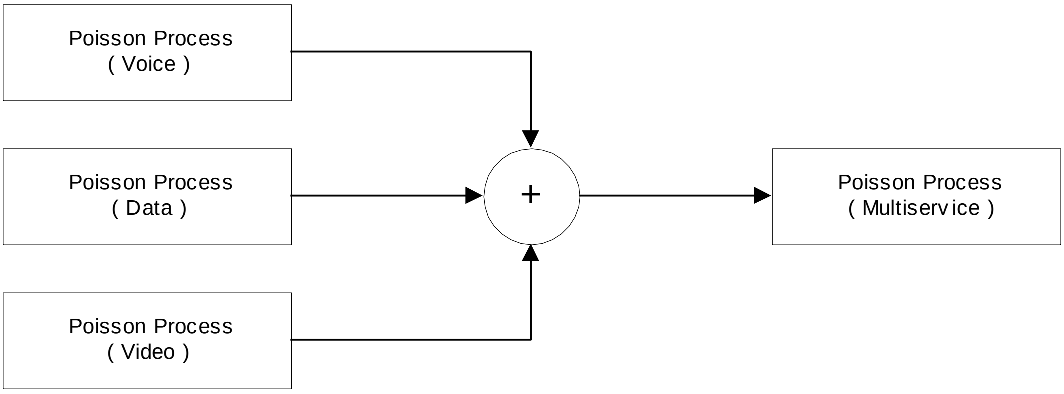


Figure 3.3 Superposition of Poisson processes.

Second, the independent increment property renders Poisson a memoryless process. This, in turn, greatly simplifies queuing problems involving Poisson arrivals. Third, Poisson processes are fairly common in traffic applications that physically comprise a large number of independent traffic streams. However, traffic aggregation (multiplexing) need not always result in a Poisson stream. The Poisson distribution characterises a statistical process that applies to a sequence of events that take place at regular intervals of time, hence the information about arriving phone calls is required [FrMe94].

Considering a system with an infinite number of servers and assuming that the calls arrival (birth) rate is constant and equal to λ and that departure (death – end of call) from each server is equal to μ, one has

$\lambda_k = \lambda, \qquad k \geq 0$

$\mu_k = k\mu, \qquad k \geq 1$

Using (3.9) and (3.10) one obtains the probability of k system channels being busy [Hill79]:

$$P(k) = \frac{A^k e^{-A}}{k!} \tag{3.11}$$

Figure 3.4 shows an example of $P(k)$ distribution for a given traffic intensity of A=10 Erlang and A=28 Erlang

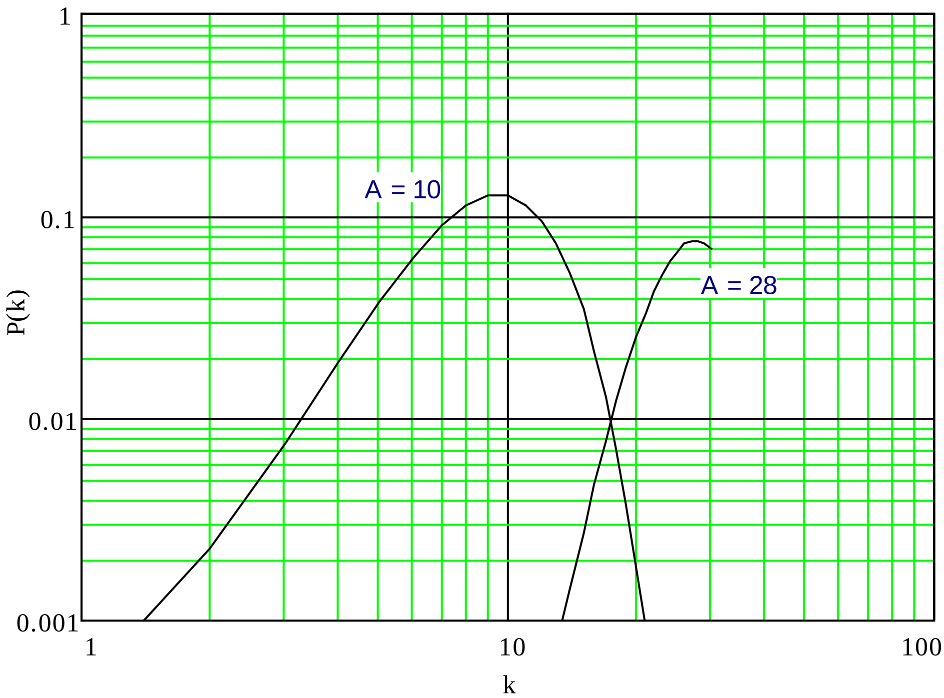


Figure 3.4 Probability of k system channels being busy (k simultaneous calls) using Poisson distribution for A=10 Erlang and A=28 Erlang.

3.4.3 Bernoulli Processes

Bernoulli Processes are the discrete-time analog of Poisson processes, i.e., they are applied when time is slotted (slots, frames). Here the probability of an arrival in any time slot is p, independent of any other one. It follows that for slot (channel) k, the corresponding number of arrivals is binomial. The time between arrivals is geometric with parameter p, i.e. Prob$\{R_t = j\} = p(1-p)^j$, j being a non-negative integer. The statistical parameters of a group of users varies with time. However they can be taken as a constant over a period of time. Thus, the probability per unit time of a new call request arising is equal to the probability per unit time of an existing call terminating. Assuming in discrete time that calls originate at random from all terminals, and that the number of users is less than the number of available channels, for C independent channels the probability of k of them being busy is given by

Bernoulli distribution (because we cannot assume that P(k) is independent of the number of calls being in progress) [Hill79]:

$$P(k) = \frac{u!}{k!(u-k)!} A_u{}^k (1 - A_u)^{u-k} \tag{3.12}$$

where:

u – Number of system users (terminals)

k – Number of channels being busy

Typically the probability of k channels being busy is represented by curves as a function of given traffic intensity $A = A_u \cdot u$, Figure 3.5.

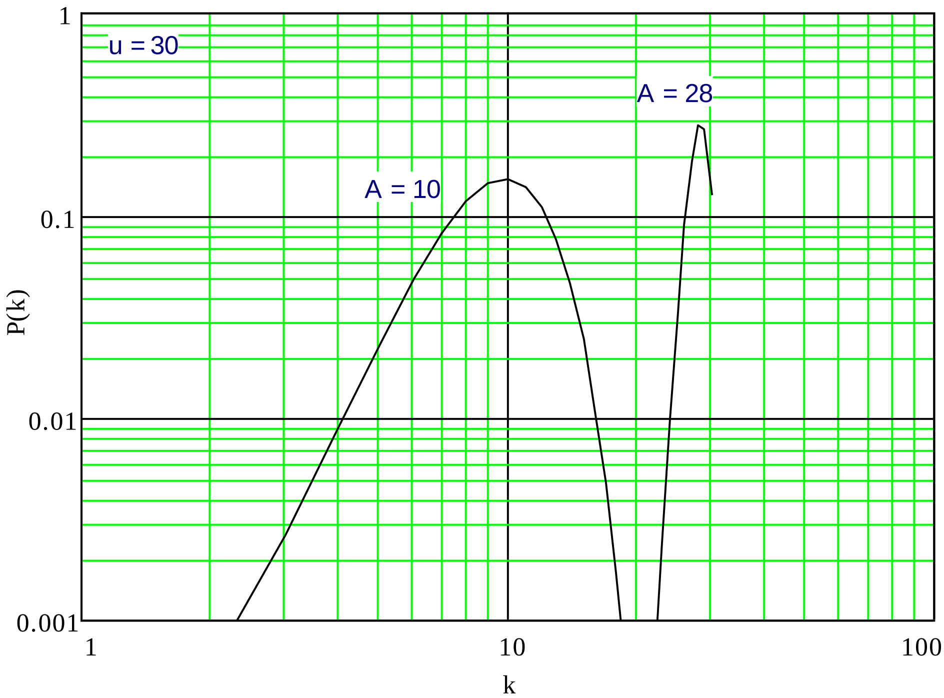


Figure 3.5 Probability of k system channels being busy (k simultaneous calls) using Bernoulli distribution for A=10 Erlang and A=28 Erlang.

If a traffic of A Erlang arises from u users (terminals), when $u \to \infty$ the relation is transformed into the Poisson distribution.

3.4.4 Markov and Markov-Renewal Traffic Models

Unlike renewal traffic models, Markov and Markov – Renewal traffic models introduce dependence into the random sequence R_t. Consequently, they can potentially capture traffic burstiness, because of nonzero autocorrelations in R_t. Consider a continuous-time Markov process

$$M_v = \{M_v(t)\}_{t=0}^{\infty} \tag{3.13}$$

where the discrete state space M behaves as follows: it stays in state i for an exponentially distributed holding time μ_i with parameter λ_i, which depends on i alone; it then jumps to state j with probability p_{ij}, such that the matrix $P = [p_{ij}]$ is a probability matrix. In a simple Markov traffic model, each jump of the Markov process is interpreted as signalling an arrival, so interarrival times are exponential, and their rate parameters depend on the state from with the jump occurred [FrMe94]. Figure 3.1 represents finite state Markov process typical for voice telephony (it can be also adopted for video applications assuming real time delivery, time based transfer and one channel occupancy for one video connection) where source is either idle or busy [AbAd97]. In models called On – Off application packets are only generated during talk spurts (On state) with fixed interarrival time. The time spent in On and Off states is exponentially distributed with mean α^{-1} and β^{-1}, respectively, Figure 3.6.

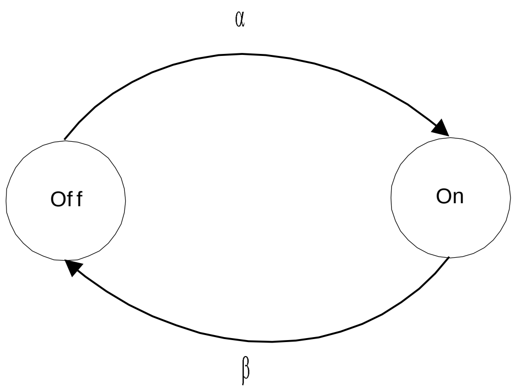


Figure 3.6 On-Off Model.

Arrivals can occur with parameter λ according to Poisson distribution (interarrivals times are independent) with service rate μ exponentially distributed, Figure 3.7. That case of On – Off model is also called Interrupted Poisson Process (IPP) [AbAd97]. Note that, for multiservice traffic, parameters λ and μ are specified independently.

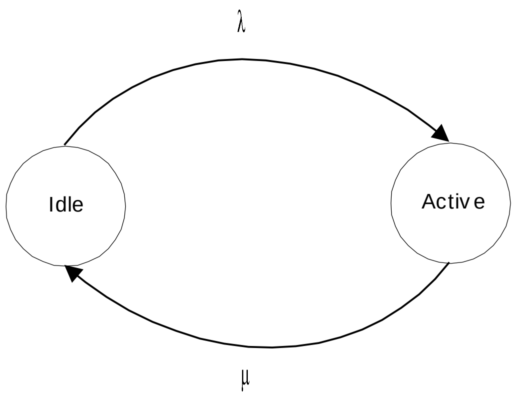


Figure 3.7 Interrupted Poisson Process (IPP).

Markov-Renewal models are more general than discrete-state Markov process, yet retaining a measure of simplicity and analytical tractability. A Markov renewal process

$$M_r = \left\{M_n, \tau_n\right\}_{n=0}^{\infty} \tag{3.14}$$

is defined by Markov a chain $\{M_n\}$ and it is associated with jump times τ_n, subject to the following constraint: the pair (M_{n+1}, τ_{n+1}) of the next state and inter-jump depends only on the current state M_n , but not on previous states or on previous inter-jumps times [FrMe94]. This means that all transitions are to the states just above (a birth) or to the state just below (a death) and it is also quoted on Figure 3.1 as graph representing limited sources (channels) telephony system. As it was assumed above, the Markov models can potentially capture traffic burstiness. Let one now assume an example of a single server queuing system with one server as typical (for example ATM or other packet switching solution) data traffic solution, as presented in Figure 3.8.

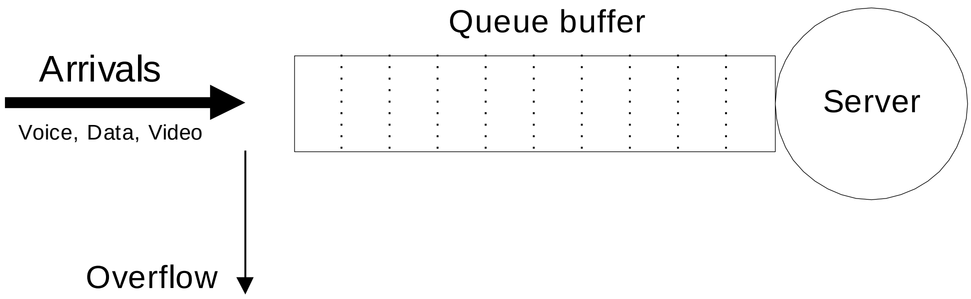


Figure 3.8 M/M/1 queue as an example of single server system.

The average number of basic traffic units (ATM cells, IP frames) in the queue, L_q can be obtained as follows [DoPh87]:

$$L_q = \frac{A}{1-A} \tag{3.15}$$

where:

A – traffic intensity [Erlang]

and this is also called an M/M/1 (Markov single server) queue. It includes the in following assumptions:

- first come first served discipline
- one server
- exponentially distributed interarrival rate λ
- exponentially distributed service rate μ
- infinite population of users system users

Note that this model does not contain AAL (ATM Adaptation Layer) prioritising schemes for real time applications (voice, video). The result of mean queue length L_q, as a function of traffic intensity is presented in Figure 3.9.

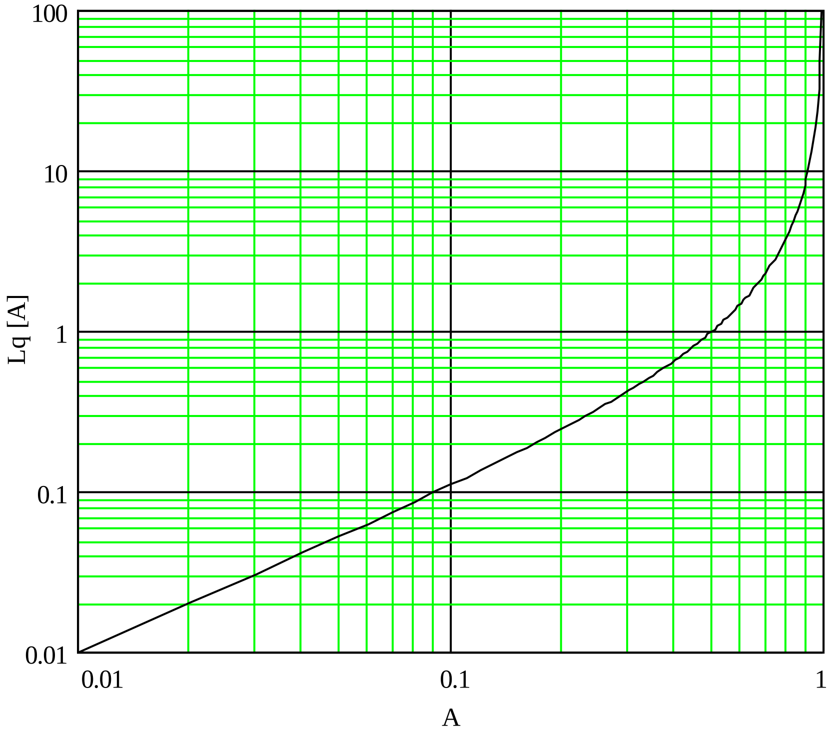


Figure 3.9 Average queue length for M/M/1 model as a function of traffic intensity.

As it is shown in Figure 3.9 the better utilisation (higher A) drives to higher capacity buffer requirements because of longer queue. Requested cells buffer length can be predicted using equation (3.15). Now taking into account the processing time requested to serve (switch) one cell, which simply can be calculated by multiplying the average queue by the requested serving time, the average delay time on the server (switch) can be estimated. In practice for real time applications, like voice or video, end-to-end signal delay time should never jump over 100 ms because of received quality. Hence, in working systems based on IP or ATM, specially dedicated software and hardware components take care about traffic intensity on switches, to keep utilisation value not higher then 80 – 90 % (depending on the number of routers or switches connected in cascade and single traffic unit processing time). This is also called Virtual Connection Management and the main idea is to switch new arising connections on servers with lower utilisation rates.

Applications burstiness presented on Figure 3.2 implies to use more advanced schemes to model multiservice traffic queue then M/M/1, because of its exponential service rate for each application and differential applications behaviour. Taking into account differential service rate (time) and its variance for each application the M/G/1 model can be used, Figure 3.10.

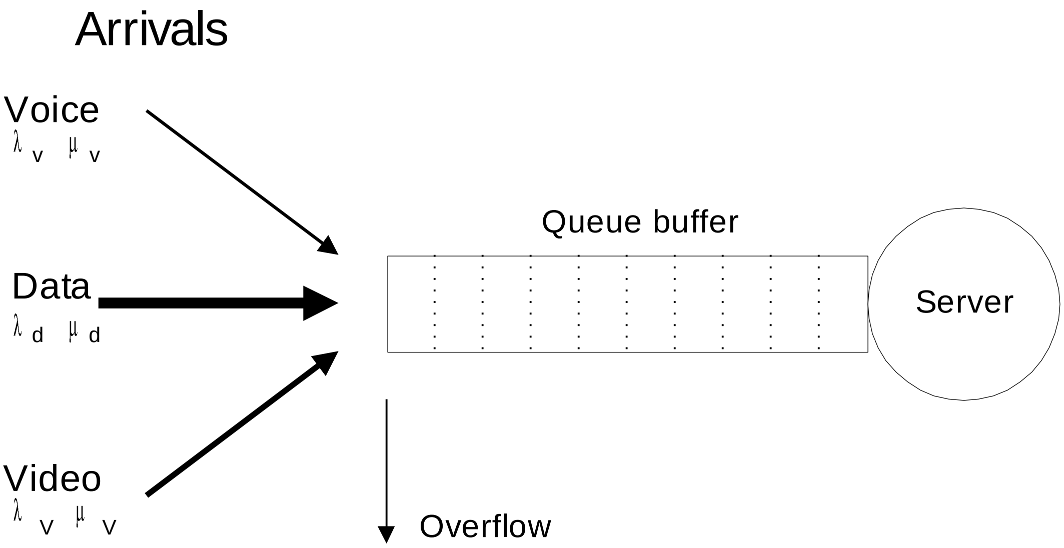


Figure 3.10 M/G/1 Queue.

The assumptions of the M/G/1 model are as follows:

- interarrival rate λ is exponentially distributed
- service rate μ is independently defined for each application
- infinite population of system users
- first come first served discipline
- one server

The M/G/1 average queue length is given by [Schw87] and it is also named as Pollaczek – Khintchinie formula.

$$L_q = \left(\frac{A}{1-A}\right)\left[1-\frac{A}{2}\left(1-\mu^2\sigma^2\right)\right] \tag{3.16}$$

where:

σ - service time distribution variance

As an example one can use service rates presented in [Vele98] in order to simulate an realistic scenario. Table 3.1 presents transfer rates and service rates for different service components.

Table 3.1 MBS Services characteristics (extracted from [Vele98]).

Component	Transfer Rate [Mbit/s]	Service Rate μ [min^{-1}]
High Density TV (MPEG – 2)	8*	0.02 – 2
Video and Image	2	(1.67 – 5) 10^{-3}
Data	1	120
Voice (today)	0.015	0.33

Considering services behaviour in transmission network for the following input parameters: μ_{HDTV}^{-1} = 20 min, σ_{HDTV} = 30%, μ_{DATA}^{-1} = 0.5 min, σ_{DATA} = 50% one obtains the curves of Figure 3.11.

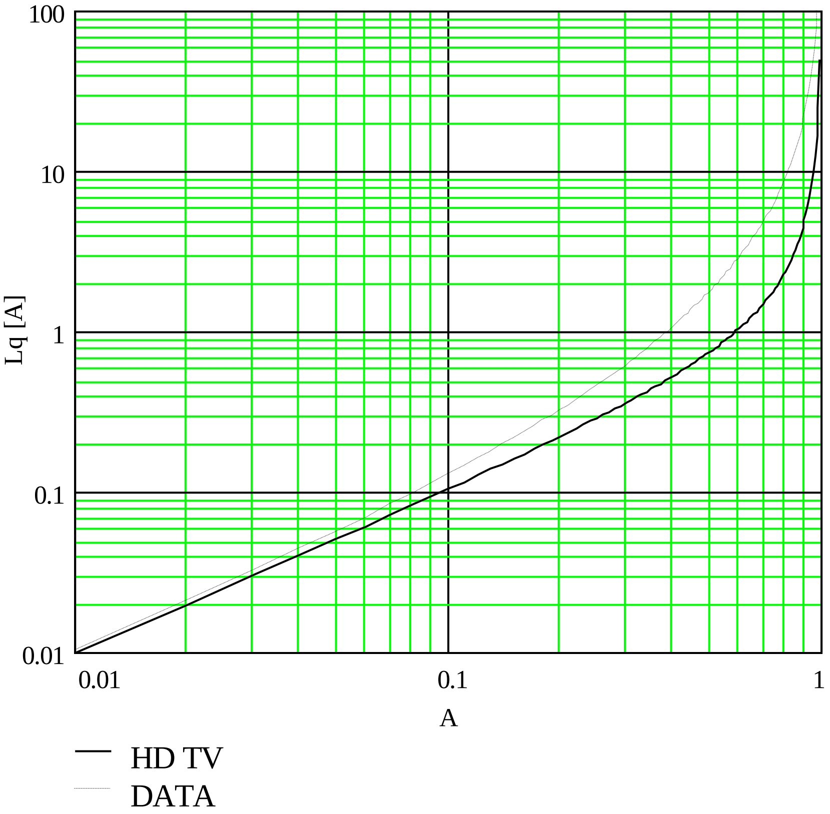


Figure 3.11 Average queue length for M/G/1 model as a function of traffic intensity.

Note that Video stream in example above (Figure 3.11) is considered without compression. For applications more conductive with higher burstiness rate the average queue becoming longer. Longer queue of incoming to server cells implies longer processing time required for cell switching, hence continuous time applications are more welcomed in one server queuing networks.

For a multiserver systems another queue model can be obtained. Such a system would be assigned by *M*/*M*/*C*, where *C* is the number of available in system servers (channels). Most popular for multiserver (multistate Markov chain) traffic modelling are Erlang formulas.

3.4.5 Erlang Models

The Erlang theory deals with constant bit rate sources that hold one unit of a resource for the whole duration of the connection, i.e., circuit switching, while in packet switching networks (usually they are single server networks), traffic is segmented into blocks of data (cells). The Erlang B model is useful for the systems where:

- the number of users is much greater than the number of available channels, such that no matter how many devices are currently busy, the rate of call arrivals will be constant;
- if no channels are available, the requesting user is blocked without access and is free to try again later (such system is also known as *Blocked Calls Cleared*);
- all users, including blocked ones, may request a channel;
- the probability of a user occupying a channel is exponentially determined;
- there are finite number of channels available in pool and all of them are accessible for each user.

Blocked calls cleared this is the case of a Markov chain, when for C channels available in the system transitions terminates at state S_C and:

$\lambda_k = \lambda, \qquad k \le C - 1$

$\mu_k = k\mu, \qquad k < C$

Using equations (3.12) and (3.13) and for C available in system channels the blocking probability (GOS) can be calculated by well known Erlang B formula as follows [Rapp96]:

$$P_b = \frac{\frac{A^C}{C!}}{\sum_{k=0}^{C} \frac{A^k}{k!}} = GOS \tag{3.17}$$

The blocking probability arising from the traffic intensity A is usually represented as a function of the number of available channels (given for each curve) C. The numbers of C=30 and C=100 are considered, Figure 3.12. A value of C=30 channels is typical for PDH E-1 (Plesiochronous Digital Hierarchy) level trunk and also approximately (depends on number of dedicated signalling channels) to the number of physical channels in one cell of a GSM network in an urban area. A value of C=100 channels is predicted value for future networks (for example UMTS).

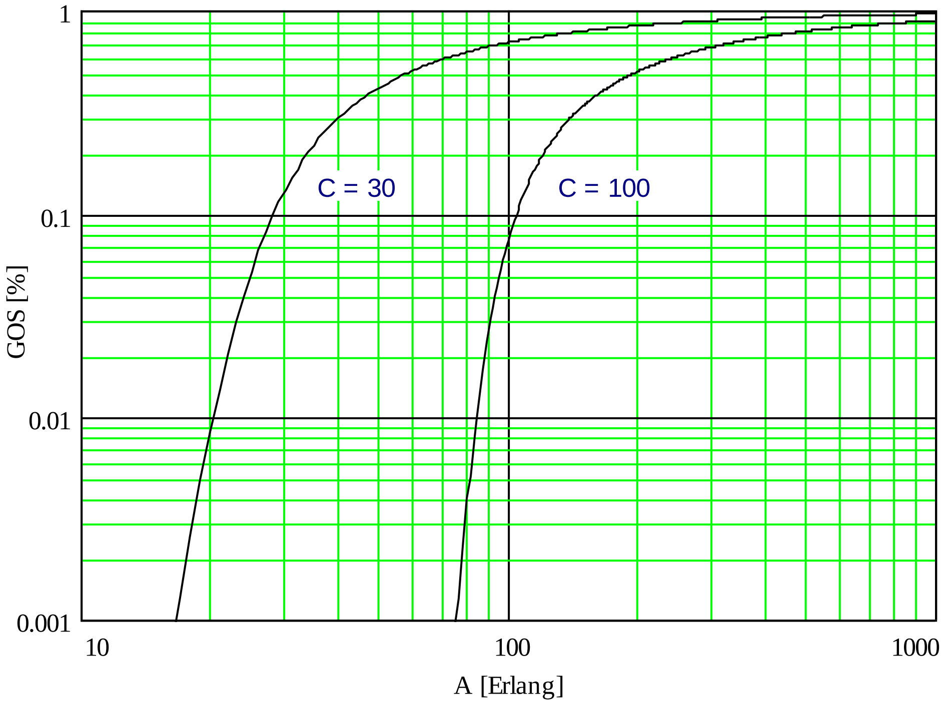


Figure 3.12 Probability of blocking (*GOS*) for *C*=30 and *C*=100 according to Erlang B.

In practice Erlang B curves usage is limited to *GOS* below 10%. In the Erlang C Model if a channel is not immediately available, the call request may be delayed until a channel becomes available. This is known as *Blocked Calls Delayed* system. A measure of *GOS* is defined as the probability that a call is blocked after waiting a specific length of time in queue. The probability of a call not having immediate access to channel is determined by Erlang C formula [Rapp96]:

$$P_{[\text{delay} > 0]} = \frac{A^C}{A^C + C!\left(1\text{-}\dfrac{A}{C}\right)\displaystyle\sum_{k=0}^{C-1}\frac{A^k}{k!}} \tag{3.18}$$

As for Erlang B, Erlang C formula is usually represented by curves as a function of the traffic intensity *A*, with the number of available channels *C* as a parameter, Figure 3.13. As one can observe on Figure 3.13 the curves aim to point *C*=*A* for *GOS*=1.

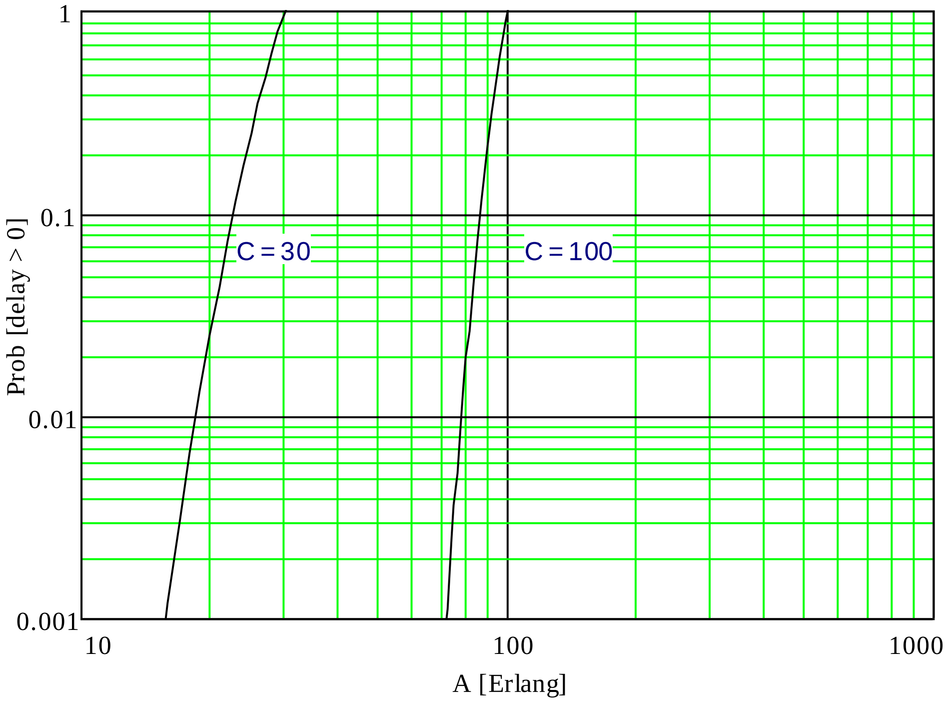


Figure 3.13 The Erlang C formula probability of a call being delayed (t >0) for *C*=30 and *C*=100.

If no channels are immediately available, the probability that a call will be delayed more than *t* seconds is given by the probability that the call is delayed times the probability that the delay is longer than *t* seconds [Rapp96]:

$$P[\text{delay} > t] = P[\text{delay} > 0] \cdot e^{-(C-A)t/T} \tag{3.19}$$

where *T* represents call holding time.

Erlang C formula as function of delay time can be represented for a given number of channels *C*, predicted delay time *t*, and variable traffic intensity *A*. Figure 3.14 represents the probability of delay for two cases: *t*=5 [s] and *t*=100 [s]. As it could be predicted, assuming a longer delay time (worse QoS parameter) acceptable for operators, a higher traffic intensity rate *A* can be served by the same number of channels, hence with better channel utilisation because of continuous channels occupancy time.

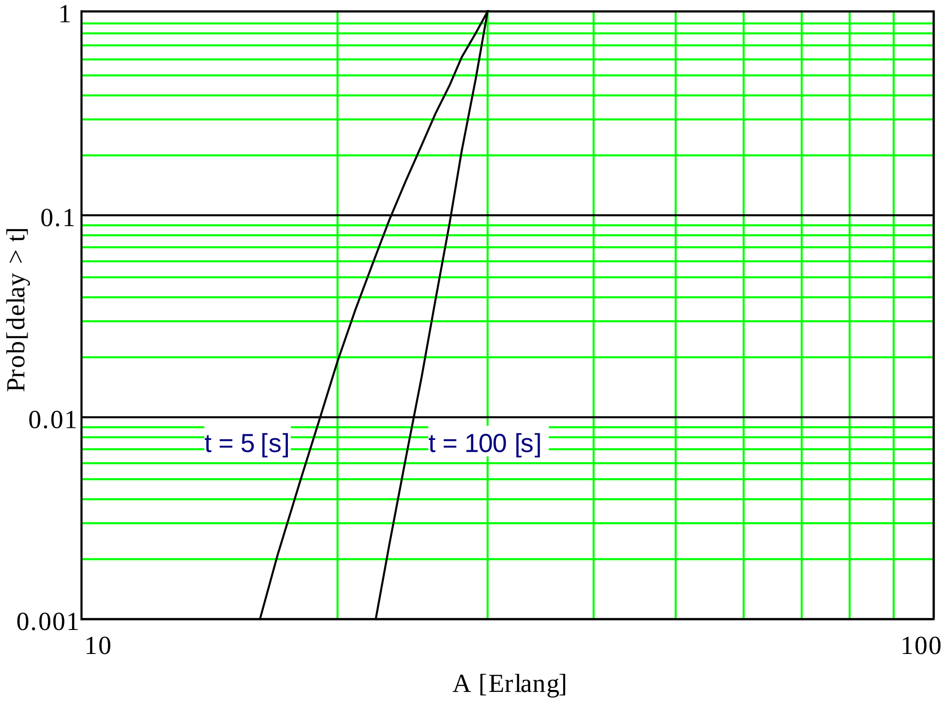


Figure 3.14 The Erlang C probability of a call being delayed for delaying time *t*, given *C*=30 and *T*=180[s].

3.4.6 Markov Based Traffic Modelling in Mobile Systems

The models described above do not include the typical users behaviour in mobile systems – their mobility during the call, hence handover between cells. Handover probability is not relevant for large cells, where it can happen sporadically, but it becomes important for micro-cells with coverage distances limited to 300 m. The high mobility and small cell coverage distance associated with future systems (MBS) yields a teletraffic analysis, where both the new calls and the handover traffics must be considered simultaneously [VeCo98]. The model of crossing cells by a user and handovers is shown on Figure 3.15.

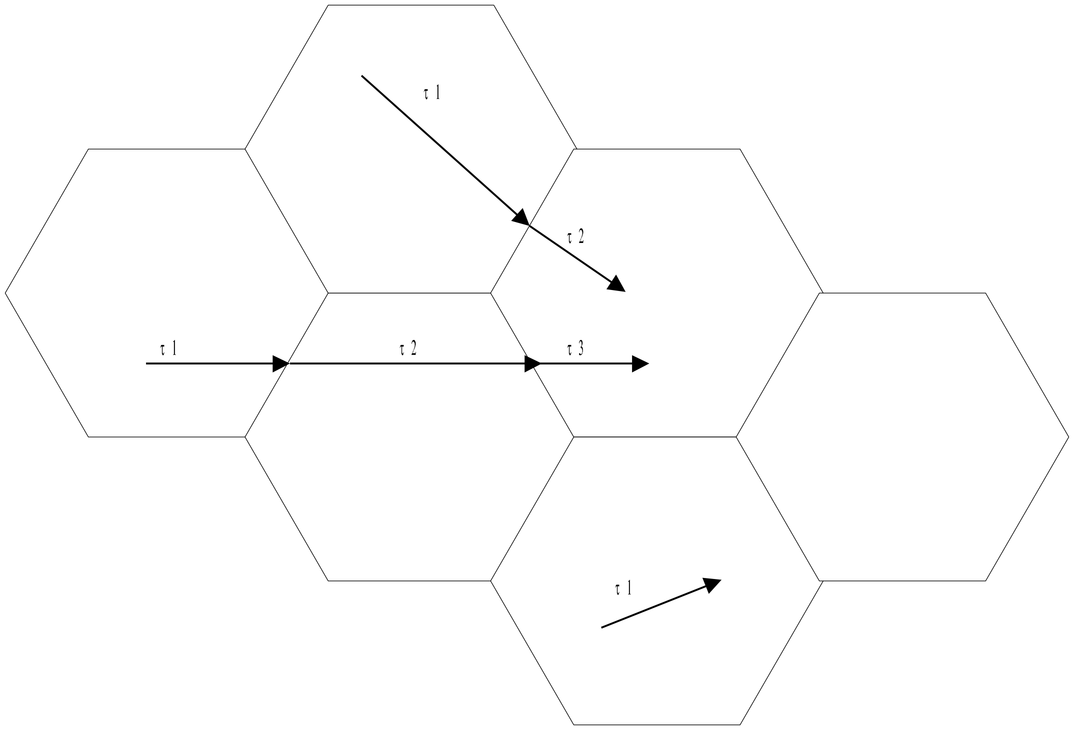


Figure 3.15 Presentation of mobility during call with cell dwell time τ.

The following assumptions are taken [Jabb96]:

- mobile terminals and their traffic are uniformly distributed over a given cell;
- mobile terminals have an average velocity of V_{av}, and their direction of movements are uniformly distributed over [0, 2π];
- the cell cross over rate η is given by [Jabb98]:

$$\eta = V_{av} \frac{L}{\pi S} \tag{3.20}$$

where:

V_{av} – mean velocity of the terminal

L – covered area length

S – area surface

- call duration time , $\tau = \tau_1 + \tau_2 + \tau_3 + \ldots + \tau_n$, channel occupancy time in a cell τ_c, and cell dwell time τ_h, follow an exponential distribution;
- new arriving traffic and also handover traffic one follow a Poisson distribution.

Assuming a linear coverage geometry with cigar-shaped cells, which is a good street micro-cells approach (note, that future systems in urban areas will be mainly deployed on street micro-cells and indoor pico-cells), Figure 3.16, and taking into account the distribution for velocity, the cross over rate can be calculated as follows [VeCo98]:

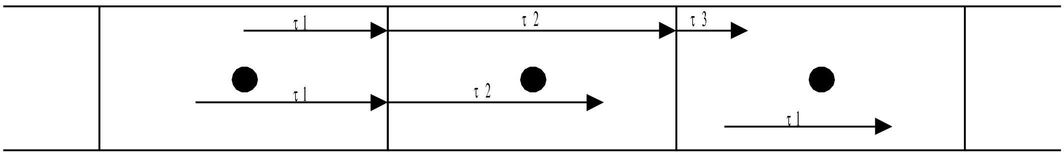


Figure 3.16 Terminal mobility and dwell time in street micro cells.

$$\eta = \frac{1}{\int_0^{V_{max}} \left(\frac{2R}{v}\right) \cdot f(v)\, dv} \tag{3.21}$$

where:

v – terminal velocity

$f(v)$ – velocity probability density function

which for triangular velocity distribution leads to the limit [VeCo98]:

$$\eta = \frac{V_{av}}{2 \cdot ln(2)} \cdot \frac{1}{2R} \tag{3.22}$$

where:

R – coverage distance

V_{av} – average terminal velocity

Typical values for terminals mobility in scenarios like street cigar shape cells (Figure 3.16) are presented in Table 3.2.

Table 3.2 Scenarios of mobility characteristics (extracted from [VeCo98]).

Scenario	**V_{av}[m/s]**	**Δ[m/s]**
Static	0	0
Pedestrian	1	1
Urban	10	10
Main roads	15	15
Highways	22.5	12.5

From Figure 3.15 and 3.16 one can observe different behaviour of the mobile users – calls usually are finished in a cell different from the one they begun. The birth death process for a mobile environment is presented in Figure 3.17.

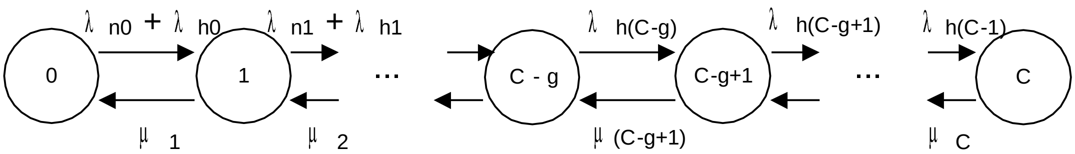


Figure 3.17 State transition diagram for mobile environments with number of C total channels and g dedicated for handover guard channels.

The mean dwell time τ_h can be estimated by knowing the cell cross over rate η [Jabb96]:

$$\tau_h = \frac{1}{\eta} \tag{3.23}$$

The channel occupancy time $\tau_c = \min\{\tau, \tau_h\}$ is the time spent in cell before crossing the cell boundary if the call continues. It is the minimum of two exponentially distributed random variables, thus being also exponentially distributed with service rate, $\mu_c = \mu + \eta$. It is important noting that service rate μ_c represents now the channel holding (occupancy) time in a cell, previously represented by μ (when mobility was not considered).

Therefore, the mean channel occupancy time τ_c for a new or handover call is given by [Jabb96]:

$$\tau_c = \frac{1}{\mu + \eta} \tag{3.24}$$

The probability of handover, P_h, is being given by [VeCo98]:

$$P_h = P\{\tau > \tau_h\} = \frac{\eta}{\mu + \eta} = \frac{\eta}{\mu_c} = \frac{\tau_c}{\tau_h} \tag{3.25}$$

The total offered traffic to a cell is dependent on the handover traffic, which is turn depends on the total offered traffic to a cell. Using the flow equilibrium property, one can write [Jabb96]:

$$\lambda_h = P_h \left[(1 - P_b)\lambda_n + (1 - P_{hf})\lambda_h\right] \tag{3.26}$$

where:

P_{hf} – probability of handover failure

which can be approximated for small values of P_b and P_{hf} as follows [Jabb96]:

$$\lambda_h = \frac{P_h}{(1 - P_h)}\lambda_n = \frac{\eta}{\mu}\lambda_n \tag{3.27}$$

The total new arriving traffic in cell in mobile scenarios is represented by:

$$A = A_n + A_h \tag{3.28}$$

where:

A_h – traffic incoming from handover: $A_h = \lambda_h/\mu_c$

A_n – new arriving traffic: $A_n = \lambda_n/\mu_c$

Considering the system with a number of c channels supporting new and handover calls and a number of g guard channels for handovers one obtains the following equation for blocking probability [Jabb96]:

$$P_b = \frac{(A_n + A_h)^c \sum_{k=c}^{c+g} \frac{A_h^{\,k-c}}{k!}}{\sum_{k=0}^{c-1} \frac{(A_n + A_h)^k}{k!} + (A_n + A_h)^c \sum_{k=c}^{c+g} \frac{A_h^{\,k-c}}{k!}} \tag{3.29}$$

Equation (3.29) is associated to the Erlang B formula, by introducing a variable number of dedicated guard channels. According to the fact that the available pool of channels is always finite, an increase of the number of guard channels leads to an increase of the blocking probability for new arriving calls. This effect is presented in Figure 3.18.

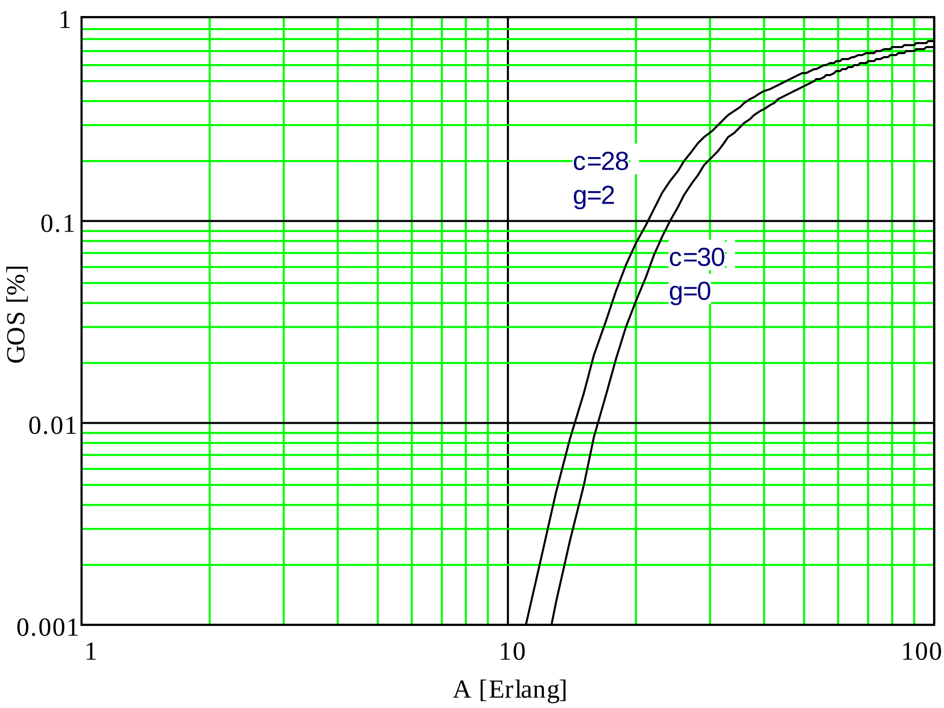


Figure 3.18 Probability of blocking as function of dedicated channels for guards with given A_h = 4 Erlang.

Assuming that new arriving traffic follows a Poisson process, handover arriving traffic depends on the total traffic in cell. Furthermore, the incoming rate of handover traffic is equal to the outgoing handover traffic rate. The probability of handover failure is than given as the probability that for the total of C available channels in the system (C=c+g) Markov chain transitions terminate at state S_C [HoRa86]:

$$P_{hf} = P_C \tag{3.30}$$

In [Jabb96] P_{hf} is derived:

$$P_{hf} = \frac{\left(A_n + A_h\right)^c \dfrac{A_h{}^g}{\left(c+g\right)!}}{\sum\limits_{k=0}^{c-1} \dfrac{\left(A_n + A_h\right)^k}{k!} + \left(A_n + A_h\right)^c \sum\limits_{k=c}^{c+g} \dfrac{A_h{}^{k-c}}{k!}} \tag{3.31}$$

When g=0, the newly arriving and handover traffics are blocked in the same way, (3.29) and (3.31) leading to the by Erlang B formula. The simulations for handover failure probability are presented in Figure 3.19 for the same configuration of channels and A_h=4 Erlang.

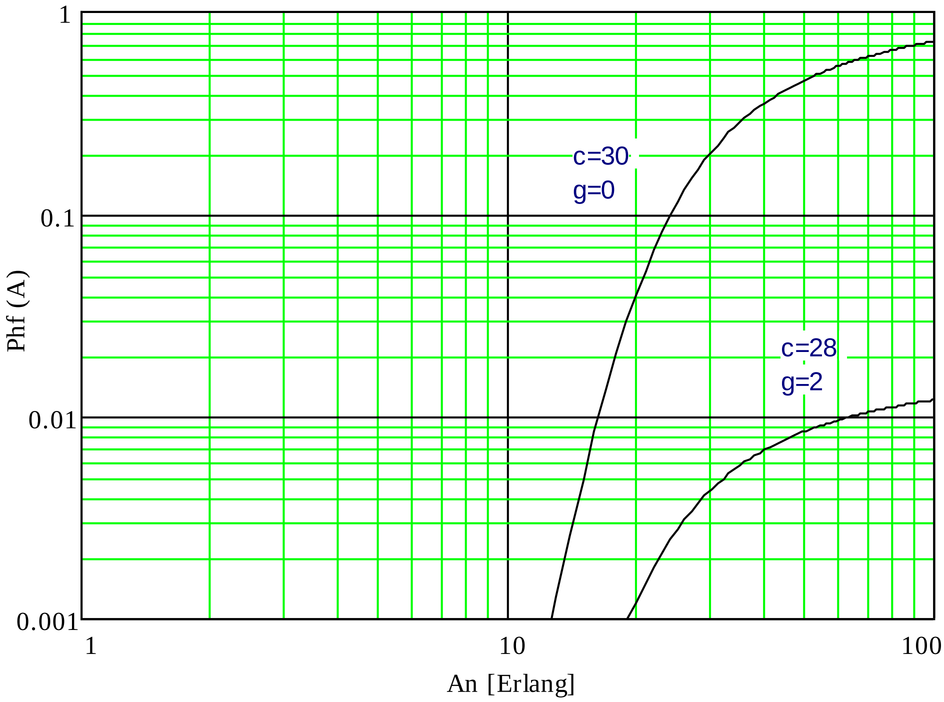


Figure 3.19 Handover failed probability as function A_n for given A_h = 4 Erlang and g as on chart.

As it could be predicted, dedicating channels for handover increases the blocking probability (Figure 3.18), but also strongly decreases the probability of handover failure (Figure 3.19). The usual requirements for the blocking probability of mobile systems consists of the following values [VeCo98]:

- lower than 1-2% for blocking probability;
- lower than 0.1 – 0.5% for call dropping probability.

Let us now define the call dropping probability P_d as the probability of dropping a call in progress during handover to another cell. As it was assumed before, the call holding time T follows an exponential distribution with parameter μ, and the cross over rate (number of handovers per unit length) η depends on the distribution for velocities [VeCo98]. The probability of call dropping can be determined as follows [Jabb96]:

$$P_d = P_h \cdot P_{hf} \sum_{i=0}^{\infty} \left[P_h \left(1 - P_{hf} \right) \right]^i = \frac{P_h \cdot P_{hf}}{1 - P_h \left(1 - P_{hf} \right)} \tag{3.32}$$

For small values of P_{hf}, P_d can be approximated by [Jabb96]:

$$P_d = \frac{\eta}{\mu} \cdot P_{hf} \tag{3.33}$$

It is represented on Figure 3.21, for: $A_n = 16$ Erlang, $c = 30 - g$, $R = 0.5$ km and $\mu = 1/3\ \mathrm{min}^{-1}$

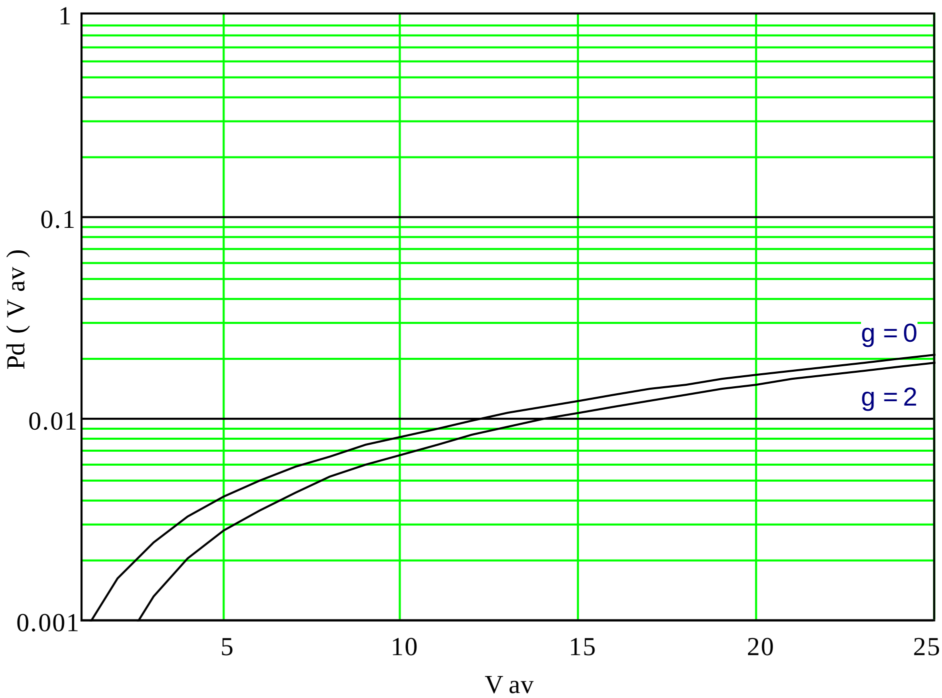


Figure 3.20 Call dropping probability as function of terminal average velocity.

The probability of call dropping as a function of the cell radius for: $A_h = 4$ Erlang, $A_n = 15$ Erlang, $c = 30 - g$, $V_{av} = 10$ m/s, $\mu = 1/3\ \mathrm{min}^{-1}$ is presented in Figure 3.21.

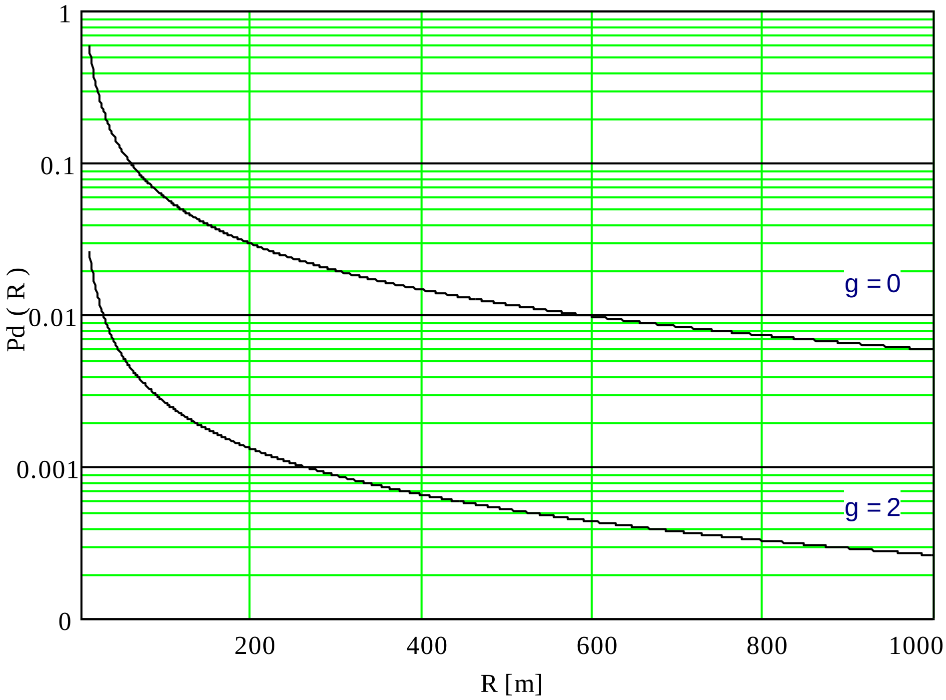


Figure 3.21 Drop call probability as function of cell radius.

Considering assuming future networks working on higher frequency bands, hence with lower coverage distance, the use of guard channels and their dimensioning should become typical for future radio planning in order to improve network performance. Nevertheless the use of guard channels improves system performance only in the case of short duration services, and not for long duration calls [VeCo99]. In practice the problem with P_{hf} can be solved as a compromise between coverage distance and the number of guard channels in order to achieve a good system performance.

3.4.7 Other Models

The M/Pareto traffic model is dedicated to system simulations, which operate under extremely bursty traffic arrival processes. Such bursts are caused by downloading large files, or long periods of high levels of VBR video activities, intensive bursts of database activity, and so on. The M/Pareto model is basically a Poisson process with rate λ. The period that represents the length of the burst has a Pareto distribution [AdZu98]. M/Pareto traffic modelling is extensively analysed in [AdZu98] and [RoPa98].

Due to the central limit theorem, the Gaussian model represents accurately the aggregation of many traffic streams. The Discrete Gaussian Model considers a FIFO single server queue and time divided into fixed-length sampling intervals. Now it can be supposed that the arrival process $\{R_t\}$ is not only stationary, but also Gaussian. The Discrete Gaussian Model can be used to investigate two cases independently [AdZu98]:

- Short Range Dependent case (SRD)
- Long Range Dependent case (LRD)

Gaussian traffic modelling is extensively analysed in [AdZu98].

3.5 Multiservice Traffic Modelling

3.5.1 Markov Modulated Traffic Models

Markov-Modulated models constitute an extremely important class of traffic models. The idea is to introduce an explicit notion of state into the descriptions of traffic stream - an auxiliary Markov process, evolving in time and its current state controls (modulates) the probability law of the traffic mechanism. Let M_v be a continuous-time Markov process, with state space $\{1,2,\ldots,m\}$. Now let us assume that while M_v is in state k, the probability law of traffic arrivals is completely determined by k, and this holds for every $1 \leq k \leq m$. Note that when M_v undergoes a transition to, say, state j, then the new probability law for arrivals takes effect for the duration of state j, and so on. Thus, the probability law for arrivals is modulated by the state of M_v [FrMe94].

Markov-Modulated Poisson Process (MMPP)

The most commonly used Markov-modulated model is the Markov-Modulated Poisson Process, which combines the simplicity of the modulating (Markov) process with that of modulated (Poisson) process. In this case, the modulation mechanism simply stipulates that at state k of M_v, arrivals occur according to a Poisson process at rate λ_k. MMPP models can be used in a number of ways. The simple MMPP process consider two states (On and Off), where state “On” is associated with positive Poisson rate, and the “Off” state is associated with zero rate. This is also called an Interrupted Poisson Process (IPP). This can be translated as follows: “On” state corresponds to talk spurt (application in use in case of multiservice traffic), and “Off” state corresponds to silence. The basic MMPP model can be extended to aggregations of independent traffic sources (each user can get an access to differential services), each with MMPP modulated by an individual Markov process $M_{v\,i}$.

Let $J(t) = (J_1(t), J_2(t),\ldots,J_r(t))$, where J_i is the number of active sources of traffic type i, and let $M_v(t) = (M_{v\,1}\ (t),\ M_{v\,2}\ (t),\ldots\ M_{v\,r}\ (t))$ be the corresponding vector-valued Markov process taking values on all r – dimensional vectors with non-negative integer components. The arrival rate of class i traffic in state $(j_1, j_2,\ldots,j_r)$ of $M_{v\,t}$ is $j_i\lambda_i$ [FrMe94]. The MMPP process is presented in Figure 3.22.

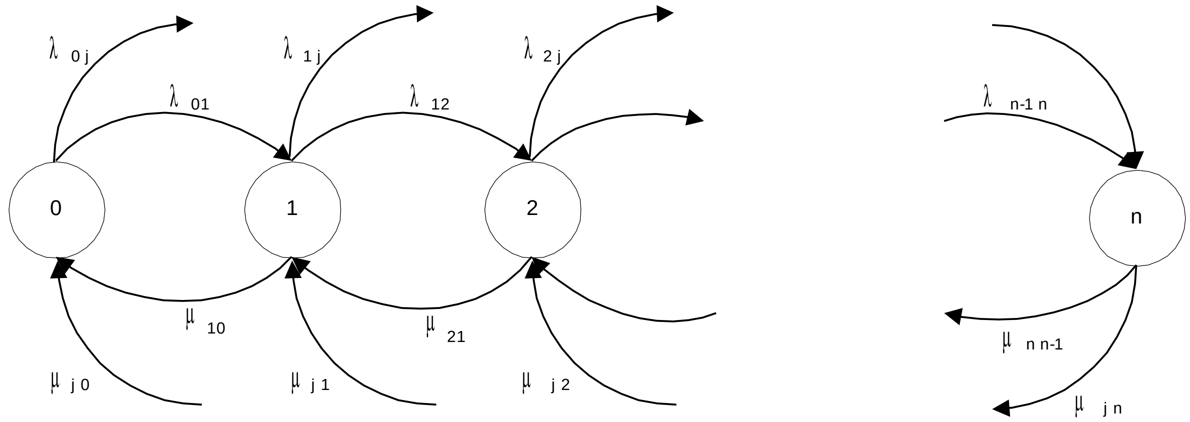


Figure 3.22 MMPP process.

Hence MMPP can model a mixture of voice and data traffic with according arrival rates λ_v for voice calls and λ_d for data calls that are Poisson distributed [AbAd97]. Let us now present an example of an MMPP model (Figure 3.23) with the following assumptions:

- system containing 10 physical channels
- one voice call taking 1 channel
- one data call taking 4 channels

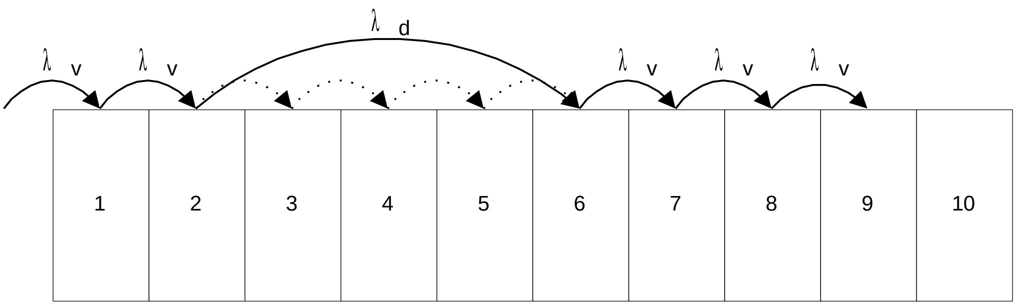


Figure 3.23 MMPP process arrival rates for voice/data common abilities usage.

Figure 3.23 represents one of the possibilities of S_9 state reached by the assumed system. In this case the system is serving 5 voice users and 1 data user at the same time. One can find how different arrival rates, specific for different application, are modulating (changing states) basic Markov chain states. Performance analysis for MMPP is extensively detailed in [MMMM98] and [RoPa98]. In [RoPa98] data traffic is modelled as M/Pareto distributed.

Markov Modulated Fluid Models

Fluid Models characterise traffic as a continuous stream with a parameterised flow rate (such as bit/s) typical for each application. These Models are appropriate in the case where individual units of traffic (packets or cells) have little impact on the performance of the network. In contrast to other fluid models this one characterises the incoming cells by flow rate. An event is only triggered when the flow rate changes. Since flow rate changes happen much less frequently then cell arrivals, considerable savings in computing and memory resources are achieved [AbAd97]. The Birth – Death Markov chains used as a basic concept of MMFM as Figure 3.24 shows.

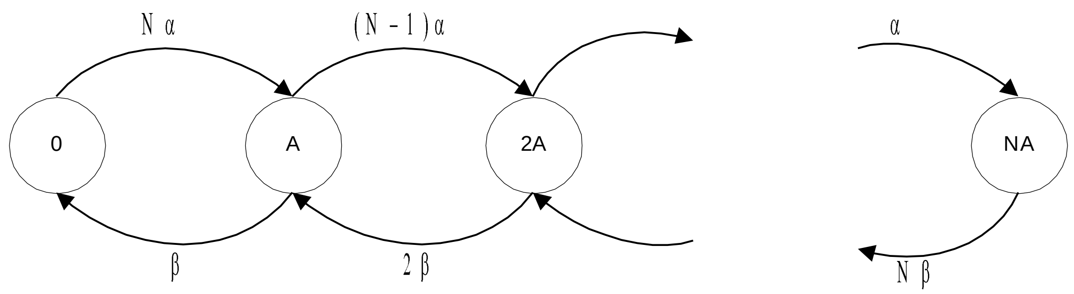


Figure 3.24 MMFM process.

In this model, the bit rate while in state *i* is constant and is given by *iA*, where *A* is the quantisation step size. The transition rates are chosen such that lower bit rate states tend to jump to higher bit rate states and vice versa. Moreover, jumps are only allowed to neighbouring states in Birth – Death Markov chain, so the model lacks the ability to capture abrupt changes (traffic burstiness) in the arrival rate between frames. Markov Modulated Fluid Model of a set of quantised (fluid) traffic rates is presented in [SMRA89].

3.5.2 Bernoulli - Poisson - Pascal Process

The Bernoulli-Poisson-Pascal process is usually used to model the superposition of MMPP Processes. In modelling a BPP process we consider a model where discrete resources of finite capacity are completely shared amongst customers (subscribers) pertaining to *K* different applications, Figure 3.25.

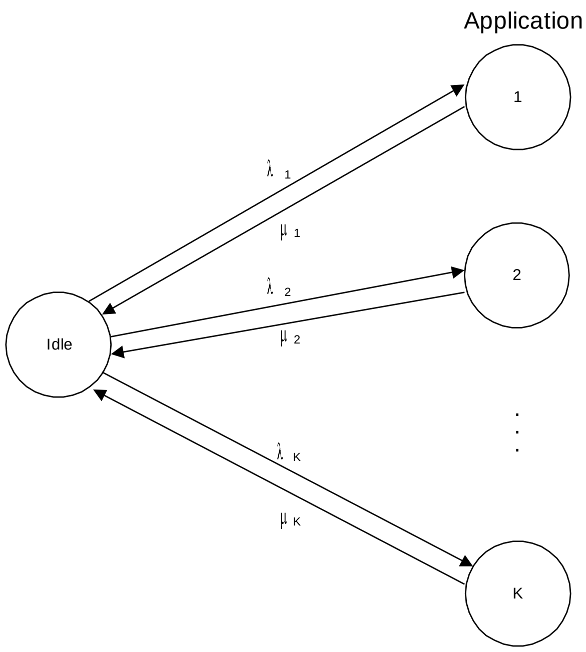


Figure 3.25 BPP model for K applications.

For each application customers arrive according to a BPP process. The amount of resource-units each customer requests and the average holding time T may be different for each application. When the system is in state $N(t)$ = $\boldsymbol{n}$, the time after the next arrival of class k customer's demand is exponentially distributed with parameter $\lambda_k(n_k)$**.** This parameter is normalised with respect to the average class k holding time, thus one introduces different units of time for each customer class. For exponential holding times a BPP process can be modelled by a Markov chain shown on Figure 3.26,

where:

α_k – BPP process parameter;

β_k – activation factor of application k.

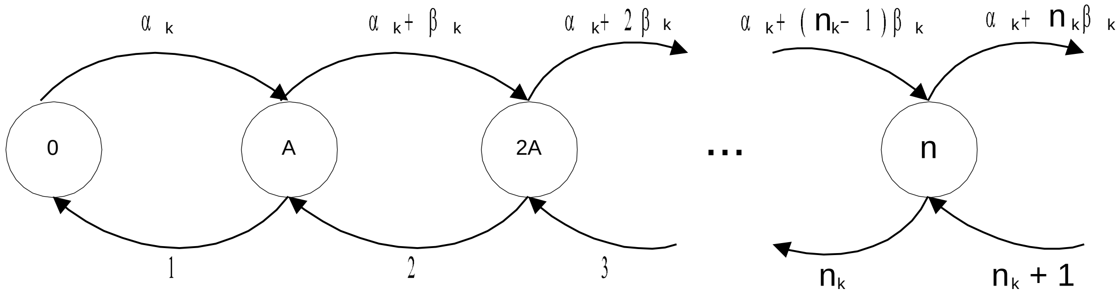


Figure 3.26 Markov chain model of a BPP process, extracted from [AwVl96].

The capacity of the resource facilities is partitioned into capacity units. A customer is assumed to need a given number of units of each facility, and the demand is granted on first a come first serve basis. If a customer demand cannot be satisfied, it is cleared and the customer is said to be blocked [AwVl96]. The arrival process for BPP is conditioned on u_k customers (users accessing to application k) being in the system, and from Figure 3.26 it is represented as follows:

$$\lambda_k(u_k) = (\alpha_k + u_k \cdot \beta_k) \qquad \text{for } \alpha_k > 0 \tag{3.34}$$

In the Bernoulli case we have:

$$\lambda_k(u_k) = (U_k - u_k)(-\beta_k) \qquad \text{for } \beta_k < 0 \tag{3.35}$$

where:

U_k – total number of application k users

In the Poisson case one has:

$$\beta_k = 0 \rightarrow \lambda_k(u_k) = \alpha_k \tag{3.36}$$

Note that α_k and β_k depend on the applications. Pascal theory is out of this work and will be not considered. In the theoretical model the arrival rate ($\lambda_k(u_k)$) is used normalised by the service rate (μ_k), resulting:

$$A_k(u_k) = \frac{\lambda_k(u_k)}{\mu_k} \tag{3.37}$$

then A_k is the traffic generated per free user and for each application k. The blocking probability of k application can be obtained as[AwVl96]:

$$P_b^k = \frac{\sum_{n \in B_k} \lambda_k(u_k) \cdot p(n)}{\sum_{n \in U} \lambda_k \cdot p(n)} \tag{3.38}$$

where:

U – vector of active users of each application: $U=[U_1, \ldots, U_K]$

B_k – vector of steady states where k application arrive can not be granted

The state probability marginal function, $p(n)$, can be expressed by:

$$p(n) = \frac{\prod_{k=1}^{K} v_k(u_k)}{\sum_{n \in U} \prod_{k=1}^{K} v_k(u_k)} \qquad \text{for } n \in U \tag{3.39}$$

where the unnormalised marginal probabilities, $v_k(u_k)$ are:

$$v_k(u_k) = \binom{U_k}{u_k} \cdot (-\beta_k)^{u_k} \qquad \text{for the Bernoulli case;}$$

(3.40)

$$v_k(u_k) = \frac{\alpha_k^{n_k}}{u_k!} \qquad \text{for the Poisson case.}$$

System Average Load

If there is a total number of C available resources in each cell being used by a number of M users, each user can be either in an idle state or using one of the applications, k=1,2,...,K with generation and total service rates, λ_k and μ_k , respectively and with a proportion among all the applications of $prop_k$

$$\sum_{k=1}^{K} prop_k = 1 \tag{3.41}$$

The proportion of users of an application among all the available ones can be expressed like:

$$prop_k = \frac{A_k}{\sum_{i=1}^{K} A_i} \tag{3.42}$$

where:

$$A_k = A \cdot prop_k$$

(3.43)

$$A = \sum_{i=1}^{K} A_i$$

In [Vele99] one can find the following formula for the probability of an user having an active application k:

$$p_k = \frac{A_k}{1+\sum_{i=1}^{K} A_i} = \frac{A}{1+A} \cdot prop_k = f \cdot prop_k \tag{3.44}$$

where:

the fraction of active users $f = A / (1+A)$

In teletraffic usually one is interested in obtaining the blocking probability as a function of the average load. The load from each user is obtained by computing the expectation of every application data rate [Vele99]:

$$L_u = \sum_{i=1}^{K} p_i \cdot b_i \tag{3.45}$$

where:

b_i – application i data rate.

p_i – probability of a user having application i opened

The load from each user lead to the system average load (multiplying by M):

$$L = L_u \cdot M = f \cdot c_1 \cdot M \tag{3.46}$$

where:

$$c_1 = \sum_{i=1}^{K} prop_i \cdot b_i \tag{3.47}$$

The parameter c_1 gives information about the maximal resources that will be used by each user when f=1 i.e., maximal load per user, which leads to the best understanding of the system behaviour.

Equivalent User

Now, if the applications have access to different service components, equivalent users should be considered. An application k equivalent user is composed by a set of the service components virtual users (service components are HDTV, Data, high quality pictures, etc.), which arise according to application's activation. The activation of service components is presented in Figure 3.27

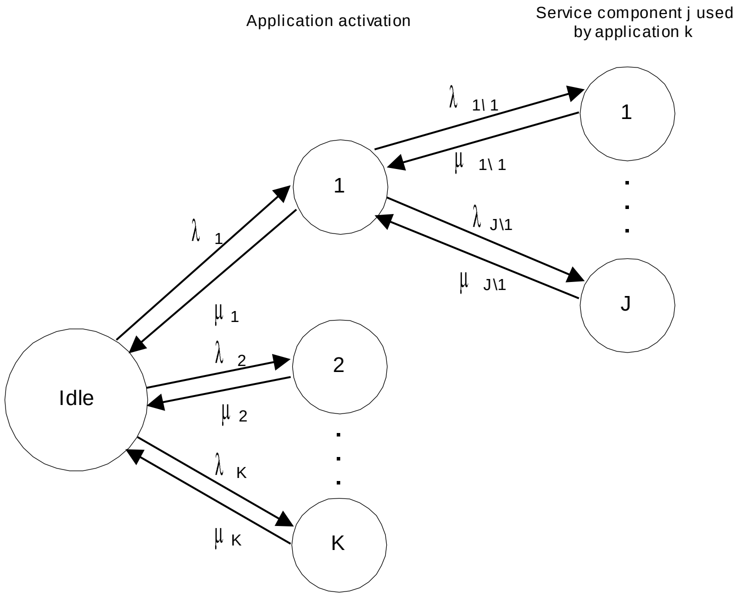


Figure 3.27 Service components activation.

Each service component uses resources with its required data rates a_j, and exponentially distributed holding time. While the application k is active, the service components are activated with rate $\lambda_{j\backslash k}$ and extinguished with total service rate $\mu_{j\backslash k}$, $j=1,2,\ldots,J$ (Figure 3.27) they can be simultaneously active, or not. This is a loss system, whose performance can be measured by the blocking probability of each service component. For service activation the Bernoulli model is used (Figure 3.28), because of [Vele99]:

- the population accessing to service components is assumed small and it correctly models the reduction of the call arrival intensity when the number of active users increase;
- activation of each service component is independent.

The activation rate of each component given an application k is defined by [Vele99]:

$$\lambda_{j\backslash k} = \frac{n_{j\backslash k}}{1/\mu_k} \tag{3.48}$$

where:

$n_{j\backslash k}$ – average number of active service component j request

When the system is in state $N(t)$ = $\boldsymbol{n}$, the time after the next arrival of class j customer's arrival is exponentially distributed with parameter $\lambda_j(n_j)$**.** This parameter is normalised with respect to the average class k holding time, thus one introduces a different unit of time for each customer class. The arrival rate is represented as follows [Vele99].

$$\lambda_j(n_j) = \alpha_j + n_j \cdot \beta_j = (U_j - u_j)(-\beta_j) \qquad (3.49)$$

where:

U_j – total number of component *j* users

u_j – number of users accessing to service component *j*

In the Bernoulli case, where ($-\beta_j$) is the activation rate of the component *j* (Figure 3.28), $\alpha_j=-\beta_j \cdot U_j$, where U_j is equal to the total number of system users *M*. As it was said before, these parameters should be normalised with respect of the total service rate of component *j*, meaning that different time scales should be introduced for each *j*, thus $\beta_j' = \beta_j / \mu_j$ and $\alpha_j' = \beta_j' \cdot U_j$.

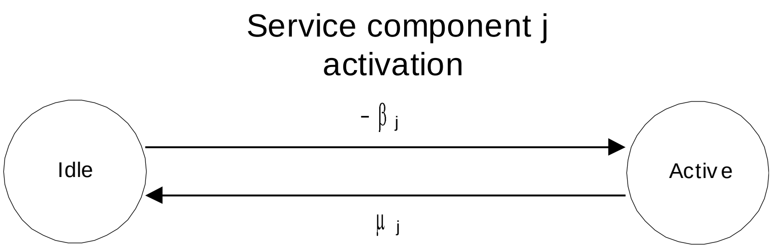


Figure 3.28 Service components activation according to Bernoulli model (extracted from [Vele99]).

The activation rate of service component *j* is given by [Vele99]:

$$(-\beta_j) = \sum_{k=1}^{K} \lambda_{j\backslash k} \cdot p_k = \frac{\lambda}{1+\lambda} \cdot \sum_{k=1}^{K} \lambda_{j\backslash k} \cdot prop_k \qquad (3.50)$$

If the system is stationary, the average occupancy of service component *j* is given by [Vele99]:

$$(-\beta_j) = \frac{-\beta_j}{\mu_j} = \sum_{k=1}^{K} \frac{\lambda_{j\backslash k}}{\mu_{j\backslash k}} \cdot p_k \qquad (3.51)$$

The normalised average occupancy of service component *j* is given by [Vele99]:

$$\mu_j = \frac{\sum_{k=1}^{K} \lambda_{j\backslash k} \cdot \frac{\lambda_k^*}{\mu_k}}{\sum_{k=1}^{K} \frac{\lambda_{j\backslash k}}{\mu_{j\backslash k}} \cdot \frac{\lambda_k^*}{\mu_k}} \qquad (3.52)$$

where:

$$\lambda_k^* = \mu_k \cdot prop_k \qquad (3.53)$$

The data rates associated with each application are [Vele99]:

$$b_k = \sum_{j=1}^{J} \frac{n_{j\backslash k} \cdot \frac{1}{\mu_{j\backslash k}}}{\frac{1}{\mu_k}} \cdot a_j \tag{3.54}$$

where:

a_j – service component j data rates

If the influence of application mobility is taken into account the arrival rate λ_k is the sum of arriving in cell traffic and traffic from handover.

$$\lambda_{k_n} + \lambda_{k_h} = \lambda_{k_n} \cdot \frac{\mu_k + \eta_k}{\mu_k} \tag{3.55}$$

Consequently the mobility of system users has influence on each component handover failure probability, and it can be given approximately by [Vele99]:

$$(P_{hf})_j = \left(\frac{\mu_j}{\eta_j}\right) \cdot (P_d)_{max} \tag{3.56}$$

where:

$(P_d)_{max}$ – maximum allowed dropping probability

Independence in service components activation during application service time is assumed, allowing the BPP process described above to capture traffic burstiness. Thus it can correctly model MMPP in future multiservice networks.

4 *System Performance Simulation*

4.1 Introduction

In this chapter some simulations have been done in order to obtain a first Mobile Broadband System network approach and its performance. Some different scenarios are considered to find best hardware solution (TDD or FDD mode) as well as the optimal number of operators serving Broadband Applications, to make system users satisfied. An user is satisfied if all of the following requirements are fulfilled:

- The user does not get blocked when arriving to the system
- The user has sufficiently good quality more than 95% of the session time
- The user does not get dropped due to BER requirements

The second and third requirement do not deal with this work, hence, only the first will be analysed.

Because both MBS bands (40 and 60 GHz) have the same bandwidths, the same number of channels seems to be available for each band. Due to different path losses the 40 GHz and 60 GHz segments coverage pattern should be planned independently. Thus, it is enough to make simulations for only one segment channels to obtain a system performance vision. In [VeCo00] one can find value of 663552 kbit/s per 1 GHz band as the total bandwidth available for users applications in future MBS. Bernoulli case of BPP process has been used for blocking probability computation because of high number of channels in comparison to number of system users in a cell.

4.2 Application Characteristics and Simulation Parameters

The algorithm used for component *j* Blocking Probability computation is a software tool written by Fernando Velez from Instituto Suprior Tecnico, Lisbon. All input parameters needed for computations are presented on Figure 4.1. As output the algorithm returns values of blocking probability respectively for each service component. Basic channel bit rate is assumed as 384 kbit/s, which leads to a number of 1728 channels per 1 GHz band and 3456 channels per segment (uplink and downlink).

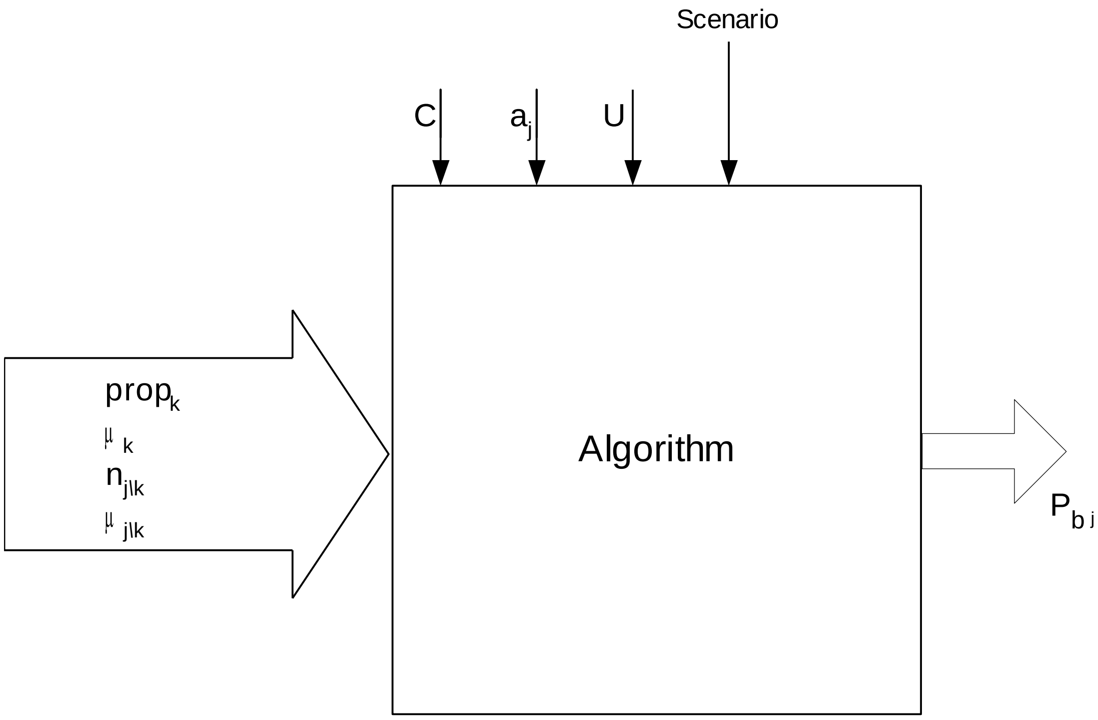


Figure 4.1 Algorithm input and output parameters.

Seeing MBS as a system generally deployed in large agglomerations the following environments can be specified [VeCo00]:

- business city centre **BCC**
- urban **URB**
- main roads **ROA**

Each scenario can be characterised by another set of values of the following parameters: proportion of applications users $prop_k$, average application usage time $1/\mu_k$, application burstiness $n_{j\backslash k}$ seen as a number of access requests to service components during application usage, service components average usage time $1/\mu_{j\backslash k}$. As a consequence different asymmetry factors *AF* between uplink and downlink can be expected for each scenario. The service components have different bandwidth requirements which can be specified as a number of basic channels from the total *C* available requested to serve service component *j*. The main future MBS applications and their parameters are extracted from [VeCo00] and presented in Table 4.1 and Table 4.2.

Table 4.1 Main MBS applications transmission parameters.

<table>
<tr><th>Application</th><th>Abbreviation</th><th>Burstiness</th><th>Time dependency</th><th>Delivery requirements</th><th>Symmetry/ Asymmetry</th></tr>
<tr><td>1 HD Video-telephony</td><td>HVT</td><td>1-5</td><td rowspan="5">TB</td><td rowspan="4">RT</td><td rowspan="2">Sym/Asy</td></tr>
<tr><td>2 ISDN Videoconference</td><td>IVC</td><td>1-5</td></tr>
<tr><td>3 Mobile Video Surveillance</td><td>MVS</td><td>1-5</td><td rowspan="6">Asy</td></tr>
<tr><td>4 HDTV Outside Broadcast</td><td>HOB</td><td>1-5</td></tr>
<tr><td>5 Wireless LAN Interconnection</td><td>WLI</td><td>1-50</td><td>NRT/RT</td></tr>
<tr><td>6 Data File Transfer</td><td>FTP</td><td>1-50</td><td>NTB</td><td>RT</td></tr>
<tr><td>7 Professional Images</td><td>PIM</td><td>1-20</td><td>TB/NTB</td><td>RT</td></tr>
<tr><td>8 Desktop Multimedia</td><td>DMM</td><td>1-20</td><td rowspan="5">TB</td><td rowspan="5">RT</td></tr>
<tr><td>9 Mobile Emergency Services</td><td>MES</td><td>1-5</td><td rowspan="4">Sym</td></tr>
<tr><td>10 Mobile Repair Assistance</td><td>MRA</td><td>1-5</td></tr>
<tr><td>11 Mobile Tele-working</td><td>MTW</td><td>1-20</td></tr>
<tr><td>12 Freight and Fleet Management</td><td>FFM</td><td>1-5</td></tr>
<tr><td>13 Electronic Mailbox Service for Multimedia</td><td>EMB</td><td>1-20</td><td>TB</td><td>NRT</td><td>Asy</td></tr>
<tr><td>14 E-commerce</td><td>ECO</td><td>1-20</td><td rowspan="2">TB</td><td rowspan="3">RT</td><td rowspan="6">Asy</td></tr>
<tr><td>15 Multimedia Library</td><td>MML</td><td>1-20</td></tr>
<tr><td>16 Tourist Information</td><td>TIN</td><td>1-20</td><td rowspan="2">NTB</td></tr>
<tr><td>17 Remote Procedure Call</td><td>RPC</td><td>1-50</td><td rowspan="3">NRT/RT</td></tr>
<tr><td>18 Urban Guidance</td><td>UGD</td><td>1-5</td><td rowspan="2">TB</td></tr>
<tr><td>19 Assistance in Travel</td><td>ATR</td><td>1-5</td></tr>
<tr><td>20 TV Programme Distribution</td><td>TVD</td><td>1</td><td>TB</td><td>RT</td><td>-</td></tr>
<tr><td>21 E-newspaper</td><td>ENP</td><td>1-20</td><td>TB</td><td>NRT</td><td>Asy</td></tr>
</table>

Table 4.2 Average duration and proportion of application users in different scenarios.

Application	$1/\mu_k$ [min]	BCC	URB	ROA
		$prop_k$	$prop_k$	$prop_k$
1 HVT	3	0.15	0.11	0.098
2 IVC	30	0.04	0.04	0.04
3 MVS	120	0.004	0.005	0.002
4 HOB	50	0.001	0.001	0.001
5 WLI	15	0.054	0.021	0.056
6 FTP	0.33	0.07	0.07	0.07
7 PIM	10	0.02	0.01	0.015
8 DMM	5	0.15	0.15	0.15
9 MES	20	0.018	0.001	0.016
10 MRA	40	0.002	0.001	0.003
11 MTW	20	0.073	0.022	0.033
12 FFM	5	0.007	0.002	0.023
13 EMB	1	0.03	0.03	0.02
14 ECO	5	0.07	0.07	0.07
15 MML	40	0.074	0.044	0.056
16 TIN	15	0.036	0.01	0.021
17 RPC	5	0.03	0.08	0.03
18 UGD	5	0.011	0.033	0.033
19 ATR	20	0.036	0.11	0.163
20 TVD	90	0.074	0.09	0.05
21 ENP	20	0.05	0.1	0.05

As it was previously remarked MBS is seen as an UMTS extension to Broadband ISDN Services, so in a natural way each operator of UMTS should get in the future license for MBS. Table 4.3 presents the consequence of such policy. Only in the first scenario (2 operators using reuse pattern 2) 155 Mbit/s per user is reachable for FDD mode.

Table 4.3 Number of 384 kbit/s channels available in a cell for different scenarios.

Number of Operators	2				3				4				5				6			
Reuse Pattern	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5	2	3	4	5
No of channels in Uplink	432	288	216	173	288	192	144	115	216	144	108	86	173	115	86	69	144	96	72	58
No of channels in Downlink	432	288	216	173	288	192	144	115	216	144	108	86	173	115	86	69	144	96	72	58

In [VeCo00] some analysis concerning the optimal number of service components and their bandwidth (thus channel requirements) has been done. The preferred bit rates requirements are the ones presented in Table 4.4.

Table 4.4 Service components and their bandwidth request.

Service component	j	a_j	$R_{bs\,j}$ [kbit/s]
BAS	1	1	384
MED1	2	3	1152
MED2	3	4	1536
MED3	4	5	1920
HDV	5	21	8064
HID	6	83	31872

The usage of service components by applications is characterised by two parameters:

- number of request of application *k* service component *j* (application burstiness) $n_{j\backslash k}$
- average service rate (usage time) of service component by application $\mu_{j\backslash k}$

If the application access to service component is permanent, such case parameter $n_{j\backslash k} = 1$ and the application average usage time is equal to relevant average service component usage time ($1/\mu_k = 1/\mu_{j\backslash k}$). Such situation occurs in the case of real time applications like videoconferencing and video broadcasting. The values used in simulations are extracted from [VeCo00] and presented in Tables 4.5 – 4.8.

Table 4.5 Parameter $n_{j\backslash k}$ for uplink.

Application	$n_{j\backslash k}$					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	1	0	0	0	0	0
3 MVS	0	0	0	1	0	0
4 HOB	0	20	0	0	1	0
5 WLI	0	34.5	0	0	0	0
6 FTP	2	0	0	0	0	0
7 PIM	1	0	0	0	0	0
8 DMM	15	0	0	0	0	0
9 MES	0	10	0	1	4	0
10 MRA	0	20	0	1	4	0
11 MTW	0	20	0	1	0	0
12 FFM	0	5	0	1	1	0
13 EMB	3	0	0	0	0	0
14 ECO	25	0	0	0	0	0
15 MML	0	20	0	0	0	0
16 TIN	0	120	0	0	0	0
17 RPC	0	5	0	0	0	0
18 UGD	0	8	0	1	0	0
19 ATR	0	30	0	1	0	0
20 TVD	0	0	0	0	0	0
21 ENP	5	0	0	0	0	0

Table 4.6 Parameter $\mu_{j\backslash k}$ for uplink.

Application	$1/\mu_{j\backslash k}$ [min]					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	3	0	0
2 IVC	30	0	0	0	0	0
3 MVS	0	0	0	120	0	0
4 HOB	0	0.0083	0	0	50	0
5 WLI	0	0.055	0	0	0	0
6 FTP	0.0083	0	0	0	0	0
7 PIM	10	0	0	0	0	0
8 DMM	0.055	0	0	0	0	0
9 MES	0	0.0083	0	20	0.5	0
10 MRA	0	0.0083	0	40	0.5	0
11 MTW	0	0.0083	0	20	0	0
12 FFM	0	0.0083	0	5	0.5	0
13 EMB	0.055	0	0	0	0	0
14 ECO	0.0083	0	0	0	0	0
15 MML	0	0.0083	0	0	0	0
16 TIN	0	0.0083	0	0	0	0
17 RPC	0	0.0083	0	0	0	0
18 UGD	0	0.0083	0	5	0	0
19 ATR	0	0.0083	0	20	0	0
20 TVD	0	0	0	0	0	0
21 ENP	0.0083	0	0	0	0	0

Table 4.7 Parameter $n_{j\backslash k}$ for downlink.

Application	$n_{j\backslash k}$					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	1	0	0	0	0	0
3 MVS	30	0	0	0	0	0
4 HOB	0	20	0	1	0	0
5 WLI	0	0	0	0	0	34.5
6 FTP	1	0	0	0	0	0
7 PIM	0	0	0	0	1	0
8 DMM	11.5	0	0	0	0	0
9 MES	0	10	0	1	4	0
10 MRA	0	20	0	1	4	0
11 MTW	0	20	0	1	0	0
12 FFM	0	5	0	1	1	0
13 EMB	0	0	1	0	0	0
14 ECO	11.5	0	0	0	0	0
15 MML	0	20	0	1	4	0
16 TIN	0	0	0	34.5	0	0
17 RPC	0	0	11.5	0	0	0
18 UGD	0	8	0	1	0	0
19 ATR	0	30	0	1	0	0
20 TVD	0	0	0	0	1	0
21 ENP	0	0	0	46	0	0

Table 4.8 Parameter $\mu_{j\backslash k}$ for uplink.

Application	$1/\mu_{j\backslash k}$ [min]					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	3	0	0
2 IVC	30	0	0	0	0	0
3 MVS	0.0083	0	0	0	0	0
4 HOB	0	0.0083	0	50	0	0
5 WLI	0	0	0	0	0	0.055
6 FTP	0.33	0	0	0	0	0
7 PIM	0	0	0	0	10	0
8 DMM	0.055	0	0	0	0	0
9 MES	0	0.0083	0	20	0.5	0
10 MRA	0	0.0083	0	40	0.5	0
11 MTW	0	0.0083	0	20	0	0
12 FFM	0	0.0083	0	5	0.5	0
13 EMB	0	0	1	0	0	0
14 ECO	0.055	0	0	0	0	0
15 MML	0	0.0083	0	40	0.5	0
16 TIN	0	0	0	0.055	0	0
17 RPC	0	0	0.055	0	0	0
18 UGD	0	0.0083	0	5	0	0
19 ATR	0	0.0083	0	20	0	0
20 TVD	0	0	0	0	90	0
21 ENP	0	0	0	0.055	0	0

Results

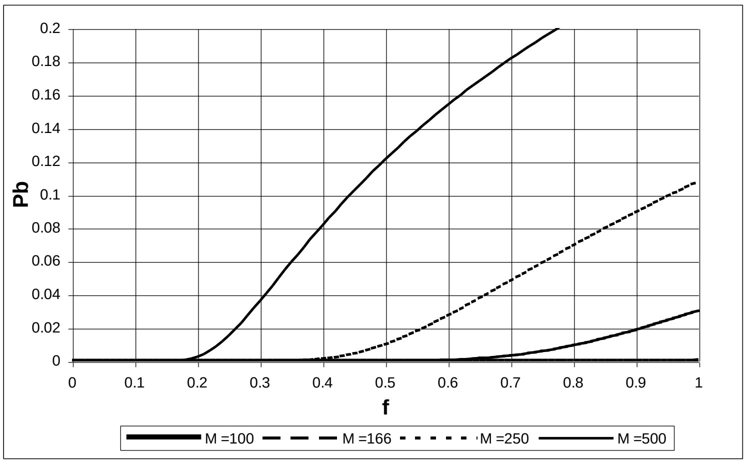
In this section some results are obtained for different environments and scenarios in order to show the first system performance approach. The blocking probability is represented as a fraction of active users in a cell. Four pools of the numbers of potential users, M in a cell are considered: 100, 166, 250 and 500 users. Thus, a traffic engineer while knowing the forecasted number of subscribers in the considered area, can make cell capacity dimensioning, hence preparing base stations raster referring to acceptable path loss for choosing the working frequency. Optimisation of the existing system in terms of a better utilisation of channels can be done as well.

A number of 216 channels has been chosen both for uplink and downlink in order to prepare the set of simulations. The obtained results for such a symmetric case, in different environments are presented in Figures 4.2, 4.3 and 4.4. This value of 216 channels in the system, fulfilling some scenarios, can be referred results to other scenarios, which are characterised by a similar number of available channels (e.g., 3 operators with re-use pattern 3 implies a number of 192 available channels both for uplink and downlink).

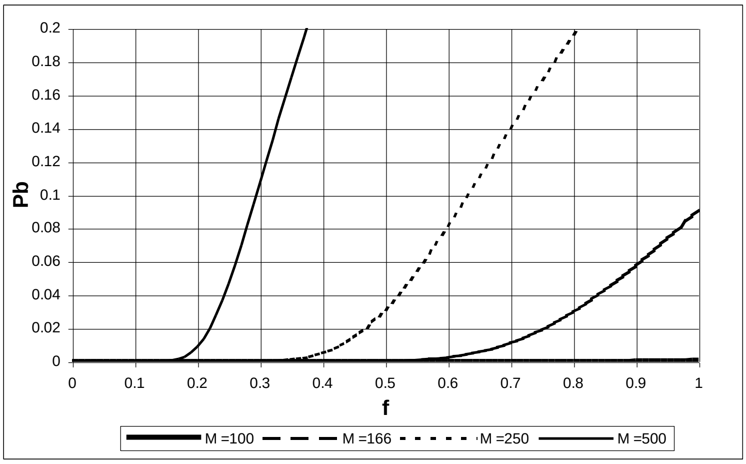
Environment: **BCC**

Uplink (216 ch.)

BAS



MED1



MED2

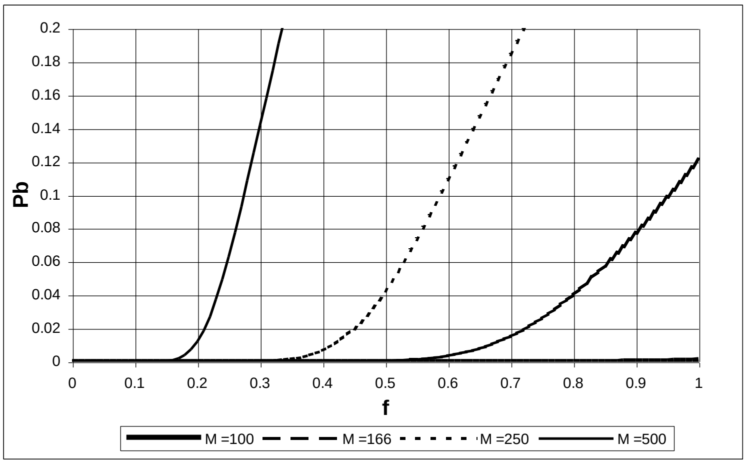
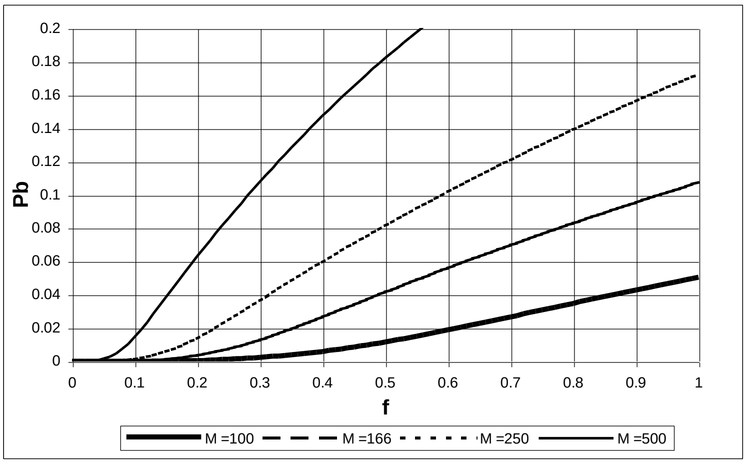


Figure 4.2 Service components Blocking Probability in BCC environment.

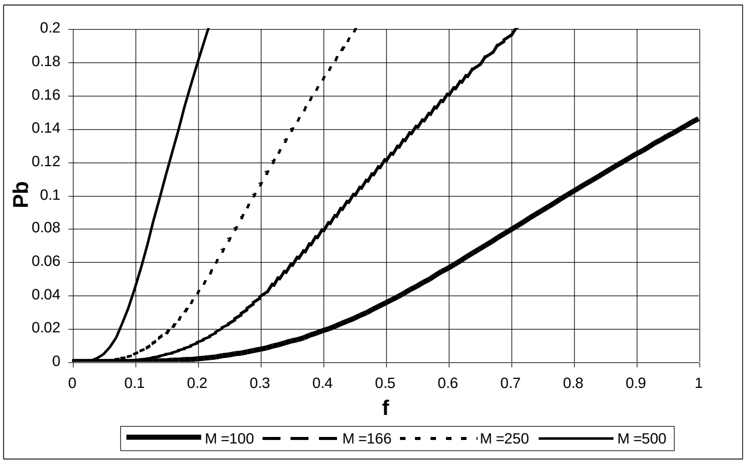
Environment: **BCC**

Downlink (216 ch.)

BAS



MED1



MED2

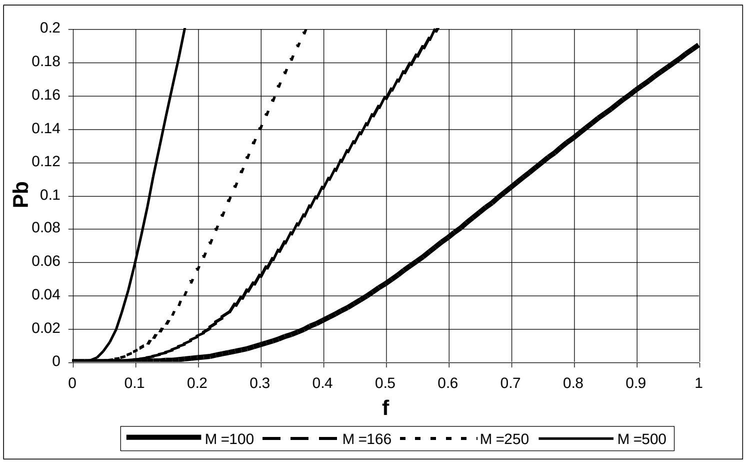
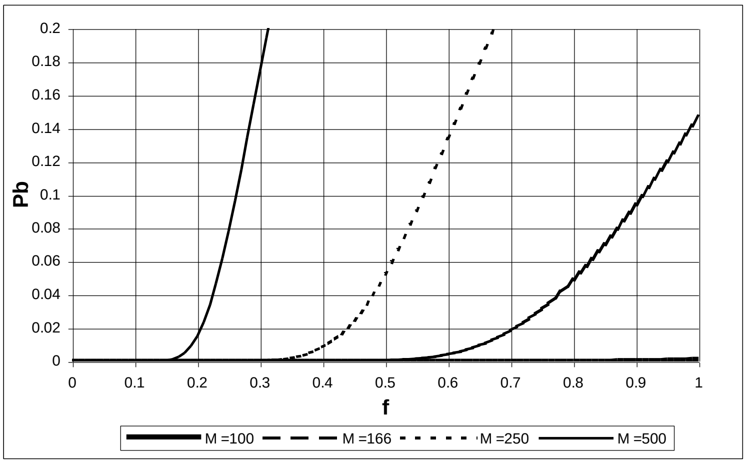


Figure 4.2 Service components Blocking Probability in BCC environment – cont.

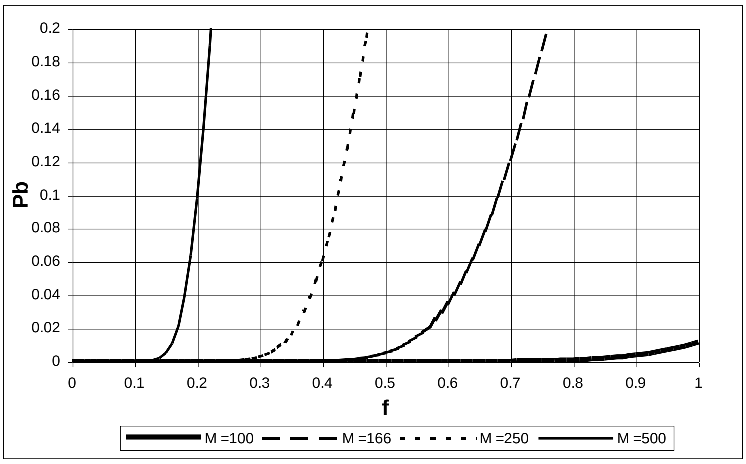
Environment: **BCC**

Uplink (216 ch.)

MED3



HDV



HID

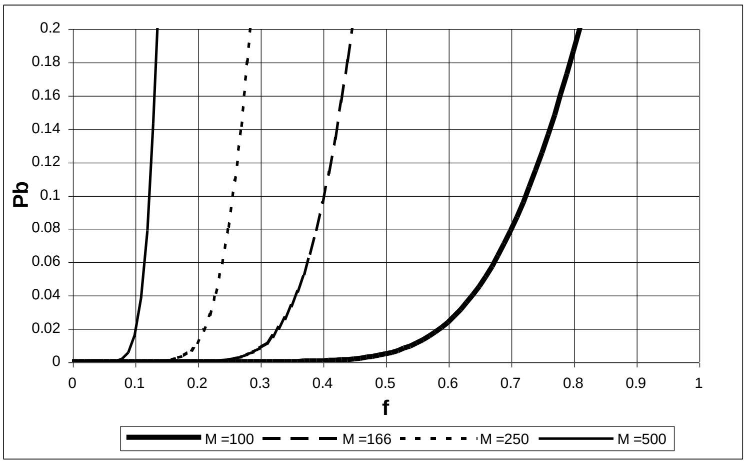
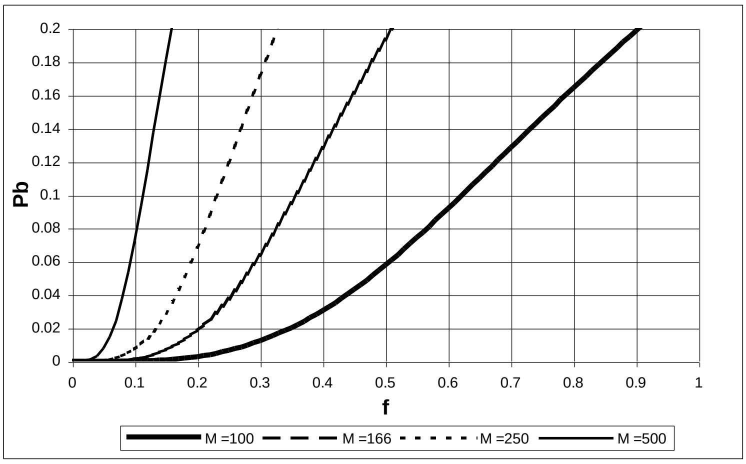


Figure 4.2 Service components Blocking Probability in BCC environment – cont.

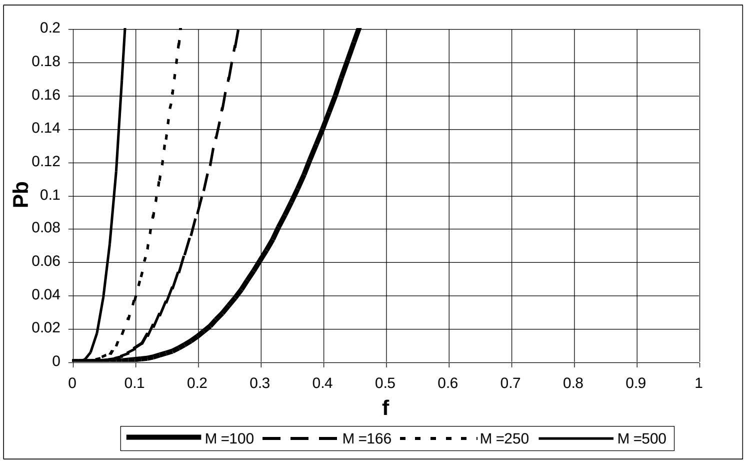
Environment: **BCC**

Downlink (216 ch.)

MED3



HDV



HID

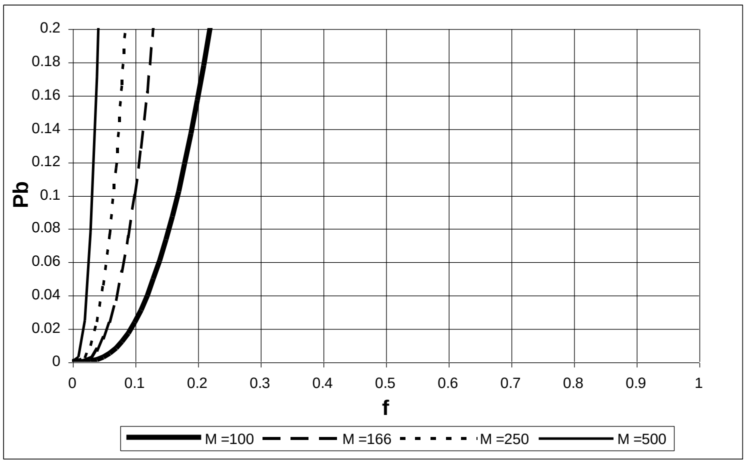
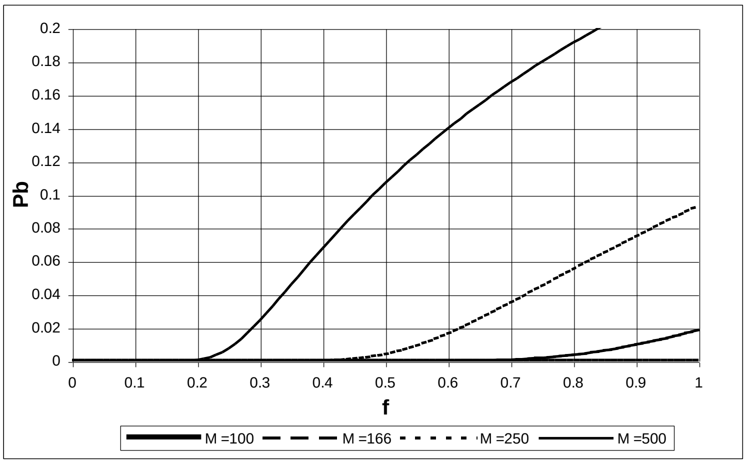


Figure 4.2 Service components Blocking Probability in BCC environment – cont.

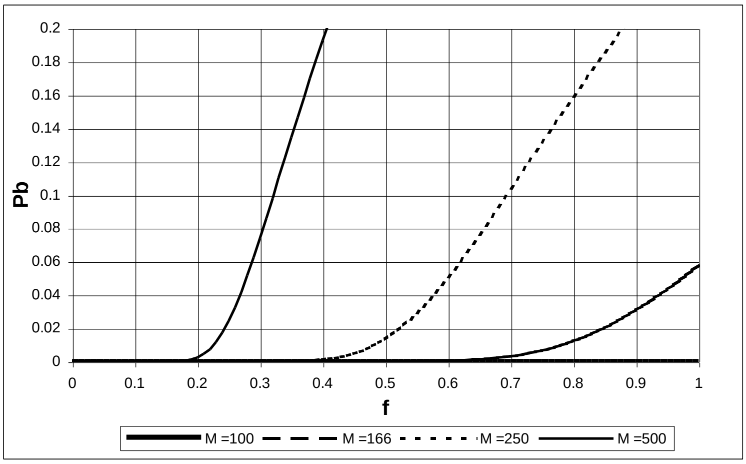
Environment: **URB**

Uplink (216 ch.)

BAS



MED1



MED2

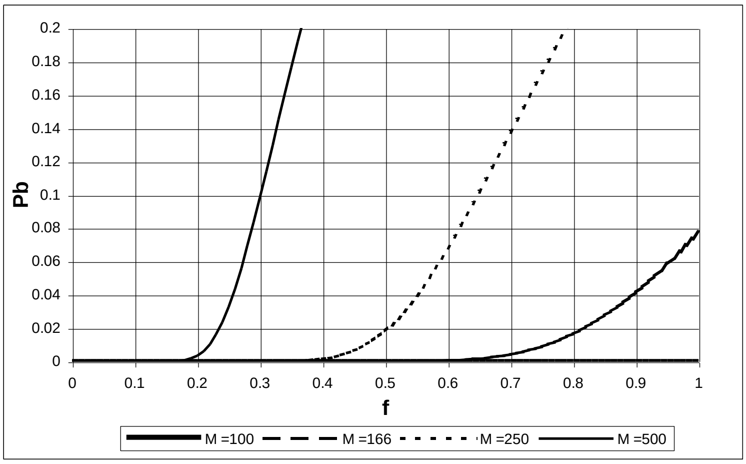
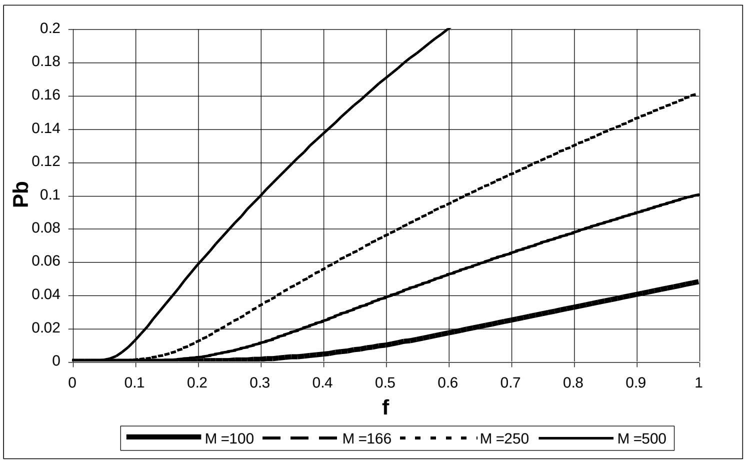


Figure 4.3 Service components Blocking Probability in URB environment.

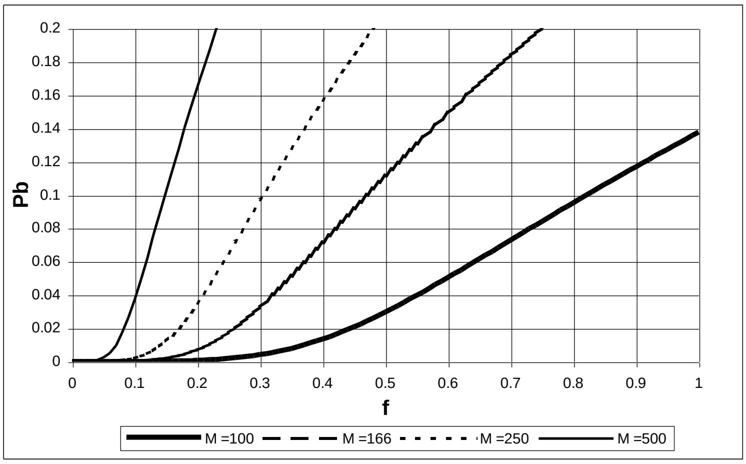
Environment: **URB**

Downlink (216 ch.)

BAS



MED1



MED2

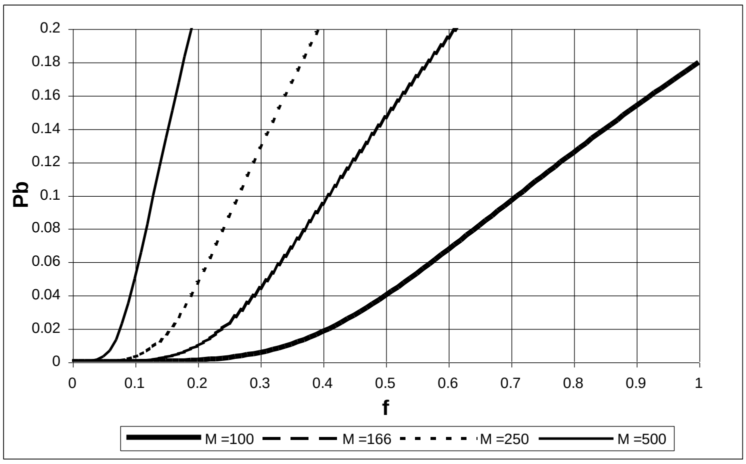
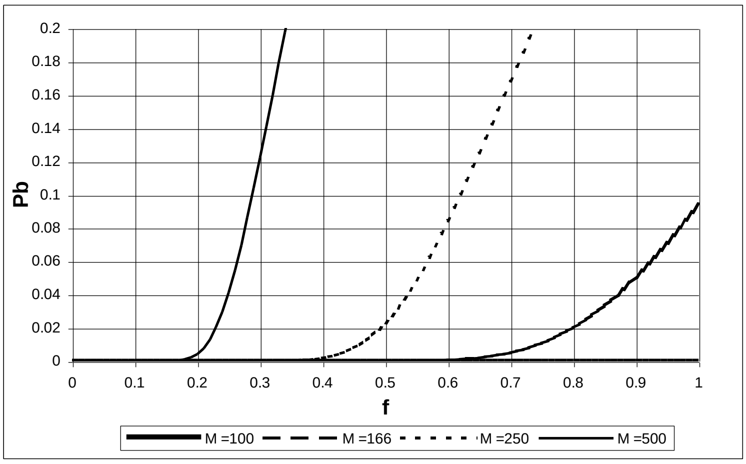


Figure 4.3 Service components Blocking Probability in URB environment – cont.

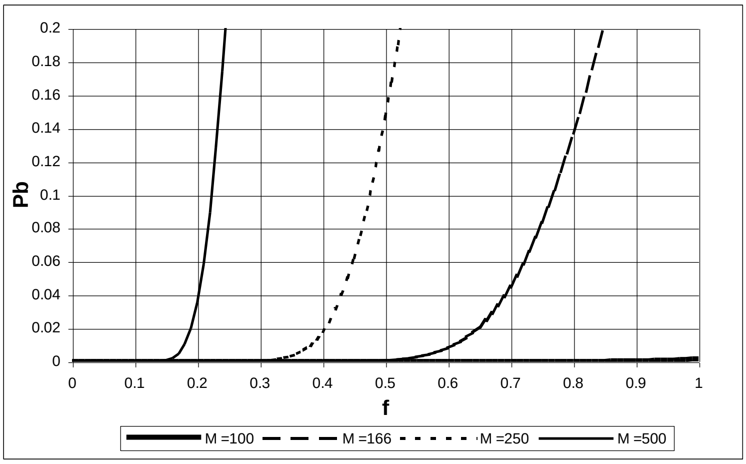
Environment: **URB**

Uplink (216 ch.)

MED3



HDV



HID

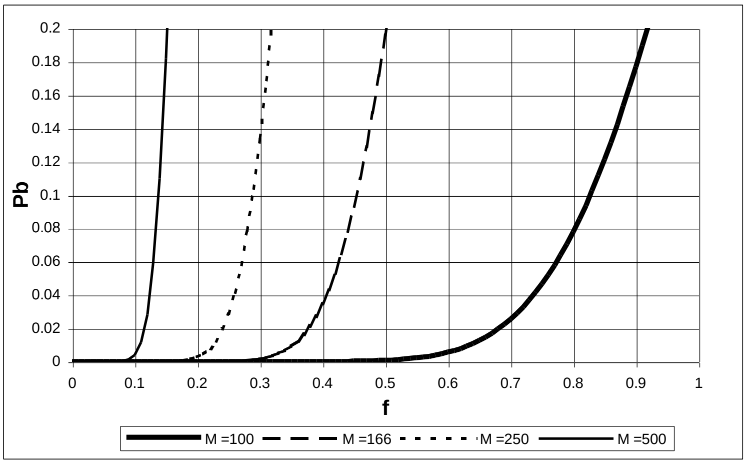
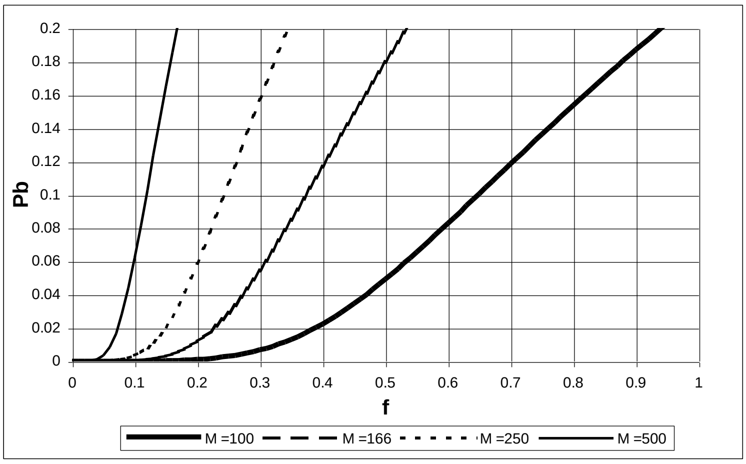


Figure 4.3 Service components Blocking Probability in URB environment – cont.

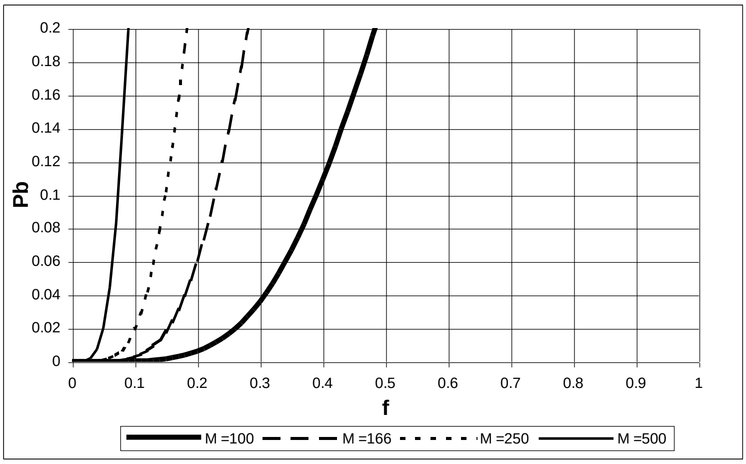
Environment: **URB**

Downlink (216 ch.)

MED3



HDV



HID

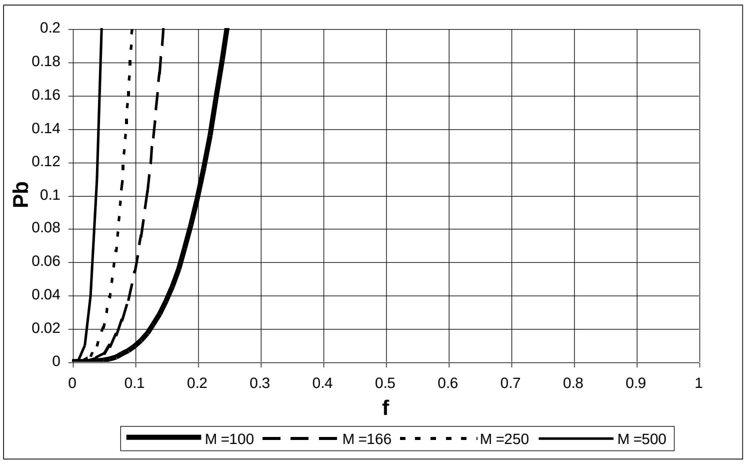
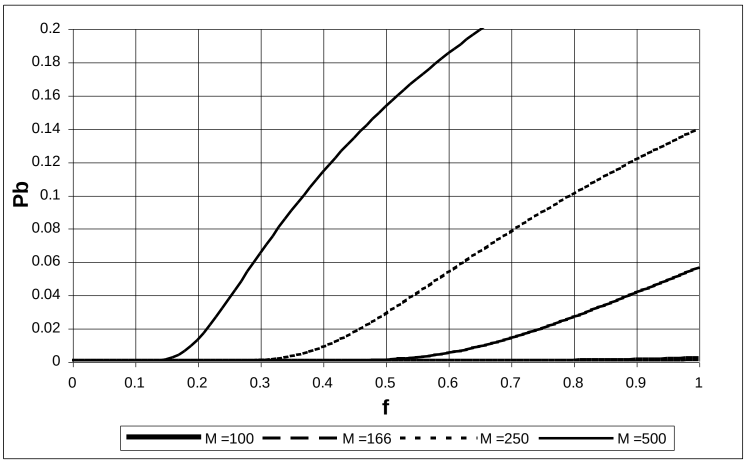


Figure 4.3 Service components Blocking Probability in URB environment – cont.

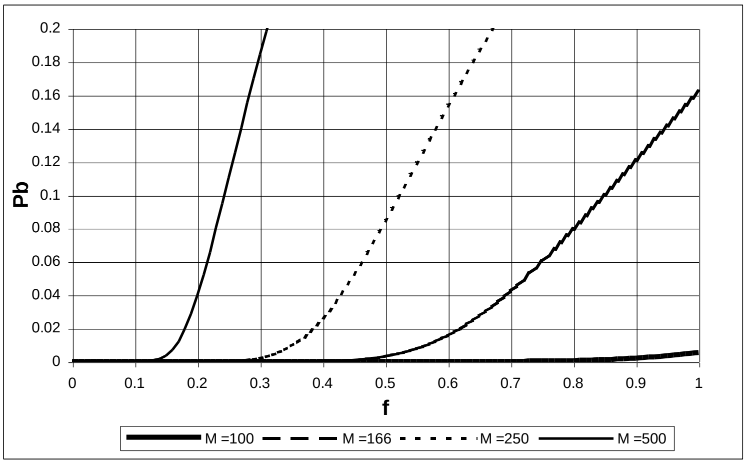
Environment: **ROA**

Uplink (216 ch.)

BAS



MED1



MED2

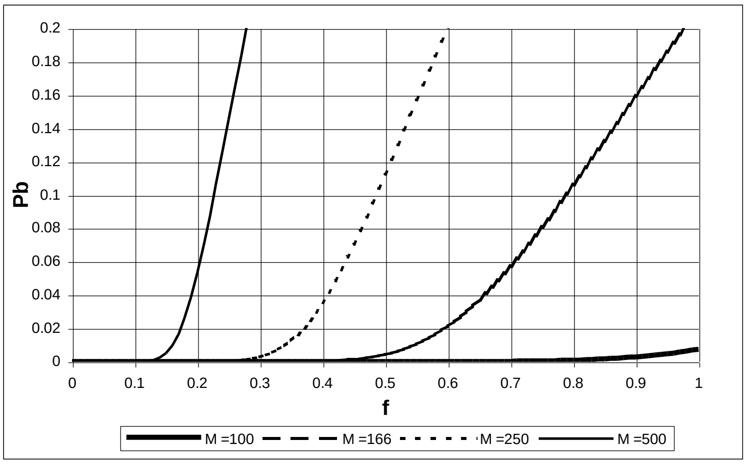
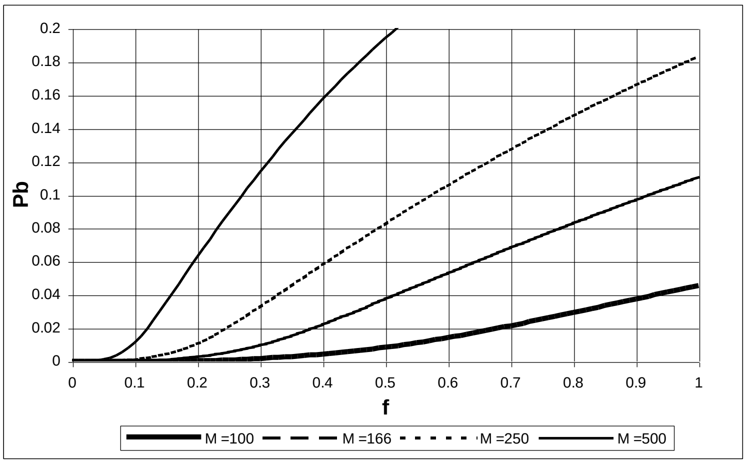


Figure 4.4 Service components Blocking Probability in ROA environment.

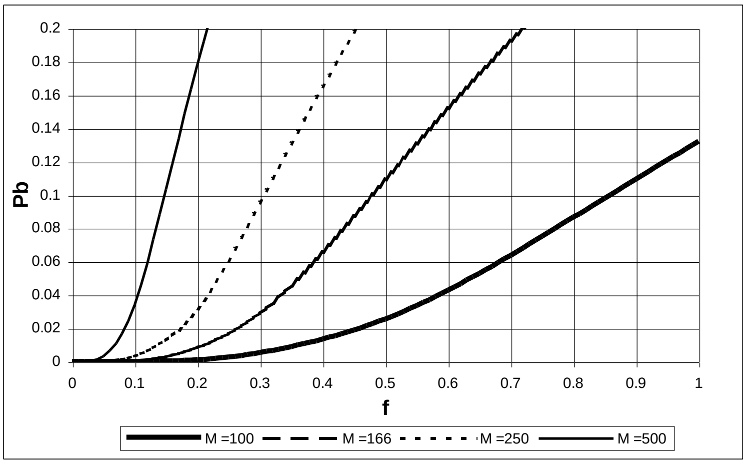
Environment: **ROA**

Downlink (216 ch.)

BAS



MED1



MED2

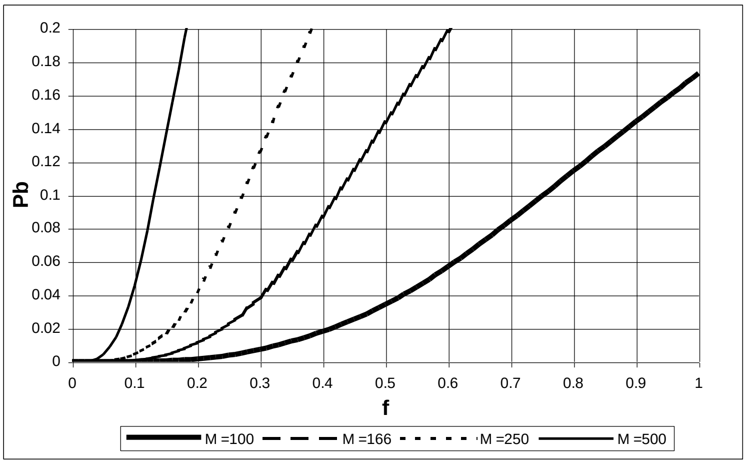
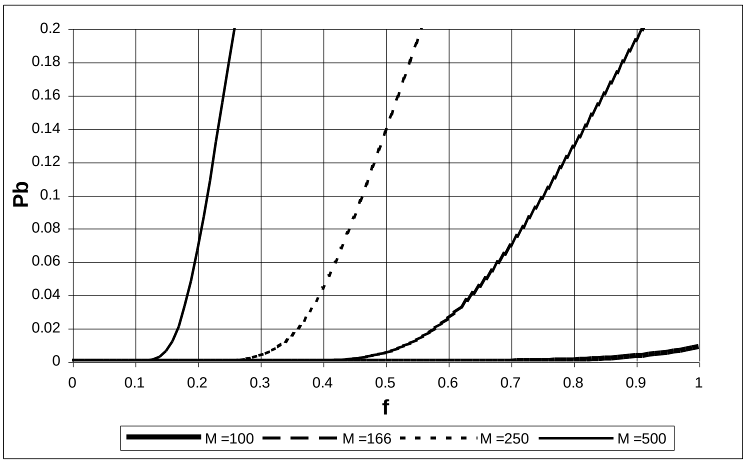


Figure 4.4 Service components Blocking Probability in ROA environment – cont.

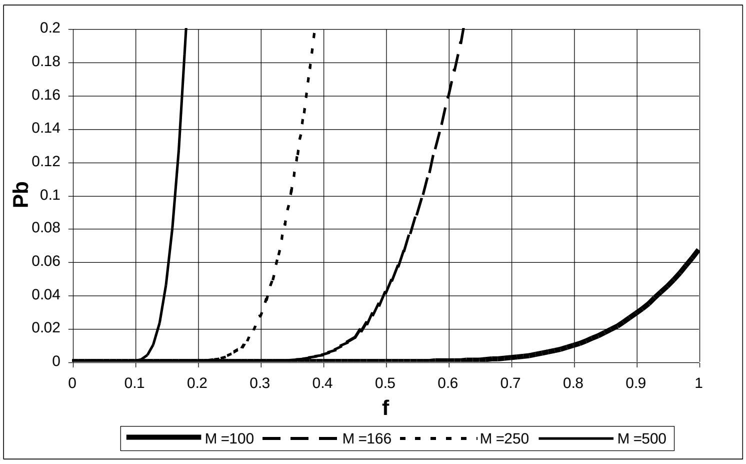
Environment: **ROA**

Uplink (216 ch.)

MED3



HDV



HID

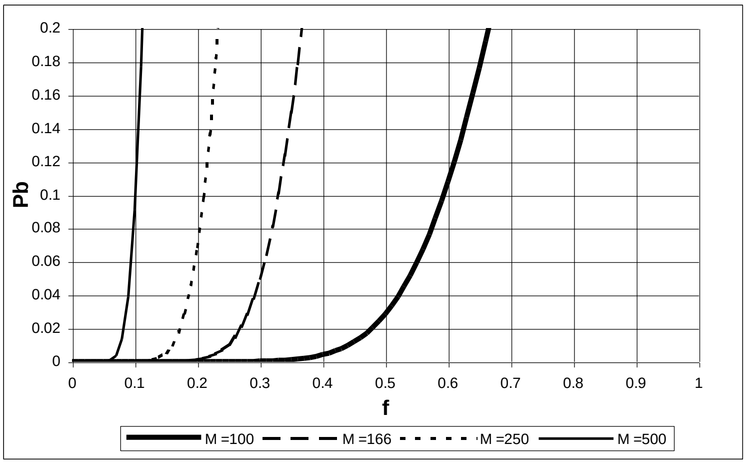
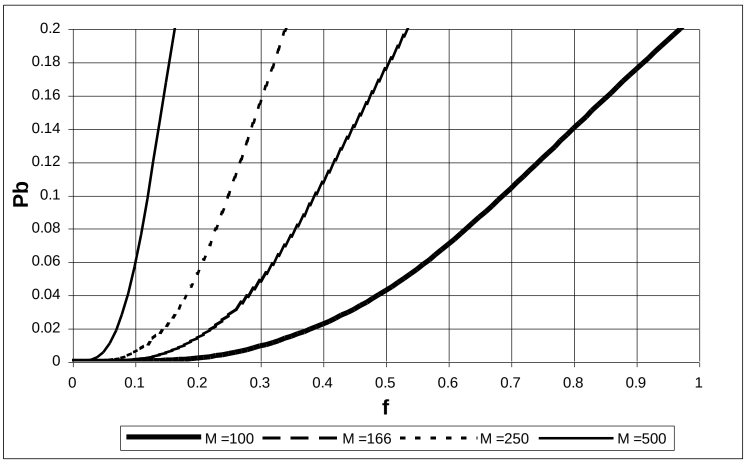


Figure 4.4 Service components Blocking Probability in ROA environment – cont.

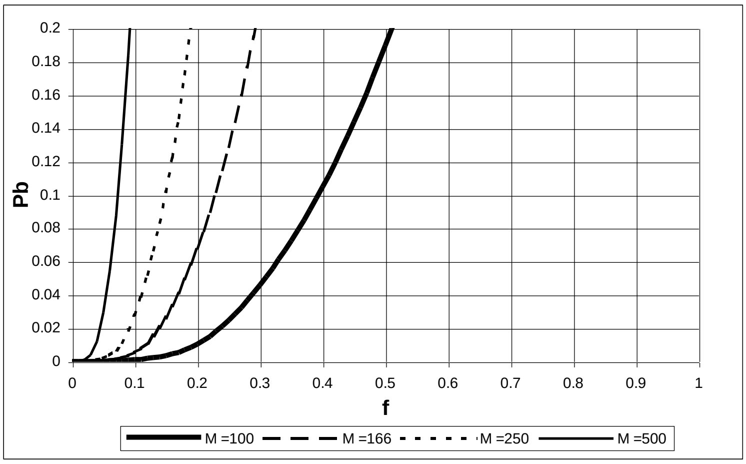
Environment: **ROA**

Downlink (216 ch.)

MED3



HDV



HID

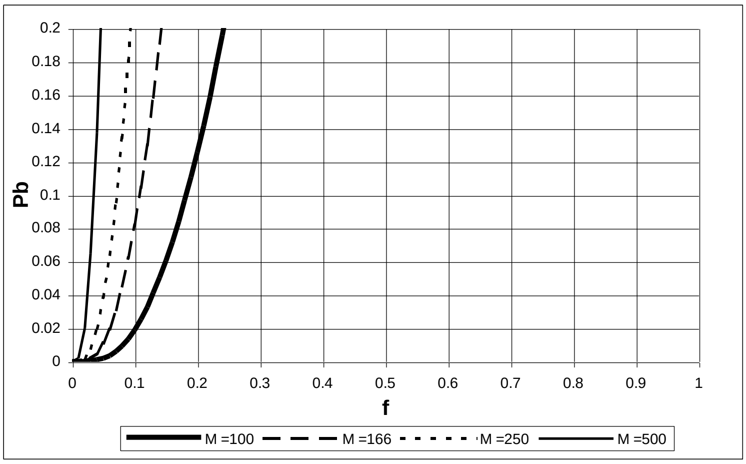


Figure 4.4 Service components Blocking Probability in ROA environment – cont.

Investigating the previous figures, a big asymmetry between uplink and downlink is observed. From the input parameters from Table 4.5 – 4.8 one can notice that downlink is much more extensively used than uplink, hence downlink is characterised by a worst Grade of Service. As an example, one can compare the results for the fraction of active users in the ROA environment for M=166 users in a cell for a blocking probability of 5 %. Because the HID component is not used in the uplink, it is only limitative for the downlink. Thus, this comparison is done between the HDV component for the uplink and HID component for the downlink. In this case the fraction of 52 % of active users can be supported by uplink while only 8 % of active users can be supported by downlink. Large asymmetry is also confirmed by analysing Table 4.9, where the bit rates associated with each application, b_k, and the asymmetry factors, AF, are presented for different environments. AF is obtained as the ratio of the maximum load per user, c_1, between the downlink and the uplink.

Table 4.9 Applications contributions for c_1 and AF for different scenarios.

Application	b_k [kbit/s]		$prop_k \cdot b_k$ [kbit/s]					
			BCC		URB		ROA	
	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink	Uplink	Downlink
1 HVT	1920.00	1920.00	288.00	288.00	211.20	211.20	188.16	188.16
2 IVC	384.00	384.00	15.36	15.36	15.36	15.36	15.36	15.36
3 MVS	1920.00	0.80	7.68	0.00	9.60	0.00	3.84	0.00
4 HOB	8067.82	1923.82	8.07	1.92	8.07	1.92	8.07	1.92
5 WLI	145.73	4031.81	7.87	217.72	3.06	84.67	8.16	225.78
6 FTP	19.32	384.00	1.35	26.88	1.35	26.88	1.35	26.88
7 PIM	384.00	8064.00	7.68	161.28	3.84	80.64	5.76	120.96
8 DMM	63.36	48.58	9.50	7.29	9.50	7.29	9.50	7.29
9 MES	2731.18	2731.18	49.16	49.16	2.73	2.73	43.70	43.70
10 MRA	2327.98	2327.98	4.66	4.66	2.33	2.33	6.98	6.98
11 MTW	1929.56	1929.56	140.86	140.86	42.45	42.45	63.68	63.68
12 FFM	2735.96	2735.96	19.15	19.15	5.47	5.47	62.93	62.93
13 EMB	63.36	1536.00	1.90	46.08	1.90	46.08	1.27	30.72
14 ECO	15.94	48.58	1.12	3.40	1.12	3.40	1.12	3.40
15 MML	4.78	2327.98	0.35	172.27	0.21	102.43	0.27	130.37
16 TIN	76.49	242.88	2.75	8.74	0.76	2.43	1.61	5.10
17 RPC	9.56	194.30	0.29	5.83	0.76	15.54	0.29	5.83
18 UGD	1935.30	1935.30	21.29	21.29	63.86	63.86	63.86	63.86
19 ATR	1934.34	1934.34	69.64	69.64	212.78	212.78	315.30	315.30
20 TVD	0.00	8064.00	0.00	596.74	0.00	725.76	0.00	403.20
21 ENP	0.80	242.88	0.04	12.14	0.08	24.29	0.04	12.14
	c_1		**656.72**	**1868.41**	**596.44**	**1677.52**	**801.24**	**1733.56**
	$c_{1\_up} + c_{1\_down}$		**2525.13**		**2273.96**		**2534.80**	
	AF		**2.85**		**2.81**		**2.16**	

Using asymmetry factors one can use the following formula for the channels in order to obtain a better balance between uplink and downlink for a service components:

$$C_{uplink} = \frac{C_{total}}{1+AF}$$
$$C_{downlink} = \frac{C_{total} \cdot AF}{1+AF} \qquad (4.1)$$

After some simulations another set of equations seems to be a better approach:

$$C_{uplink} = \frac{C_{total}}{AF} + x \qquad \left\{\begin{matrix} x = 0 & \text{for} & AF \approx 2.8 \\ x = -15\% & \text{for} & AF \approx 2.0 \end{matrix}\right\}$$
$$C_{downlink} = C_{total} - C_{uplink} \qquad (4.2)$$

The numbers used for TDD mode simulations are presented in Table 4.10. It is important to remark that still the same scenario is considered but now channels from uplink and downlink are merged which leads to a pool of 432 user channels available for the system.

Table 4.10 Number of channels used for TDD mode analysis.

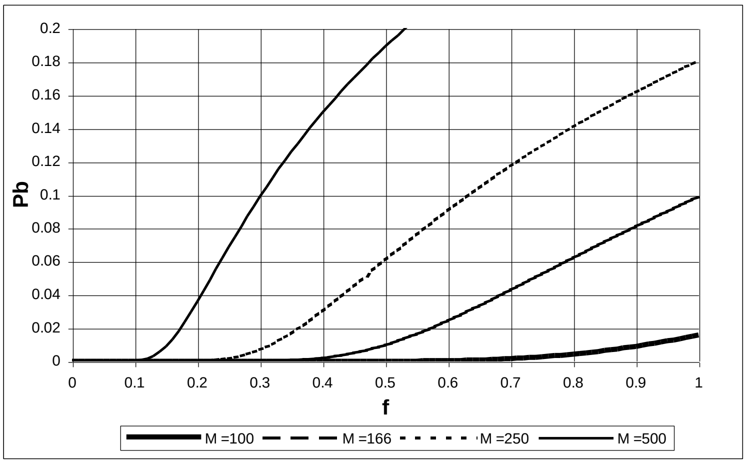
Environment	Number of channels dedicated for Uplink	Number of channels dedicated for Downlink
BCC	152	280
URB	154	278
ROA	170	262

Figure 4.5 – 4.7 present the results obtained according to the new number of channels in TDD mode i.e., the case where asymmetry can be supported (152 channels for uplink and 280 for channels for downlink). It is important to remark that the same assumptions and input parameters than in FDD mode are kept to find a more efficient solution by direct comparison.

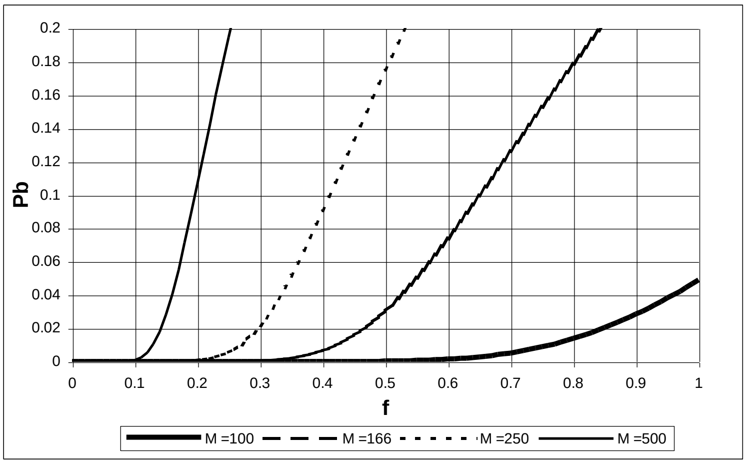
Environment: **BCC**

Uplink (152 ch.)

BAS



MED1



MED2

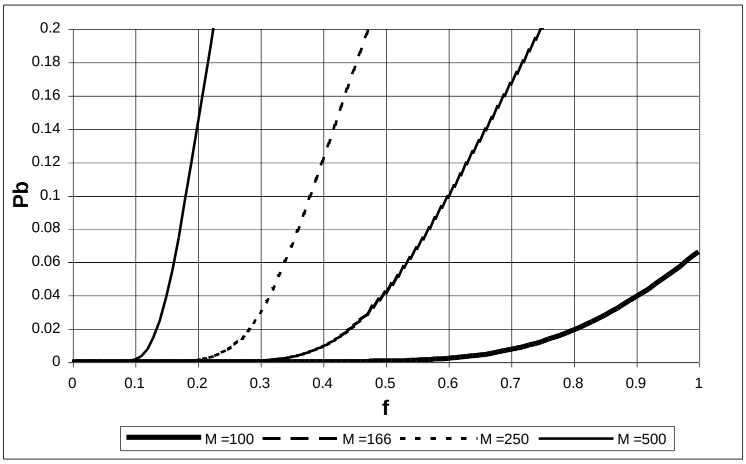
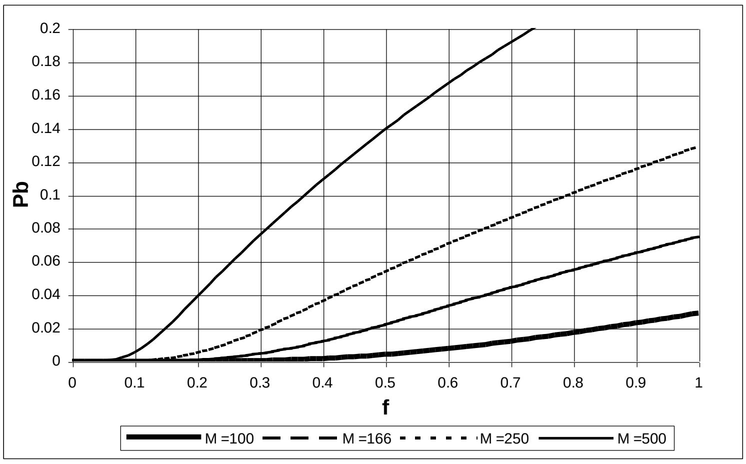


Figure 4.5 Service components Blocking Probability in BCC environment for TDD Mode.

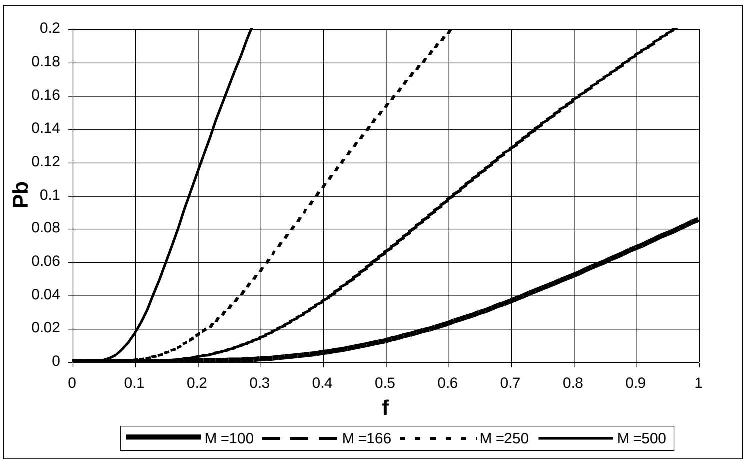
Environment: **BCC**

Downlink (280 ch.)

BAS



MED1



MED2

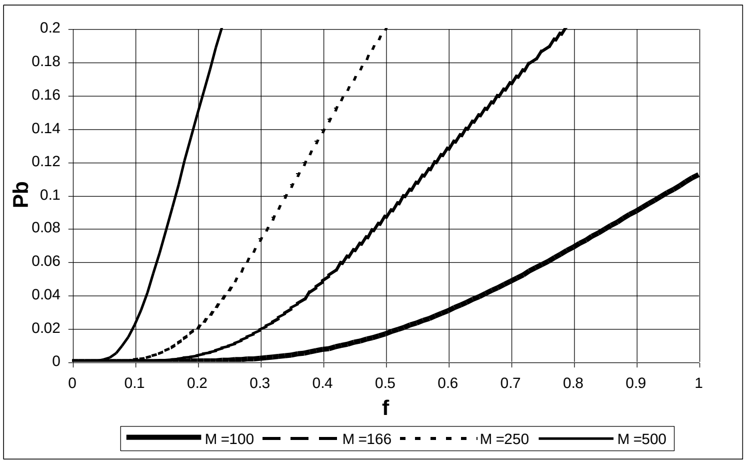
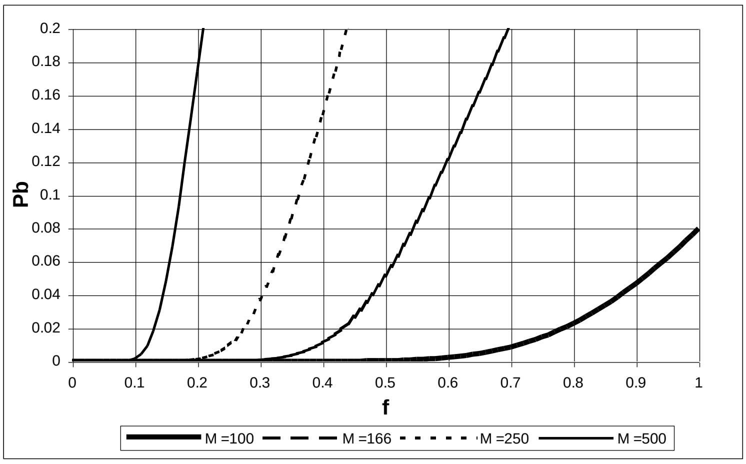


Figure 4.5 Service components Blocking Probability in BCC environment for TDD Mode – cont.

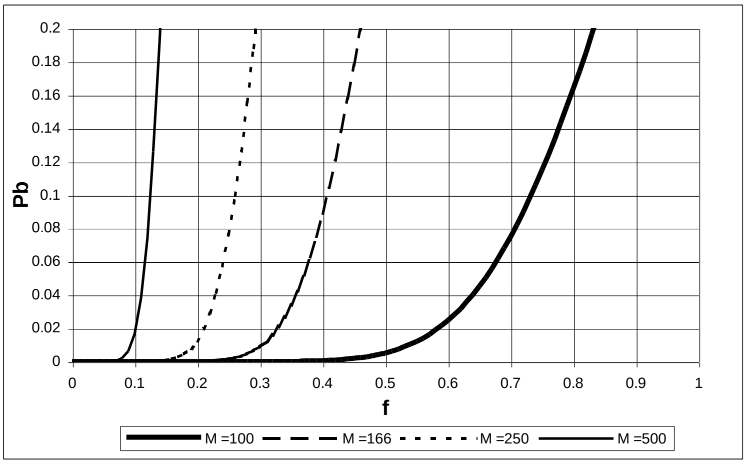
Environment: **BCC**

Uplink (152 ch.)

MED3



HDV



HID

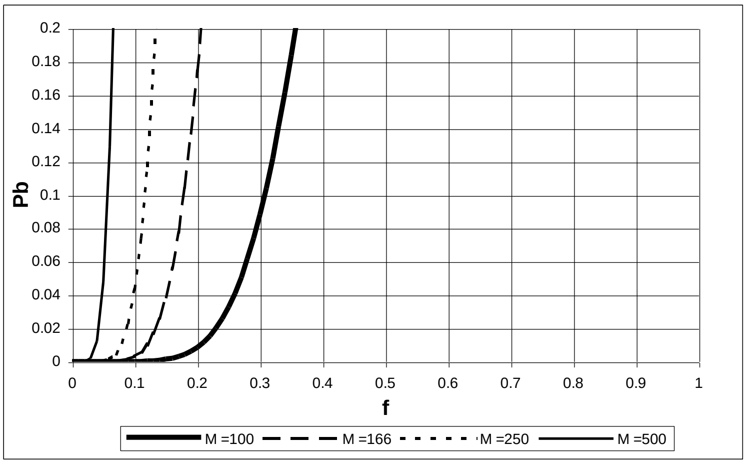
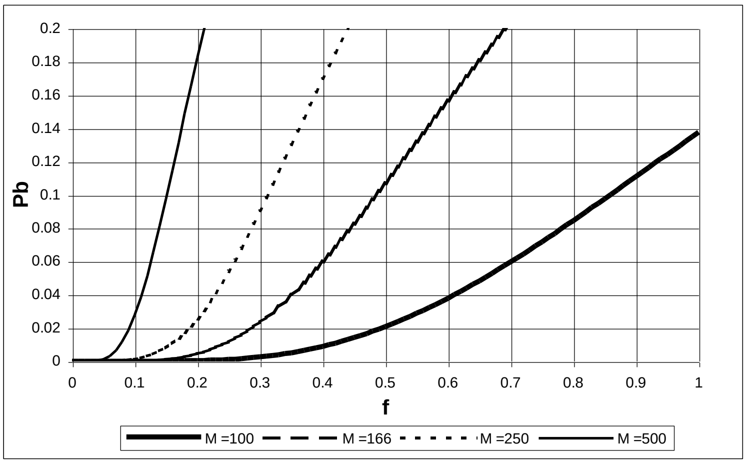


Figure 4.5 Service components Blocking Probability in BCC environment for TDD Mode – cont.

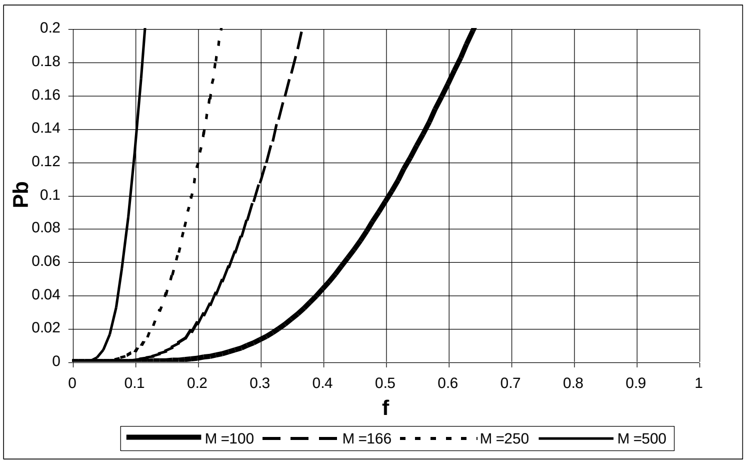
Environment: **BCC**

Downlink (280 ch.)

MED3



HDV



HID

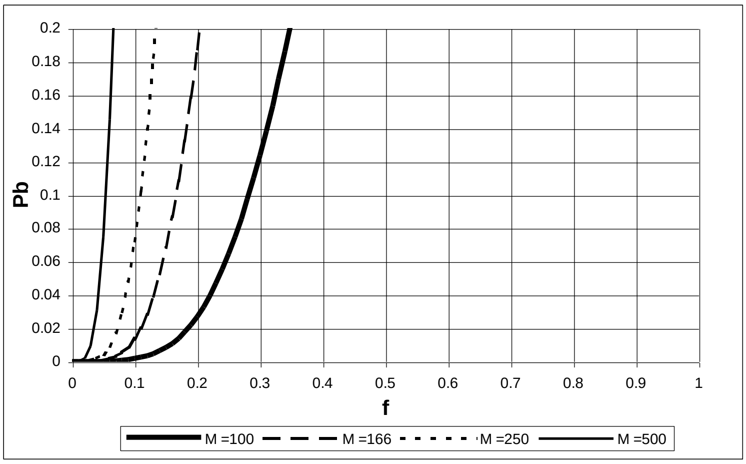
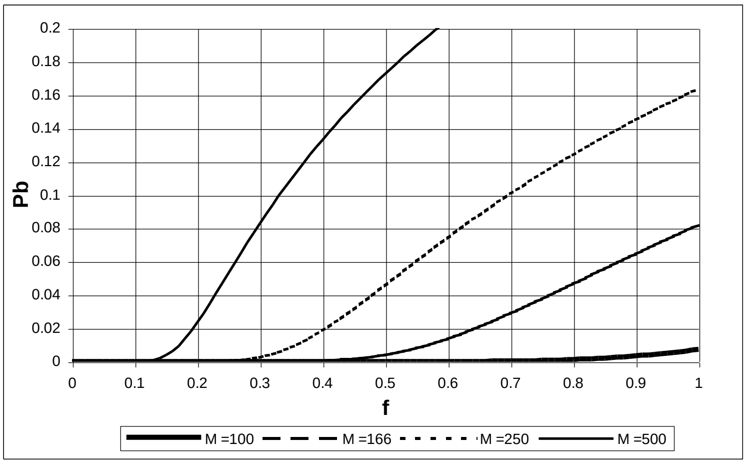


Figure 4.5 Service components Blocking Probability in BCC environment for TDD Mode – cont.

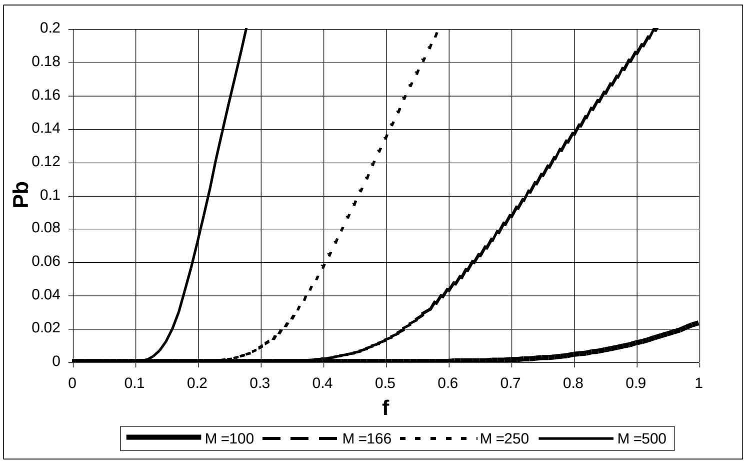
Environment: **URB**

Uplink (154 ch.)

BAS



MED1



MED2

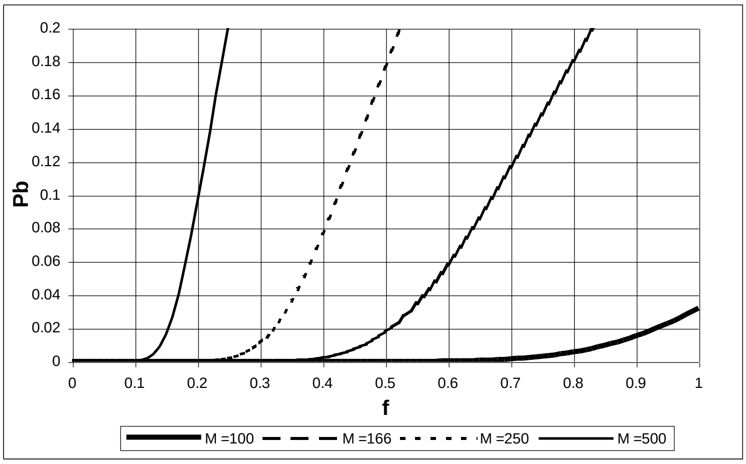
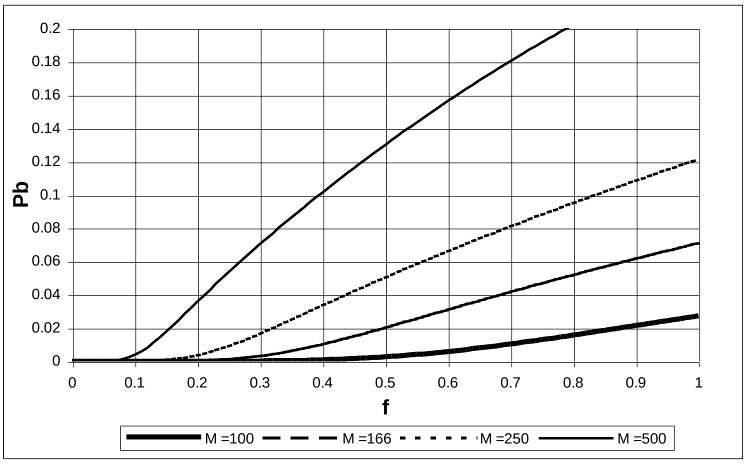


Figure 4.6 Service components Blocking Probability in URB environment for TDD Mode.

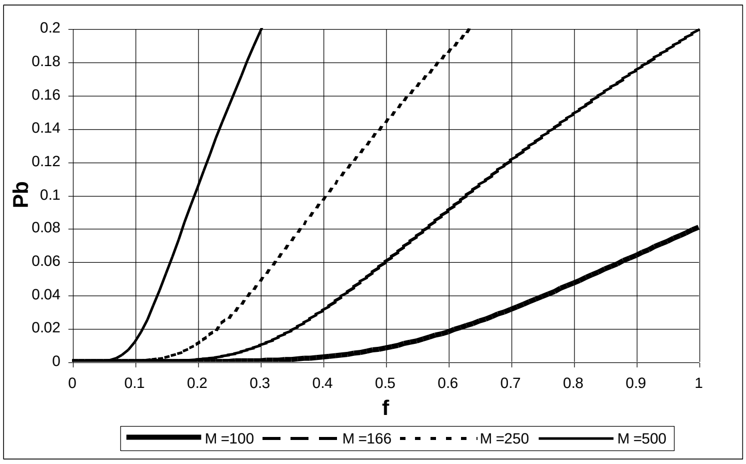
Environment: **URB**

Downlink (278 ch.)

BAS



MED1



MED2

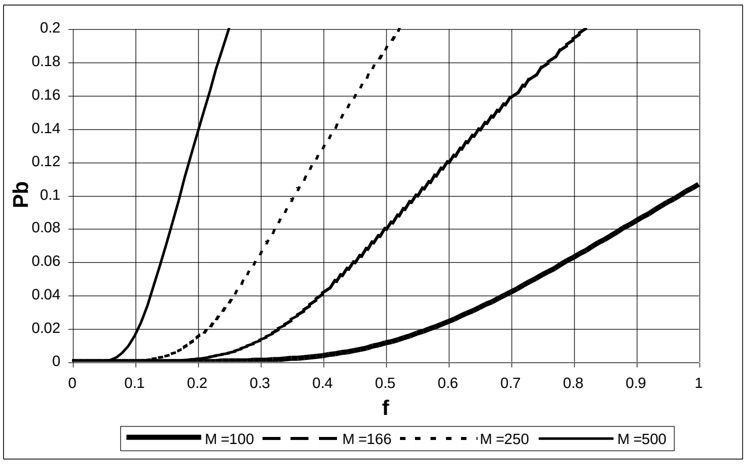
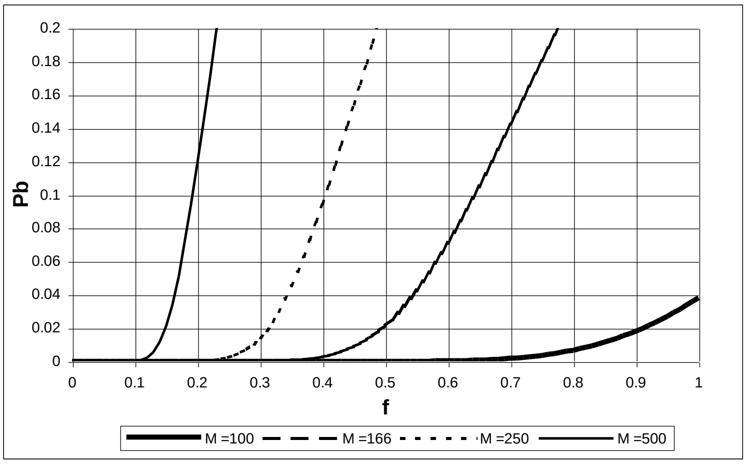


Figure 4.6 Service components Blocking Probability in URB environment for TDD Mode – cont.

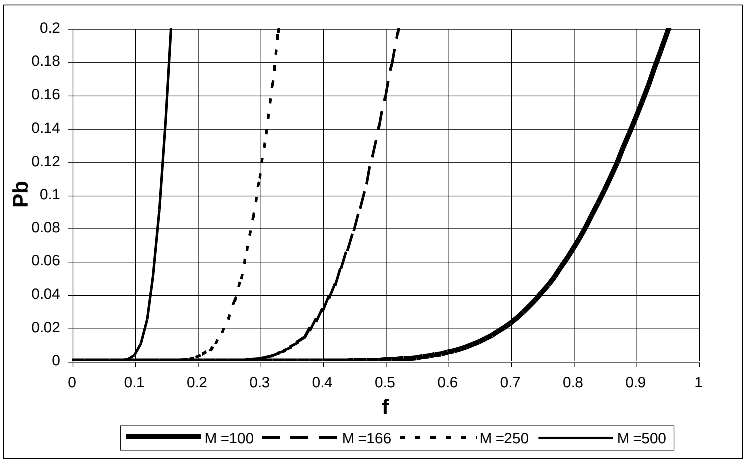
Environment: **URB**

Uplink (154 ch.)

MED3



HDV



HID

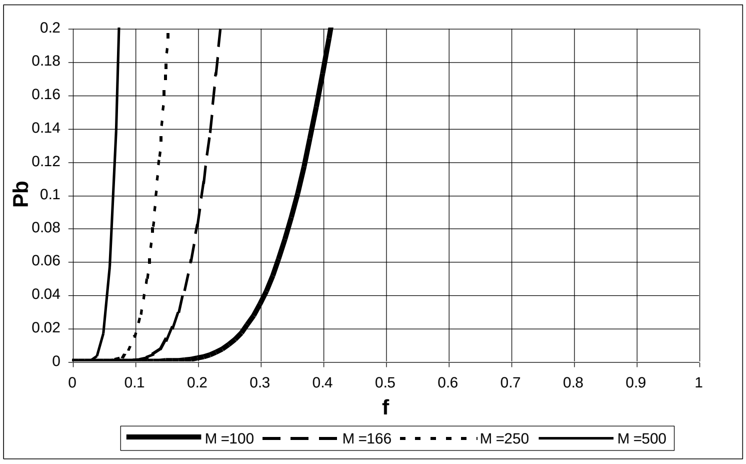
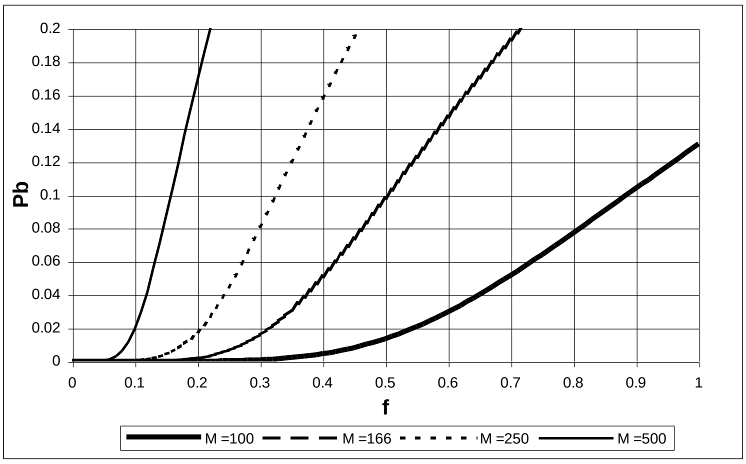


Figure 4.6 Service components Blocking Probability in URB environment for TDD Mode – cont.

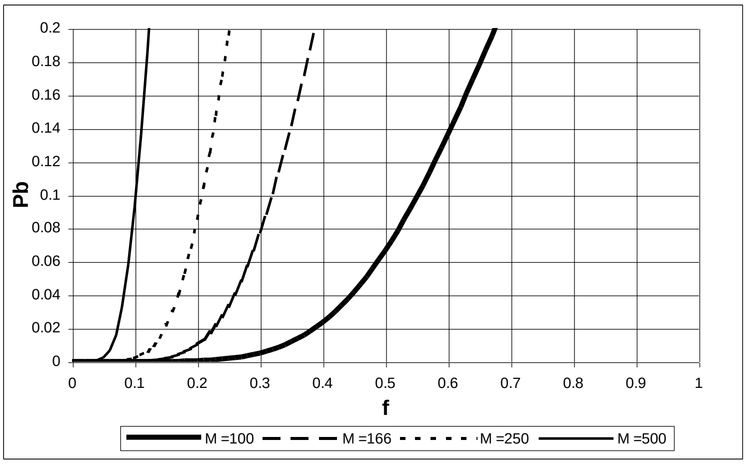
Environment: **URB**

Downlink (278 ch.)

MED3



HDV



HID

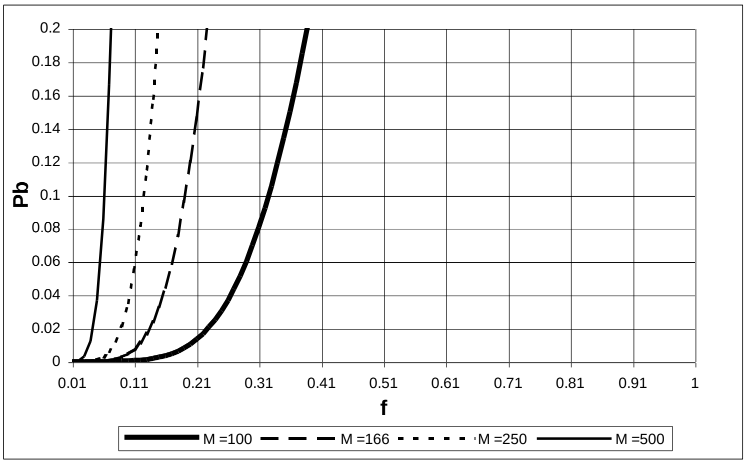
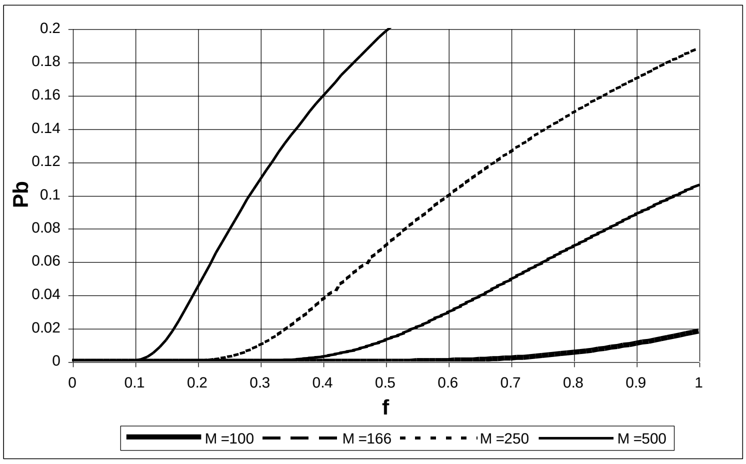


Figure 4.6 Service components Blocking Probability in URB environment for TDD Mode – cont.

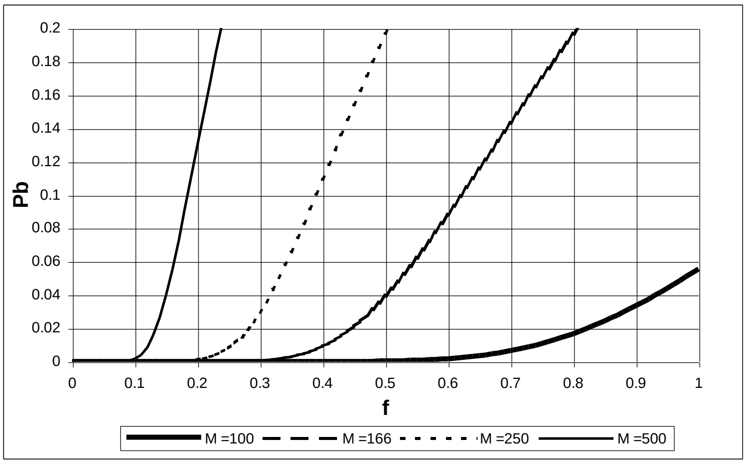
Environment: **ROA**

Uplink (170 ch.)

BAS



MED1



MED2

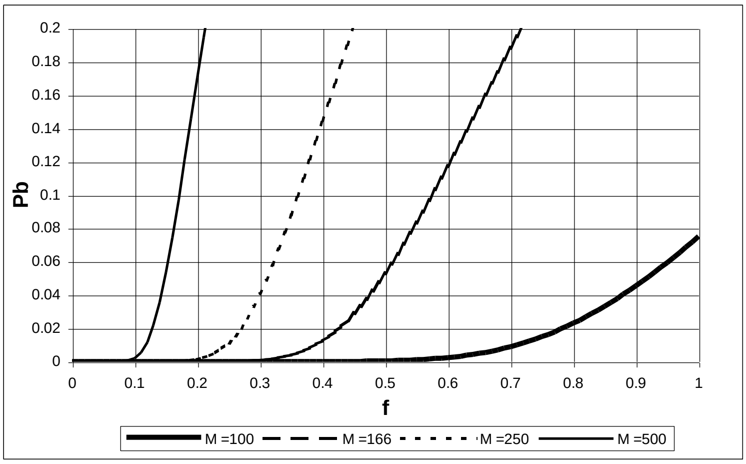
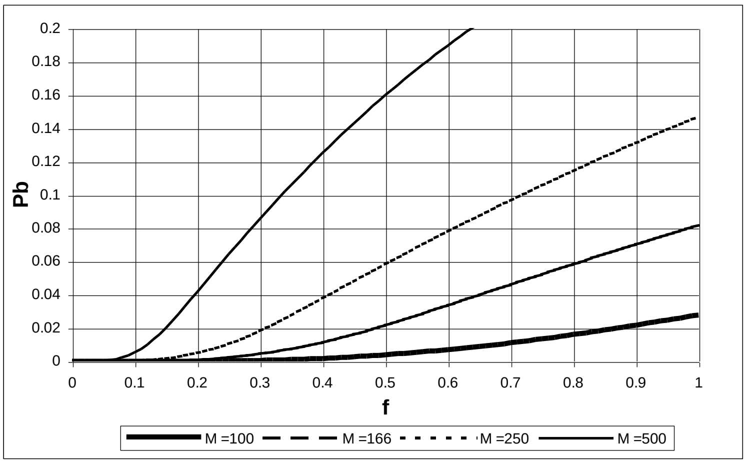


Figure 4.7 Service components Blocking Probability in ROA environment for TDD Mode.

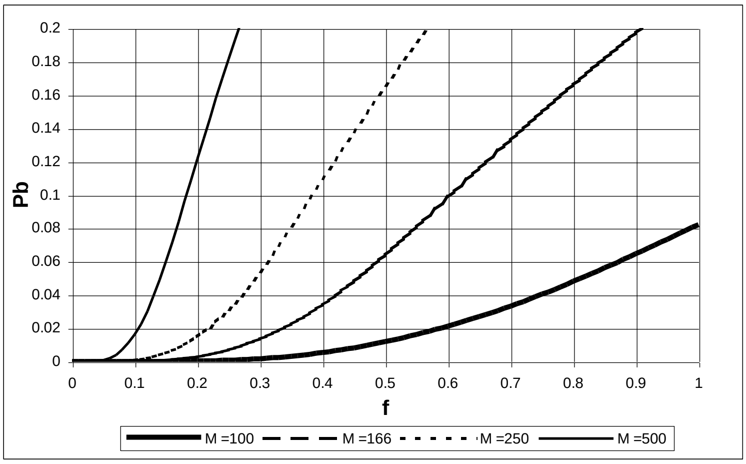
Environment: **ROA**

Downlink (262 ch.)

BAS



MED1



MED2

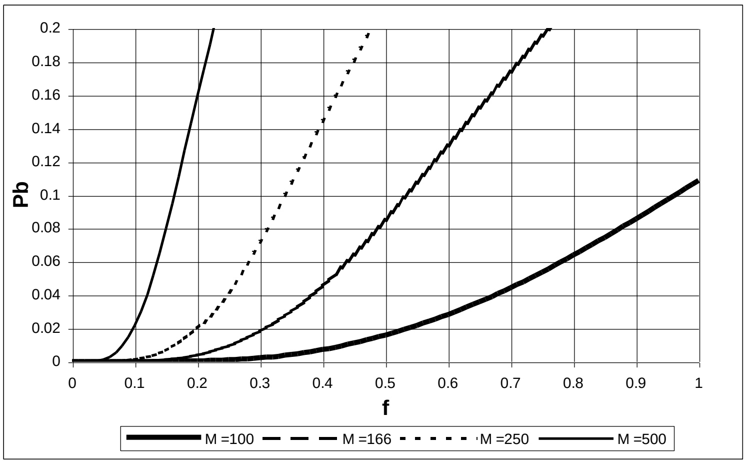
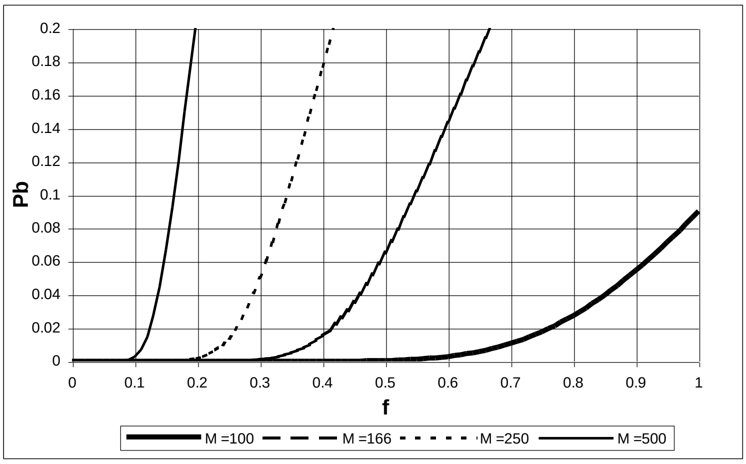


Figure 4.7 Service components Blocking Probability in ROA environment for TDD Mode – cont.

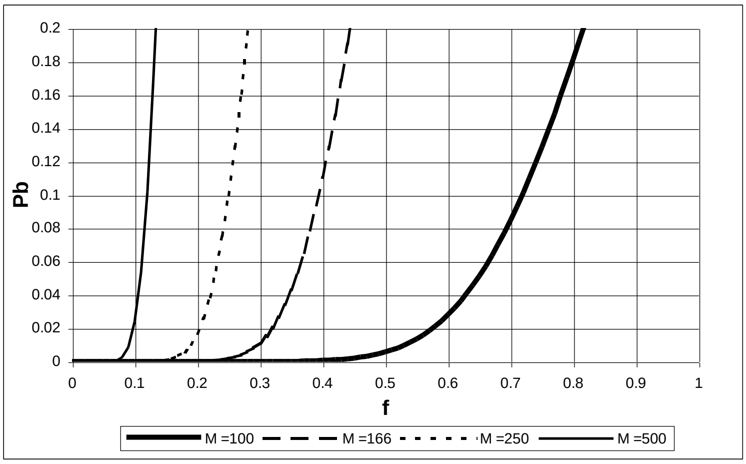
Environment: **ROA**

Uplink (170 ch.)

MED3



HDV



HID

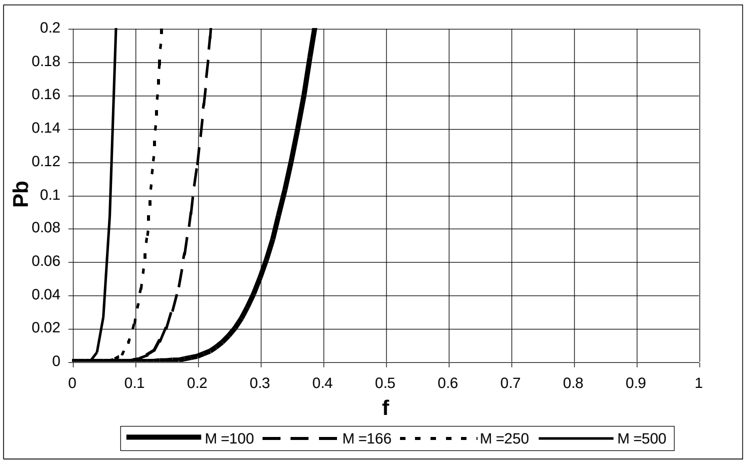
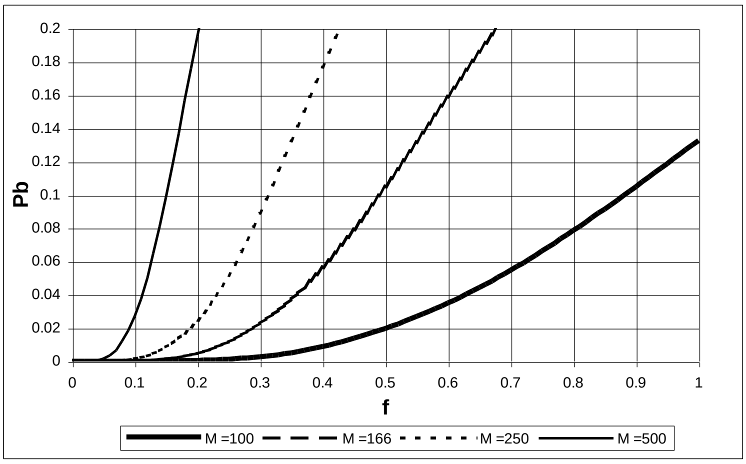


Figure 4.7 Service components Blocking Probability in ROA environment for TDD Mode – cont.

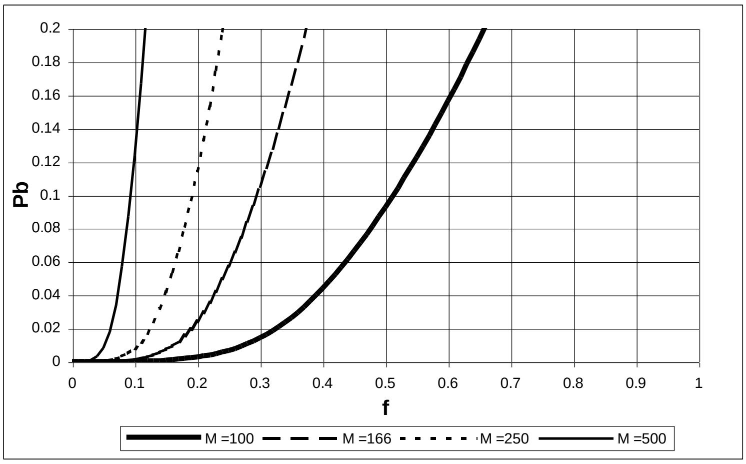
Environment: **ROA**

Downlink (262 ch.)

MED3



HDV



HID

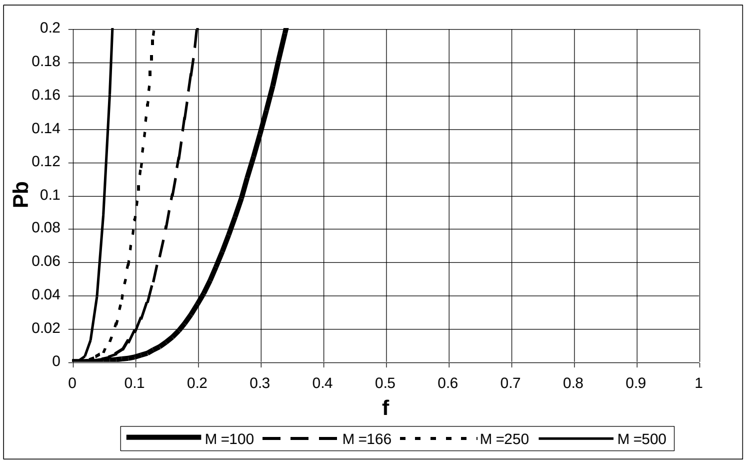


Figure 4.7 Service components Blocking Probability in ROA environment for TDD Mode – cont.

Investigating the figures above one can conclude that in TDD mode the system becomes more balanced. As an example one can consider again the ROA environment with M=166 potential users being in a cell and P_b=5 %. The fractions of 36 % and 13 % of supported users can be extracted from Figure 4.7 for uplink and downlink, respectively.

It is also important to stress that it is impossible to obtain an ideal balance for each service component and for each pool of users at the same time. Nevertheless in the TDD mode the channels available in the system seem to be better utilised. The number of served users for FDD and TDD modes respectively with the assumed Blocking Probability thresholds are presented in Tables 4.11 – 4.28. Note, that multimedia services are not the same as voice calls, hence they can be treated differently. Values of P_b equal to 5 % and 10 % are assumed for service components as the ones that will not make the future users unsatisfied while using multimedia services.

Table 4.11 Numbers of served component BAS users in BCC environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	All	All	178	240	165	230
	Downlink	99	All	93	156	90	148	90	140
No of served users in TDD mode	Uplink	All	All	123	All	115	160	110	155
	Downlink	All	All	126	All	120	200	140	190

Table 4.12 Numbers of served component MED1 users in BCC environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	144	All	135	158	125	145
	Downlink	57	79	55	75	53	73	50	70
No of served users in TDD mode	Uplink	All	All	91	108	86	105	83	100
	Downlink	79	All	75	101	73	98	70	95

Table 4.13 Numbers of served component MED2 users in BCC environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	138	159	128	148	120	140
	Downlink	51	68	50	65	48	63	50	60
No of served users in TDD mode	Uplink	95	All	85	101	81	95	78	93
	Downlink	71	95	67	90	65	88	63	85

Table 4.14 Numbers of served component MED3 users in BCC environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	133	151	124	140	115	130
	Downlink	47	62	45	60	45	58	45	55
No of served users in TDD mode	Uplink	91	All	82	96	79	93	78	85
	Downlink	66	86	63	81	61	80	58	78

Table 4.15 Numbers of served component HDV users in BCC environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	103	115	98	108	90	100
	Downlink	28	36	28	35	28	35	25	30
No of served users in TDD mode	Uplink	66	74	61	68	59	65	58	63
	Downlink	42	51	41	50	40	49	38	48

Table 4.16 Numbers of served component HID users in BCC environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	66	73	61	66	59	65	55	63
	Downlink	13	17	13	17	13	15	10	15
No of served users in TDD mode	Uplink	27	31	26	30	25	29	25	28
	Downlink	24	29	22	28	23	28	22	28

Table 4.17 Numbers of served component BAS users in URB environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	All	All	193	All	180	240
	Downlink	All	All	98	166	95	158	90	150
No of served users in TDD mode	Uplink	All	All	136	All	129	175	123	170
	Downlink	All	All	131	All	128	210	120	200

Table 4.18 Numbers of served component MED1 users in URB environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	161	All	150	175	140	160
	Downlink	60	82	58	78	55	78	55	75
No of served users in TDD mode	Uplink	All	All	103	121	98	115	93	110
	Downlink	82	All	78	105	76	101	74	100

Table 4.19 Numbers of served component MED2 users in URB environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	154	All	143	163	133	150
	Downlink	54	71	51	68	51	68	50	65
No of served users in TDD mode	Uplink	All	All	97	112	93	108	88	103
	Downlink	74	98	71	91	69	90	68	88

Table 4.20 Numbers of served component MED3 users in URB environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	149	All	138	155	128	145
	Downlink	50	65	48	63	48	63	45	60
No of served users in TDD mode	Uplink	All	All	94	108	89	103	85	97
	Downlink	70	89	66	85	65	83	63	80

Table 4.21 Numbers of served component HDV users in URB environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	117	128	110	120	103	113
	Downlink	33	39	32	38	33	38	30	36
No of served users in TDD mode	Uplink	77	85	71	78	68	74	65	72
	Downlink	47	56	45	53	44	53	43	53

Table 4.22 Numbers of served component HID users in URB environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	75	83	69	76	66	73	63	70
	Downlink	17	20	16	20	16	20	15	20
No of served users in TDD mode	Uplink	33	36	31	35	30	34	29	34
	Downlink	28	33	27	32	26	31	27	31

Table 4.23 Numbers of served component BAS users in ROA environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	All	All	178	240	165	225
	Downlink	All	All	96	153	93	143	88	135
No of served users in TDD mode	Uplink	All	All	117	161	111	153	104	145
	Downlink	All	All	123	All	115	180	110	170

Table 4.24 Numbers of served component MED1 users in ROA environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	145	All	135	158	128	150
	Downlink	64	86	60	80	58	78	58	75
No of served users in TDD mode	Uplink	98	All	87	105	83	98	78	93
	Downlink	81	All	76	101	73	98	70	95

Table 4.25 Numbers of served component MED2 users in ROA environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	138	159	129	148	120	140
	Downlink	57	76	54	70	53	70	53	65
No of served users in TDD mode	Uplink	92	All	82	96	79	91	74	86
	Downlink	73	97	69	90	66	85	65	81

Table 4.26 Numbers of served component MED3 users in ROA environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	133	151	124	143	118	130
	Downlink	53	69	51	65	49	63	48	60
No of served users in TDD mode	Uplink	89	All	79	91	75	88	72	82
	Downlink	68	88	64	81	62	80	55	75

Table 4.27 Numbers of served component HDV users in ROA environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	All	All	104	115	98	108	93	100
	Downlink	31	40	30	38	29	38	30	38
No of served users in TDD mode	Uplink	64	72	59	65	56	63	55	60
	Downlink	42	52	40	50	39	48	38	48

Table 4.28 Numbers of served component HID users in ROA environment.

Number of users in a cell		100		166		250		500	
Blocking Probability threshold [%]		5	10	5	10	5	10	5	10
No of served users in FDD mode	Uplink	66	73	61	67	60	65	58	63
	Downlink	14	18	14	18	14	18	13	18
No of served users in TDD mode	Uplink	30	34	29	32	28	31	28	31
	Downlink	23	27	27	22	21	26	23	26

As on can observe system capacity is limited by high bandwidth service components like HDV and HID. Furthermore uplink is limited by HDV because HID is never in use, while downlink is limited by HID.

In the TDD mode the system capacity is drastically increased, especially when asymmetric environments like Business City Centre are considered. For particular service components (HDV, HID) capacity gain can even jump over 100 %. In the FDD mode system capacity is limited by downlink only while in TDD it can be limited either by downlink or uplink, depending on service component and on the pool of system users; but, as it was previously remarked, it is impossible to obtain the same behaviour for each service component. Taking into account all aspects, the TDD mode seems to be the best solution for future mobile systems, where data users can become dominant, which leads to a high asymmetry in system usage.

Other Environments

Besides the considered scenarios and environments the others can be particularised as well. The important group are hot-spots where extremely different users behaviour can be met what implies different system load and asymmetry factor. In this section two hot-spots will be taken in to analysis:

- Airport, where mainly E-newspaper, Assistance in Travel, Electronic Multimedia Library and LAN users can be expected.
- Stadium, where journalists and media extensively will use High Definition TV and Professional Images applications.

The values which represents parameters specified for these environments are presented in Table 4.29

Table 4.29 Average applications service time and proportion of applications users for Airport and Stadium environment.

Application	Stadium		Airport	
	$prop_k$ [%]	$1/\mu_k$ [min]	$prop_k$ [%]	$1/\mu_k$ [min]
1 HVT	0.1	1	0.001	1
2 IVC	0.2	2	0.1	3
3 MVS	0	0	0	0
4 HOB	0.05	60	0.05	20
5 WLI	0	0	0.1	10
6 FTP	0.03	0.03	0.05	2
7 PIM	0.6	60	0.01	5
8 DMM	0	0	0.1	20
9 MES	0	0	0	0
10 MRA	0	0	0	0
11 MTW	0	0	0.01	5
12 FFM	0	0	0.05	0.033
13 EMB	0	0	0.02	0.05
14 ECO	0	0	0.05	5
15 MML	0.02	1	0.03	3
16 TIN	0	0	0.1	15
17 RPC	0	0	0	0
18 UGD	0	0	0	0
19 ATR	0	0	0.05	5
20 TVD	0	0	0	0
21 ENP	0	0	0.279	25

Table 4.30 Parameter $n_{j\backslash k}$ for uplink in Stadium environment.

Application	$n_{j\backslash k}$					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	1	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	0	0	0	0	1	0
5 WLI	0	0	0	0	0	0
6 FTP	0	1	0	1	0	0
7 PIM	0	2500	800	0	0	0
8 DMM	0	0	0	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	0	0	0	0	0	0
12 FFM	0	0	0	0	0	0
13 EMB	0	0	0	0	0	0
14 ECO	0	0	0	0	0	0
15 MML	20	0	0	0	0	0
16 TIN	0	0	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	0	0	0
19 ATR	0	0	0	0	0	0
20 TVD	0	0	0	0	0	0
21 ENP	0	0	0	0	0	0

Table 4.31 Parameter $\mu_{j\backslash k}$ for uplink in Stadium environment.

Application	$1/\mu_{j\backslash k}$ [min]					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	2	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	0	0	0	0	60	0
5 WLI	0	0	0	0	0	0
6 FTP	0	0.016	0	0.025	0	0
7 PIM	0	0.016	0.016	0	0	0
8 DMM	0	0	0	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	0	0	0	0	0	0
12 FFM	0	0	0	0	0	0
13 EMB	0	0	0	0	0	0
14 ECO	0	0	0	0	0	0
15 MML	0.0083	0	0	0	0	0
16 TIN	0	0	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	0	0	0
19 ATR	0	0	0	0	0	0
20 TVD	0	0	0	0	0	0
21 ENP	0	0	0	0	0	0

Table 4.32 Parameter $n_{j\backslash k}$ for downlink in Stadium environment.

Application	$n_{j\backslash k}$					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	1	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	0	0	0	0	0	0
5 WLI	0	0	0	0	0	0
6 FTP	0	0	0	1	0	0
7 PIM	0	0	0	0	0	0
8 DMM	0	0	0	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	0	0	0	0	0	0
12 FFM	0	0	0	0	0	0
13 EMB	0	0	0	0	0	0
14 ECO	0	0	0	0	0	0
15 MML	10	10	0	0	0	0
16 TIN	0	0	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	0	0	0
19 ATR	0	0	0	0	0	0
20 TVD	0	0	0	0	0	0
21 ENP	0	0	0	0	0	0

Table 4.33 Parameter $\mu_{j\backslash k}$ for downlink in Stadium environment.

Application	$1/\mu_{j\backslash k}$ [min]					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	2	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	0	0	0	0	0	0
5 WLI	0	0	0	0	0	0
6 FTP	0	0	0	0.033	0	0
7 PIM	0	0	0	0	0	0
8 DMM	0	0	0	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	0	0	0	0	0	0
12 FFM	0	0	0	0	0	0
13 EMB	0	0	0	0	0	0
14 ECO	0	0	0	0	0	0
15 MML	0.05	0.03	0	0	0	0
16 TIN	0	0	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	0	0	0
19 ATR	0	0	0	0	0	0
20 TVD	0	0	0	0	0	0
21 ENP	0	0	0	0	0	0

Table 4.34 Parameter $n_{j\backslash k}$ for uplink in Airport environment.

Application	$n_{j\backslash k}$					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	1	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	2	0	0	0	0	0
5 WLI	20	0	0	0	0	0
6 FTP	0	5	0	0	0	1
7 PIM	20	5	0	0	0	0
8 DMM	6	0	0	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	10	0	0	0	0	0
12 FFM	0	0	0	0	0	0
13 EMB	2	0	0	0	0	0
14 ECO	10	0	0	0	0	0
15 MML	3	0	0	0	0	0
16 TIN	10	0	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	0	0	0
19 ATR	5	0	0	0	0	0
20 TVD	0	0	0	0	0	0
21 ENP	40	0	0	0	0	0

Table 4.35 Parameter $\mu_{j\backslash k}$ for uplink in Airport environment.

Application	$1/\mu_{j\backslash k}$ [min]					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	3	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	0.05	0	0	0	0	0
5 WLI	0.0083	0	0	0	0	0
6 FTP	0	0.1	0	0	0	0.06
7 PIM	0.0083	0.05	0	0	0	0
8 DMM	0.0083	0	0	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	0.0083	0	0	0	0	0
12 FFM	0	0	0	5	0	0
13 EMB	0.025	0	0	0	0	0
14 ECO	0.01	0	0	0	0	0
15 MML	0.01	0	0	0	0	0
16 TIN	0.01	0	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	5	0	0
19 ATR	0.01	0	0	20	0	0
20 TVD	0	0	0	0	0	0
21 ENP	0.01	0	0	0	0	0

Table 4.36 Parameter $n_{j\backslash k}$ for downlink in Airport environment.

Application	$n_{j\backslash k}$					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	1	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	0	0	0	0	1	0
5 WLI	15	5	0	0	0	0
6 FTP	0	5	0	0	0	2
7 PIM	0	15	0	5	0	0
8 DMM	5	0	1	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	10	10	0	0	0	0
12 FFM	10	0	0	0	0	0
13 EMB	2	0	0	0	0	0
14 ECO	10	0	0	0	0	0
15 MML	1	0	0	2	0	0
16 TIN	3	7	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	0	0	0
19 ATR	5	0	0	0	0	0
20 TVD	0	0	0	0	0	0
21 ENP	40	0	0	0	0	0

Table 4.37 Parameter $\mu_{j\backslash k}$ for downlink in Airport environment.

Application	$1/\mu_{j\backslash k}$ [min]					
	BAS	MED1	MED2	MED3	HDV	HID
1 HVT	0	0	0	1	0	0
2 IVC	3	0	0	0	0	0
3 MVS	0	0	0	0	0	0
4 HOB	0	0	0	0	20	0
5 WLI	0.5	0.025	0	0	0	0
6 FTP	0	0.1	0	0	0	0
7 PIM	0	0.016	0	0.016	0	0
8 DMM	3	0	5	0	0	0
9 MES	0	0	0	0	0	0
10 MRA	0	0	0	0	0	0
11 MTW	0.4	0.1	0	0	0	0
12 FFM	0.01	0	0	0	0	0
13 EMB	0.025	0	0	0	0	0
14 ECO	0.01	0	0	0	0	0
15 MML	0.1	0	0	0.1	0	0
16 TIN	0.1	0.1	0	0	0	0
17 RPC	0	0	0	0	0	0
18 UGD	0	0	0	0	0	0
19 ATR	0.05	0	0	0	0	0
20 TVD	0	0	0	0	0	0
21 ENP	0.1	0	0	0	0	0

The data rates b_k (including the fraction of applications users $prop_k$) associated with each application for Stadium and Airport environments and their asymmetry factors are presented in Table 4.38.

Table 4.38 Data rates associated with applications for Airport and Stadium case.

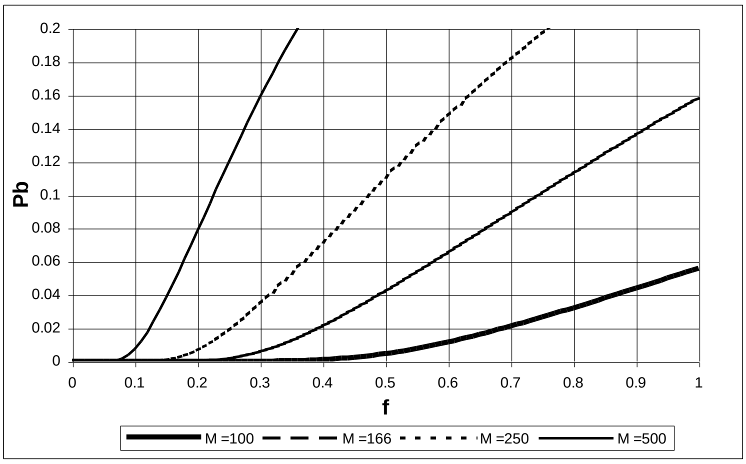
Application	$prop_k \cdot b_k$ [kbit/s]			
	Airport		Stadium	
	Uplink	Downlink	Uplink	Downlink
1 HVT	1.92	1.92	192.00	192.00
2 IVC	38.40	38.40	76.80	76.80
3 MVS	0.00	0.00	0.00	0.00
4 HOB	0.10	403.20	403.20	0.00
5 WLI	0.64	30.24	0.00	0.00
6 FTP	62.21	14.40	66.43	63.36
7 PIM	0.70	0.86	657.41	0.00
8 DMM	0.10	67.20	0.00	0.00
9 MES	0.00	0.00	0.00	0.00
10 MRA	0.00	0.00	0.00	0.00
11 MTW	0.06	5.38	0.00	0.00
12 FFM	0.00	58.18	0.00	0.00
13 EMB	7.68	7.68	0.00	0.00
14 ECO	0.38	0.38	0.00	0.00
15 MML	0.12	4.22	1.27	10.75
16 TIN	0.26	6.14	0.00	0.00
17 RPC	0.00	0.00	0.00	0.00
18 UGD	0.00	0.00	0.00	0.00
19 ATR	0.19	0.96	0.00	0.00
20 TVD	0.00	0.00	0.00	0.00
21 ENP	1.71	17.14	0.00	0.00
c_1	**114.47**	**656.31**	**1397.11**	**342.91**
AF	**5.73**		**0.25**	

A huge difference in system users behaviour can be observed; it is especially visible when looking to the values of asymmetry factors. Previously one has concluded that one of the possibility to obtain a good utilisation of future networks is the dedication of a higher number of channels for downlink and still keeping the idea with FDD mode, which naturally is less complicated from the hardware point of view. Now it is well visible that such solution could be a killer for environments like Stadium, where the uplink is more extensively used. Some simulations for the Stadium have been done and the results for the FDD mode are presented in Figure 4.8. The value of 216 channels for uplink and downlink stands still in order to show the difference between links utilisation in the currently considered scenario compared to previous ones. The Airport is out of considerations because of has not such a high load.

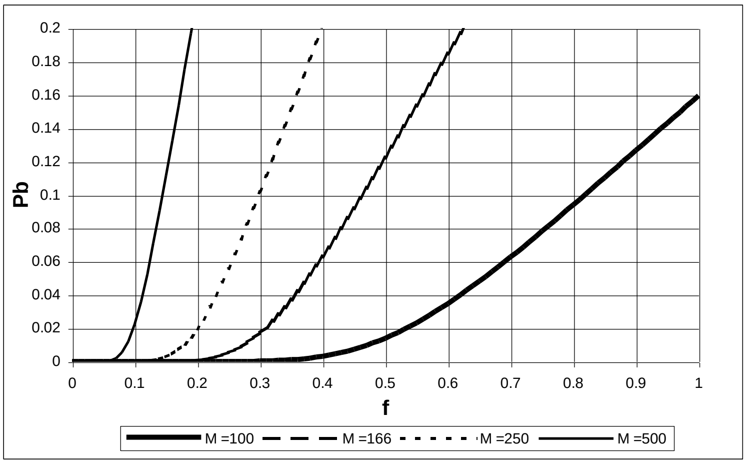
Environment: **STADIUM**

Uplink (216 ch.)

BAS



MED1



MED2

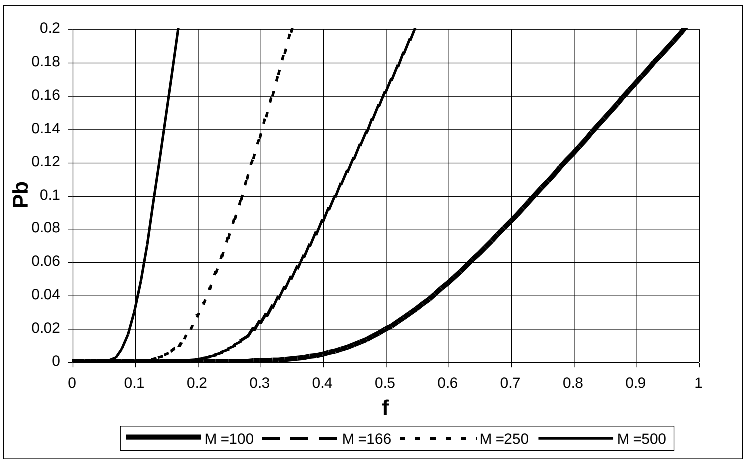
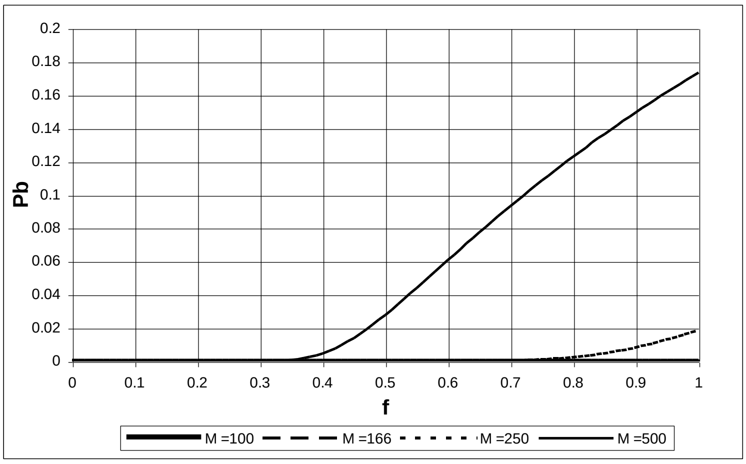


Figure 4.8 Service components Blocking Probability in Stadium environment.

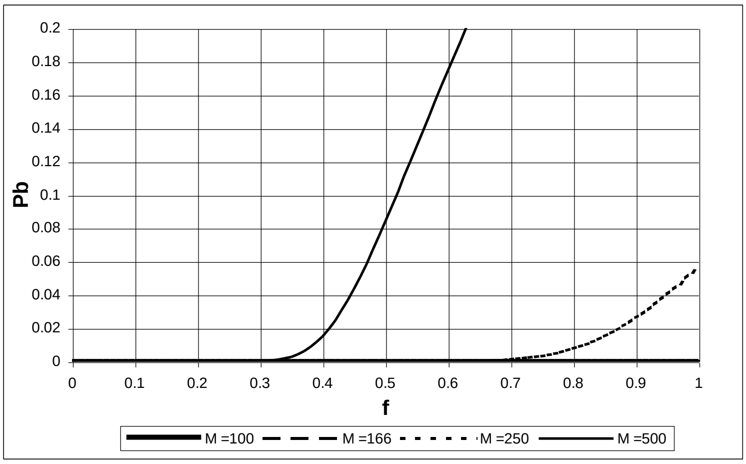
Environment: **STADIUM**

Downlink (216 ch.)

BAS



MED1



MED2

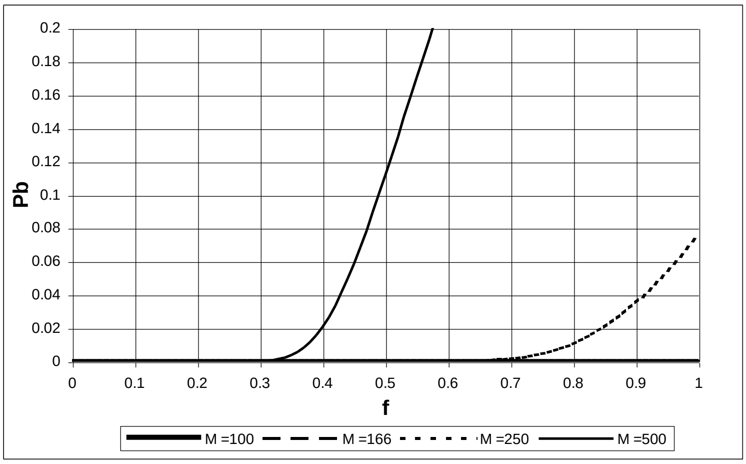
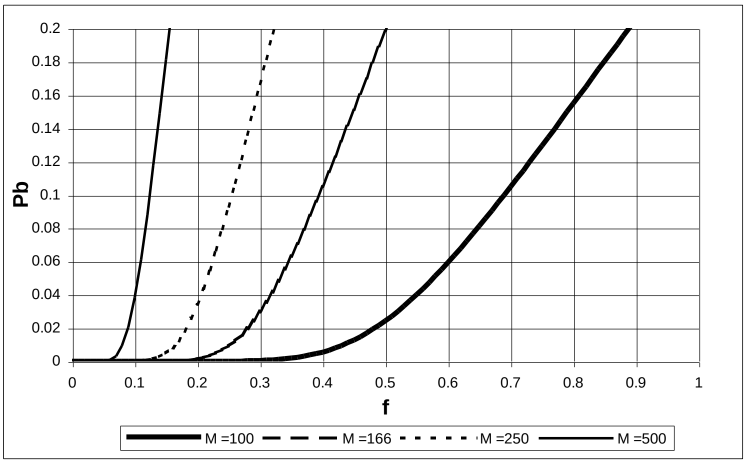


Figure 4.8 Service components Blocking Probability in Stadium environment – cont.

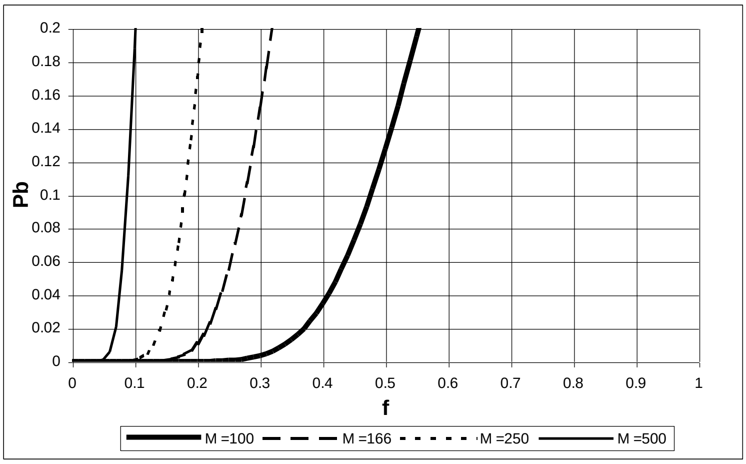
Environment: **STADIUM**

Uplink (216 ch.)

MED3



HDV



HID

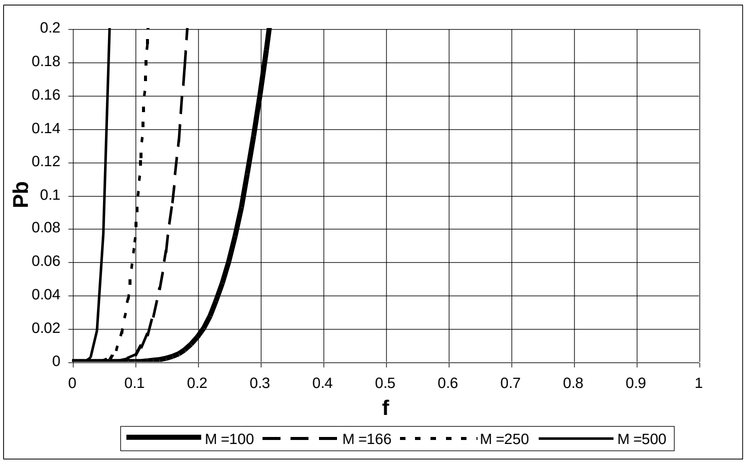
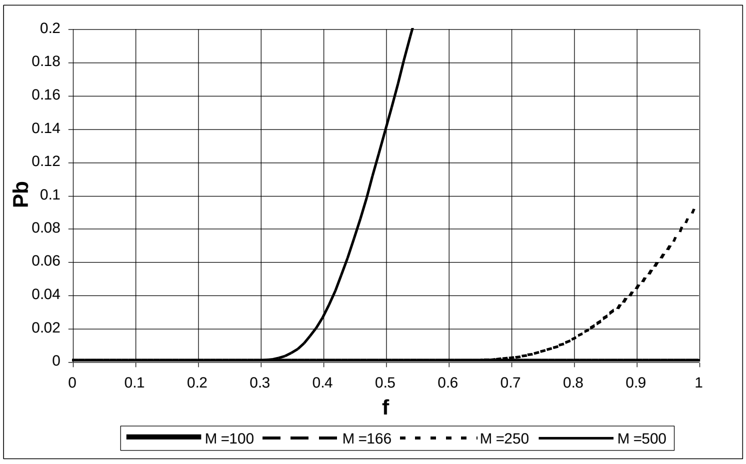


Figure 4.2 Service components Blocking Probability in Stadium environment – cont.

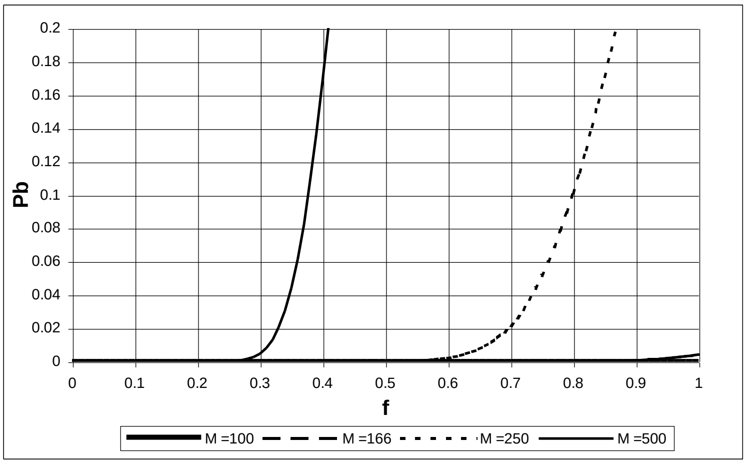
Environment: **STADIUM**

Downlink (216 ch.)

MED3



HDV



HID

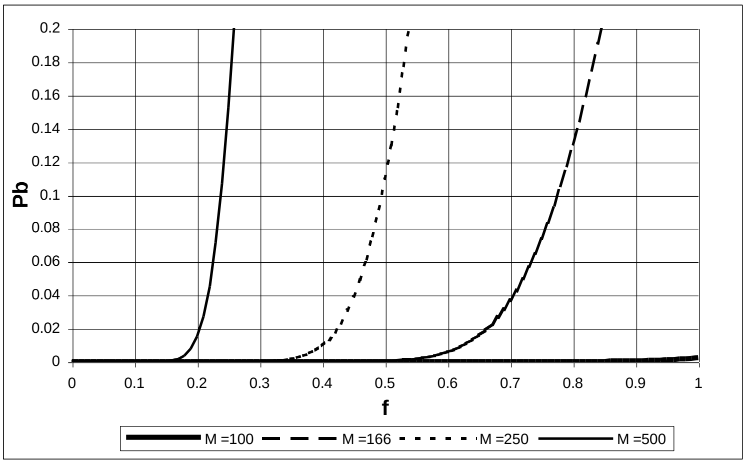


Figure 4.8 Service components Blocking Probability in Stadium environment – cont.

Comparing Figure 4.8 to e.g., Figure 4.2 a completely inverse system user behaviour can be seen. Here although the HDV component limits the uplink, the downlink is limited by MED3 component. For M=250 and P_b=5 % one can support 62 users in the uplink and 220 users in the downlink. Thus, one also should consider the asymmetry factors in order to try to balance the system, however one has not done it here. Besides the specified scenarios also the others can be foreseen like Railway Station or Exhibition Hall as well as the ones that will arise in the future. The main conclusion of this chapter is that thanks to its flexibility the TDD mode should be chosen for future systems access mode, because of its adaptation skills to each subscriber environment, thus achieving a more efficient utilisation of the bandwidth. An interested reader can find more simulations for a different number of available channels in system in Appendix A, where the usual effect of Blocking Probability increase when decreasing the number of channels can be observed. Thus, one can conclude, that a higher number of operators licensed to use MBS bandwidth decreases system capacity and limits the list of available applications which leads to loose the main assumptions of MBS done in chapter 2.

Summary

Now a value of 250 system users in a cell is considered for a final conclusions. A 5% blocking probability threshold is assumed in order to present a summary of users served by system components HDV and HID in the BCC, URB, and ROA scenarios, and by HDV and MED3 in the Stadium environment. Results are presented in Table 4.39.

Table 4.39 Summary of the results.

Environment		Number of supported active users			
		HDV		HID	
		FDD	TDD	FDD	TDD
BCC	Uplink	98	59	59	25
	Downlink	28	40	13	23
URB	Uplink	110	68	66	30
	Downlink	33	44	16	26
ROA	Uplink	98	56	60	28
	Downlink	29	39	14	21
		HDV		MED3	
		FDD	TDD	FDD	TDD
Stadium	Uplink	62	-	55	-
	Downlink	250	-	230	-

The fields marked in the Table 4.39 present the values that limit system capacity. As it was said, in the first three scenarios service component HID is never in use for the uplink, thus HDV is considered as the one that limits uplink capacity. This lead for the BCC environment to 59 and 23 supported users for uplink and downlink, respectively. That implies that even in TDD mode system did not become balanced in terms of supported active users for uplink and downlink. Highest number of supported users achieved in URB arises from lowest sum of $c_{1\_uplink}+c_{1\_downlink}$ in this environment (from Table 4.9).

4.3 Impact of Mobility

In BCC, URB and ROA environments the characteristics of terminal mobility for the considered applications can be as follows: Static, Pedestrian, Urban, Main roads, Highways, being characterised by the values for terminal velocity in Table 3.2. Some mobility characteristics included in [VeCo00] are presented in Table 4.39.

Table 4.40 Application mobility in BCC, URB and ROA environment proposal (extracted from [VeCo00]).

Application		Type of mobility		
		BCC	URB	ROA
1	HVT	pedestrian	urban	highway
2	IVC	pedestrian	static	main roads
3	MVS	pedestrian	urban	
4	HOB	static	static	
5	WLI	static	static	
6	FTP	static	urban	
7	PIM	static	static	
8	DMM	static	static	
9	MES	static	urban	
10	MRA	static	static	
11	MTW	static	static	
12	FFM	static	urban	highway
13	EMB	static	static	main roads
14	ECO	static	urban	
15	MML	static	static	
16	TIN	pedestrian	urban	highway
17	RPC	static	static	main roads
18	UGD	pedestrian	urban	
19	ATR	static	urban	
20	TVD	static	static	
21	ENP	static	static	

Using (3.52) one could obtain the probability of handover failure of each service component $(P_{hf})_j$ for a given call drop probability threshold $(P_d)_{\max}$. Due to the big volume of this work, detailed analysis of handover failure probability will be realised in future works.

5 *Conclusions*

This chapter is dedicated to extract the main conclusions after some theoretical analysis and simulations done in chapters 2 to 4. In the beginning it should be stressed, that in this work a far future telecommunications system is considered, hence due to lack of data for future customer needs only an approach based on some hypothetical scenarios could be done. Furthermore the standardisation process of fourth generation Mobile Broadband Systems is just in the very begin phase and third generation systems are still on designers desks. Besides Broadband ISDN introduction delay into the market drastically limited knowledge about user behaviour and preferences while using new multimedia services. Nevertheless, some marketing analysis has been done and some future "mobile" applications can be particularised from general ITU-T I.211 recommendation list.

Chapter 2 deals at all with this future multimedia applications and their Quality of Service requirements. The evolution of mobile systems and the user bit rates are presented as well. Today's mobile networks called, 2G and 2G+, support only two service components: low quality voice and low speed data, while future 3G and 4G systems will mainly introduce multimedia components like video. High definition video (HDV), high speed data and high quality voice seem to be essential service components for fourth generation systems.

Increase of mobile network capacity and support of several services simultaneously by the same user are key objectives of 4G. However, because of the high operating frequencies (40 and 60 GHz bands, with coverage distance up to 800m) only city centres, main roads and hotspots will be covered at least in the beginning. In these environments a big amount of high bit rate traffic is expected in high capacity pico and micro cells.

Quality of Service (QoS) parameters have to be taken in to account during the process of network planning and dimensioning in order to satisfy users. Specially the delay time will play an important role for real time applications like videoconferencing or network games. For example a delay of 100 ms is assumed as an upper acceptable limit in chapter 3. In this chapter some basic models for network performance analysis are presented like these dedicated for blocking probability, delay probability or handover failure probability. For handover failure probability computation Jabbari's Model has been delivered and simulated. One can conclude that dedicating channels only for traffic arising from handover is best solution to improve network quality when low duration calls are considered.

For today's circuit switched voice networks which supporting *Blocked Calls Delayed*, Erlang C formula can be used in order to obtain the number of supported users with a given allowable delay. In blocking probability computations one usually is interested in number of supported users. Erlang B is the most popular traffic engineers tool for voice networks traffic dimensioning today, but its usage is limited only for voice networks. The modelling of future Multiservice networks is delivered in chapter 3.

Markov Modulated Poisson Processes (MMPP) are used to compute blocking probability, with different arrival rates for different service components. Because the number of channels available in MBS cells seems to be similar to the expected number of users in a cell, we cannot assume that new call arrival is independent of the number of calls being in progress. Thus, Bernoulli case of BPP theory has been chosen in order to simulate MMPP process. Furthermore, independence in service components activation during application service time is assumed, allowing the model to capture traffic burstiness which is very important for a correct simulation of future networks, with their data applications (e-mail, WEB browsing) bursty nature.

In chapter 4 some foreseen scenarios are simulated using BPP theory. More than 20 applications getting access to 6 service components with data rates from 384 kbit/s up to 31872 kbit/s were considered. The set of simulations of blocking probability as a function of active users gives an overall view of forecasted future environments. Three of the main environments for future MBS are: Business City Centre, Urban, Main Roads. As it was remarked, in these scenarios service component HID is never in use for the uplink, thus HDV is considered as the one that limits uplink capacity. This leads for example in the BCC environment, to 59 and 23 supported users for uplink and downlink, respectively. That implies that even in TDD mode the system did not become balanced in terms of supported active users for uplink and downlink. The highest number of supported users achieved in URB arises from lowest sum of $c_{1\_uplink}+c_{1\_downlink}$ in this environment.

Furthermore one also presents an analysis of hotspots, where users behaviour can be extremely different. Such situations have to be also taken into account in system standardisation.

Comparing results and charts from chapter 4 to these presented in Appendix A one can observe an effect of increase of blocking probability while decreasing number of available in cell channels. Decrease of number of available in system channels leads also to some limitations in served applications list e.g., in FDD mode only few scenarios (mainly for 2 operators) are capable to support Fast Ethernet connections.

Future Works

Besides trying to achieve a balanced system by changing the number of channels in uplink and downlink, future work will be mainly focused in market and real statistics (e.g. from B-ISDN or UMTS networks) analysis in order to improve input parameters and obtain real results. Some other environments can be simulated, like exhibition hall or port (fleet management together with subscribers services) to make system capacity dimensioning more effective. Furthermore to control overall network planning process, propagation models (for 40 GHz and 60 GHz) should be attached to this work as well. Influence of the impact of terminal mobility on traffic performance also will take part of future works. Some analysis concerning to delay time in radio interface (Medium Access Control protocol study) should be done also.

Appendix A

In this section some results for different scenarios are presented in order to show effect of changes in blocking probability while changing the number of available in cell channels. TDD and FDD mode are either simulated to take overall system view. Considered scenarios are presented in Table A.1

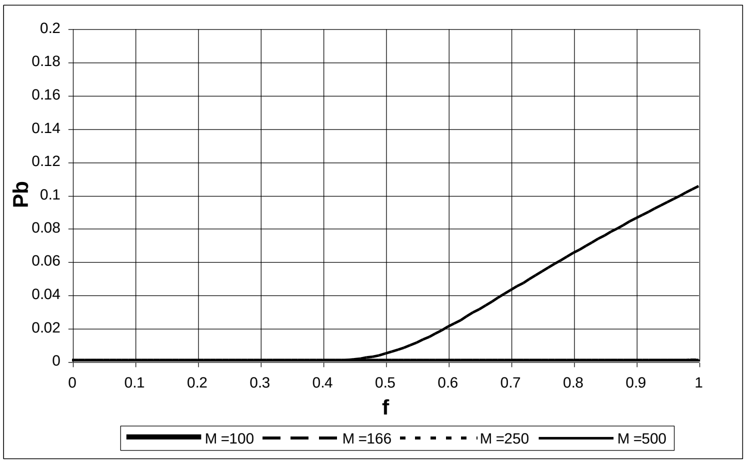
Table A.1 Scenarios considered in Appendix A

Environment	Mode	Number of channels for uplink	Number of channels for downlink
BCC	FDD	432	432
	FDD	108	108
	TDD	216 (76/140)	
URB	FDD	108	108
	TDD	216 (77/139)	
ROA	FDD	432	432
	FDD	108	108
	TDD	216 (85/131)	

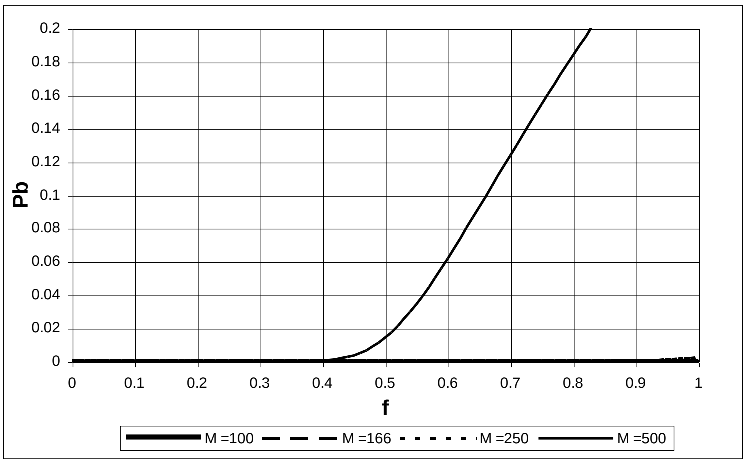
Environment: **BCC**

Uplink (432 ch.)

BAS



MED1



MED2

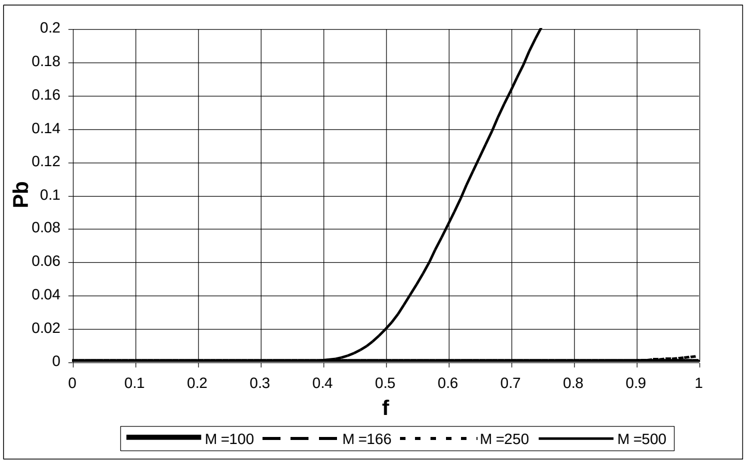
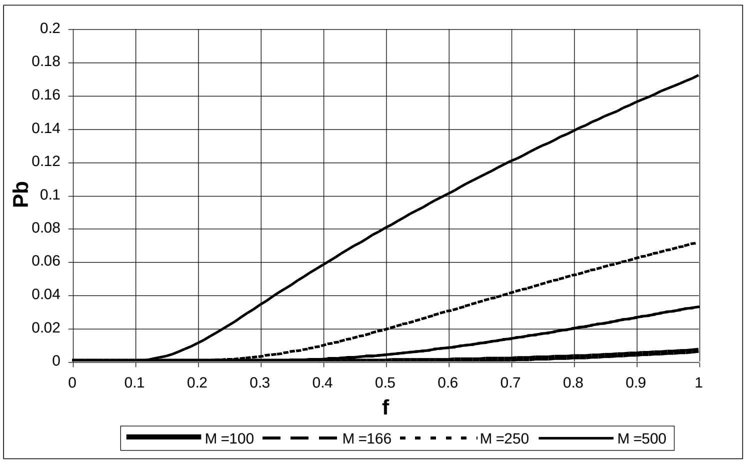


Figure A.1 Service components Blocking Probability in BCC environment

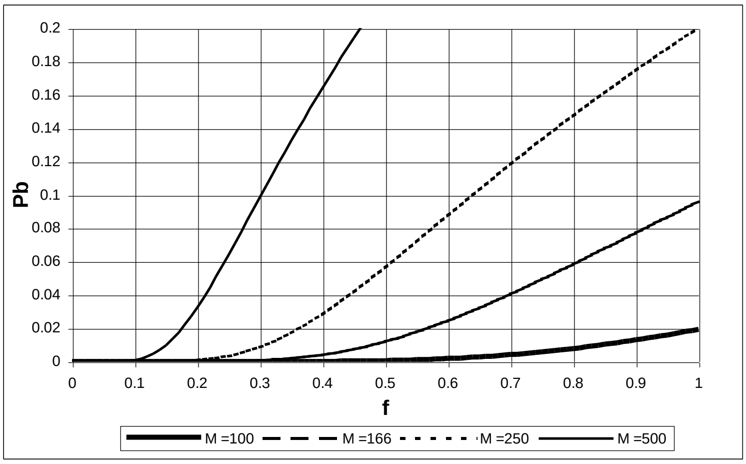
Environment: **BCC**

Downlink (432 ch.)

BAS



MED1



MED2

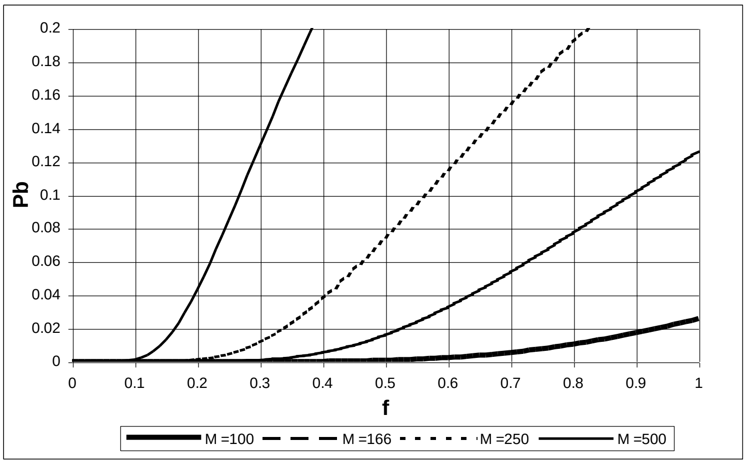
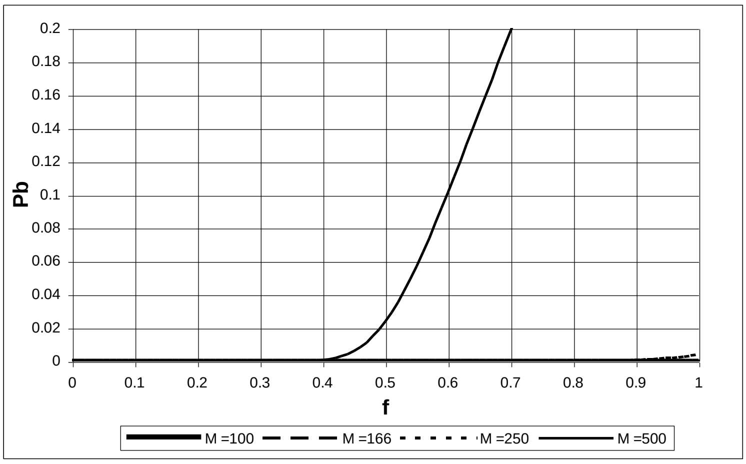


Figure A.1 Service components Blocking Probability in BCC environment – cont.

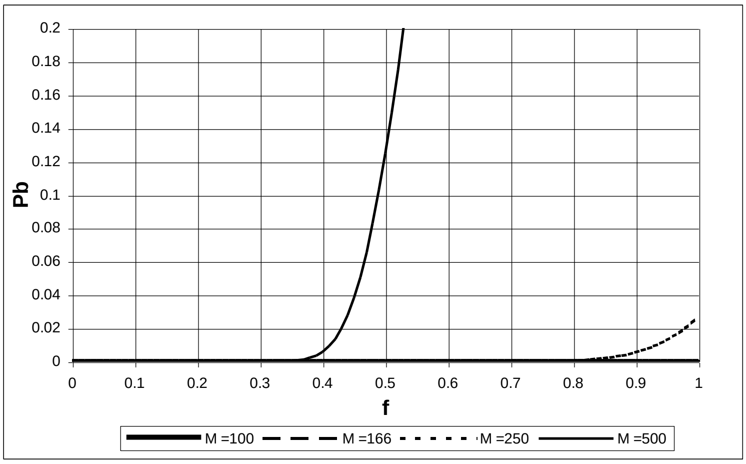
Environment: **BCC**

Uplink (432 ch.)

MED3



HDV



HID

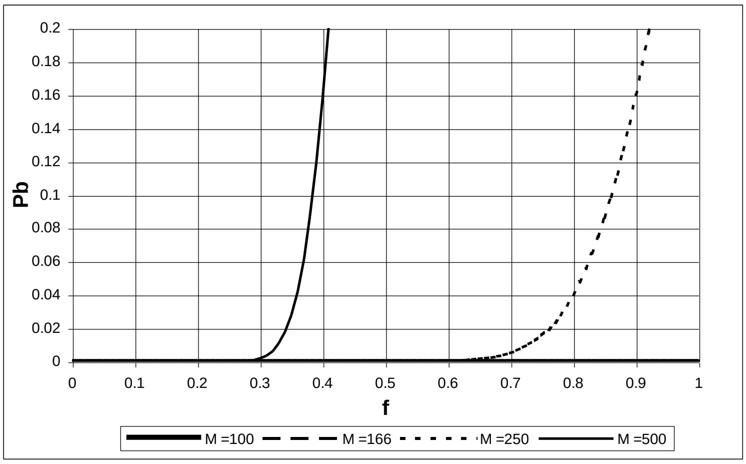
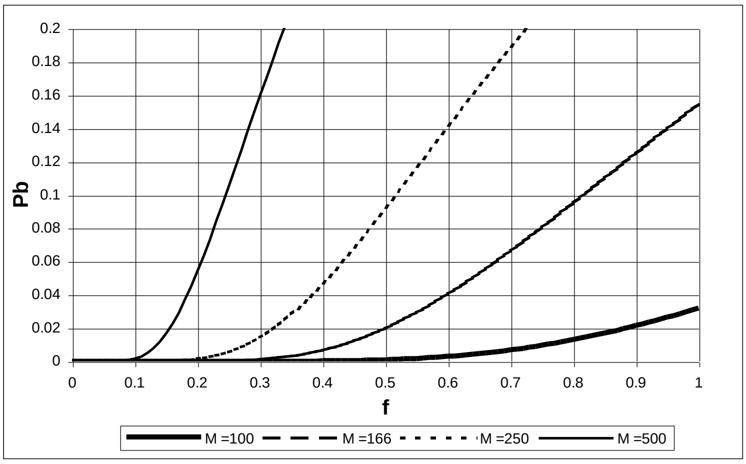


Figure A.1 Service components Blocking Probability in BCC environment – cont.

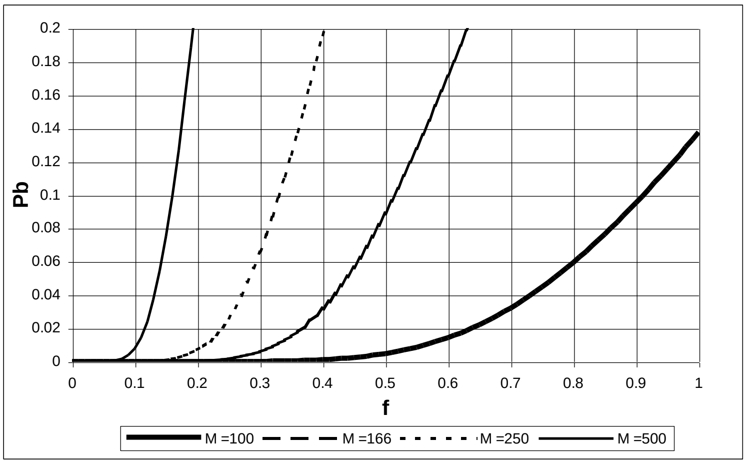
Environment: **BCC**

Downlink (432 ch.)

MED3



HDV



HID

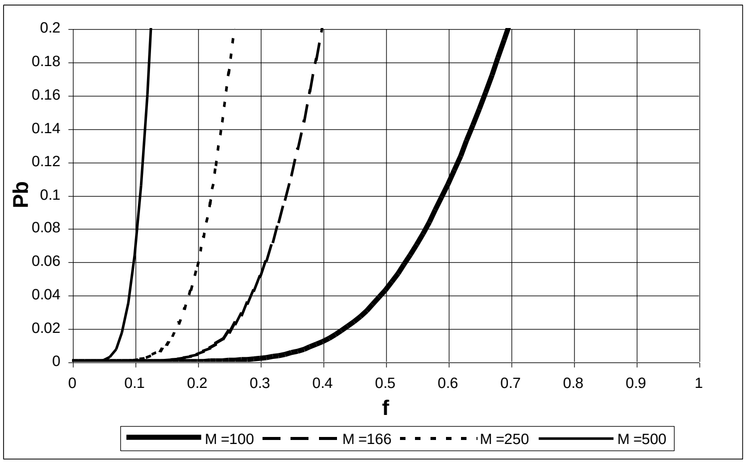
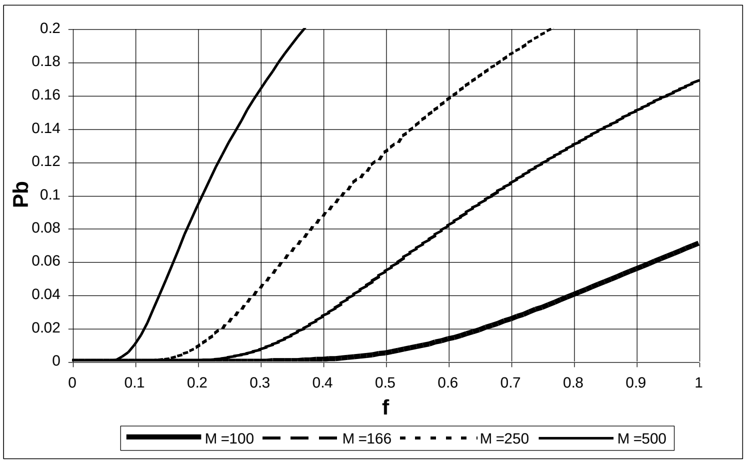


Figure A.1 Service components Blocking Probability in BCC environment – cont.

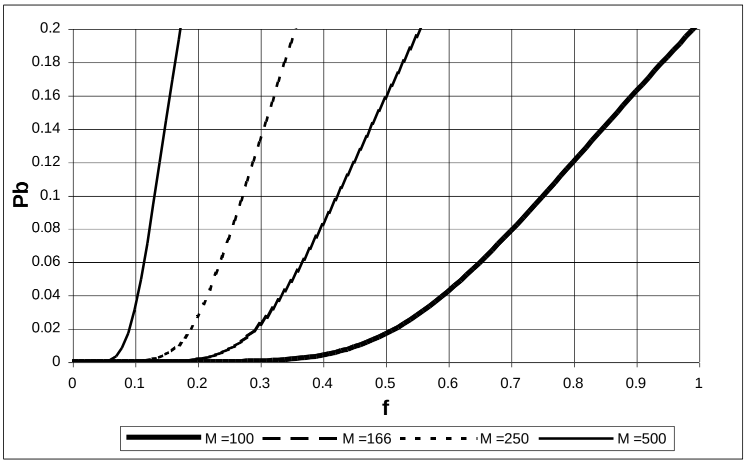
Environment: **BCC**

Uplink (108 ch.)

BAS



MED1



MED2

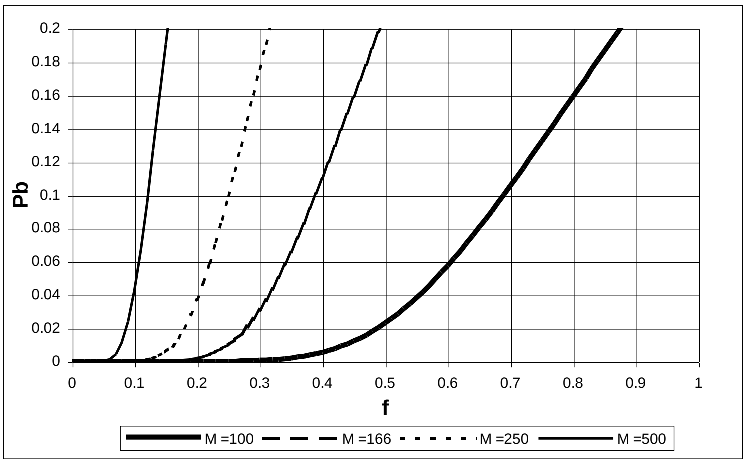
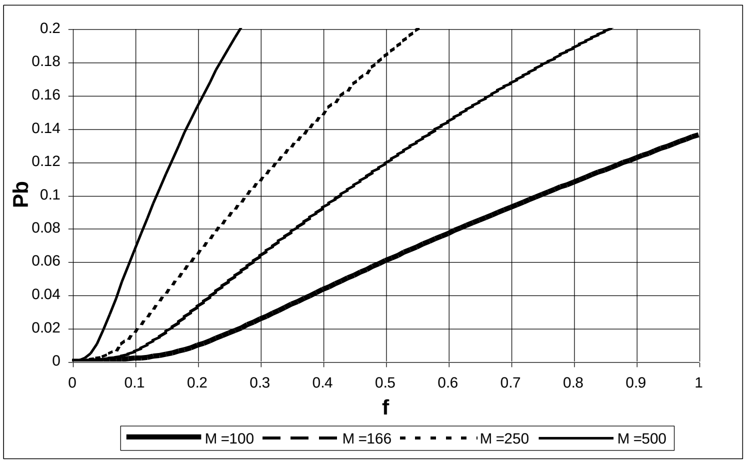


Figure A.1 Service components Blocking Probability in BCC environment – cont.

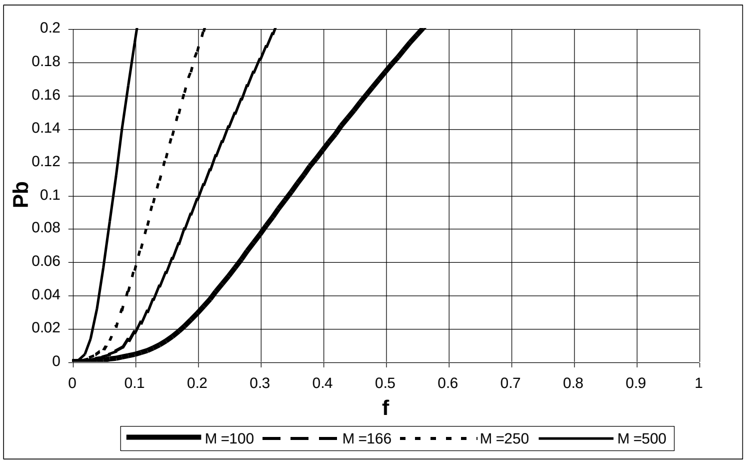
Environment: **BCC**

Downlink (108 ch.)

BAS



MED1



MED2

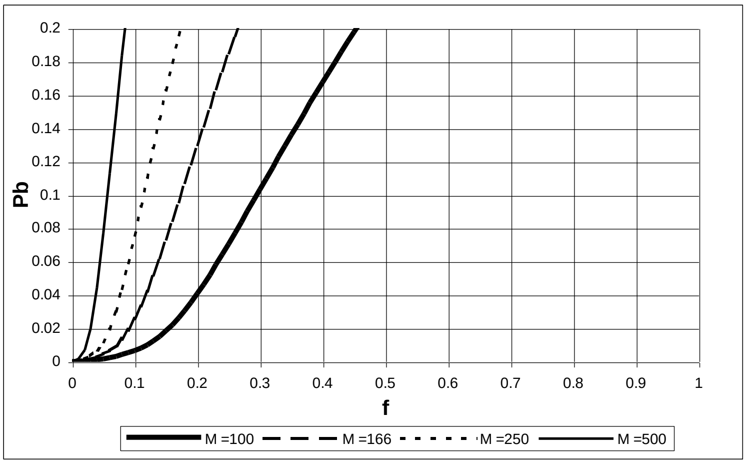
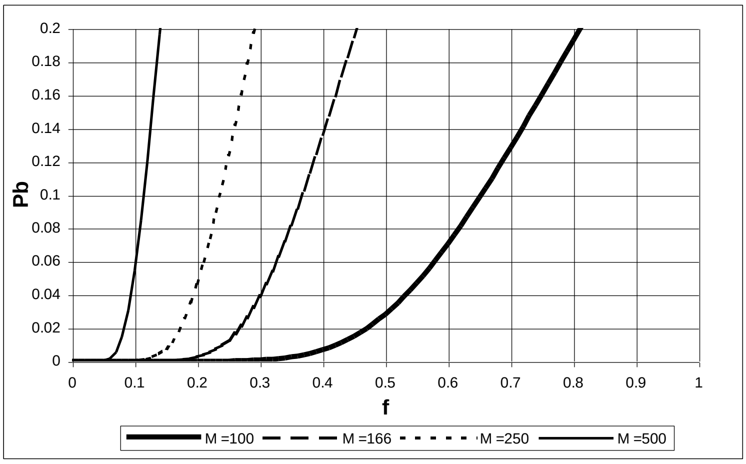


Figure A.1 Service components Blocking Probability in BCC environment – cont.

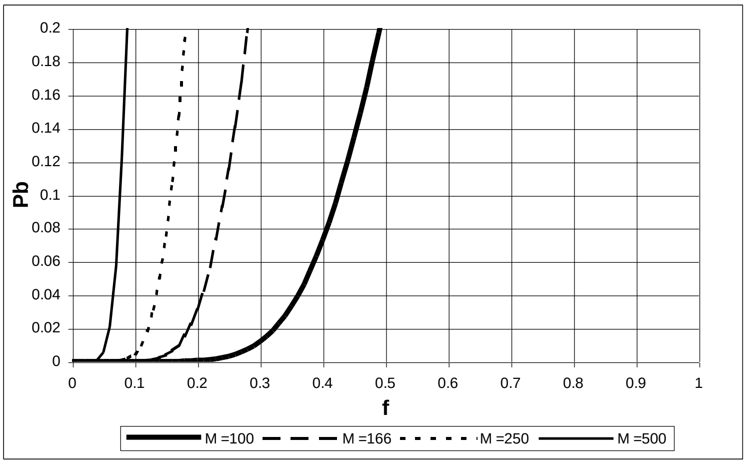
Environment: **BCC**

Uplink (108 ch.)

MED3



HDV



HID

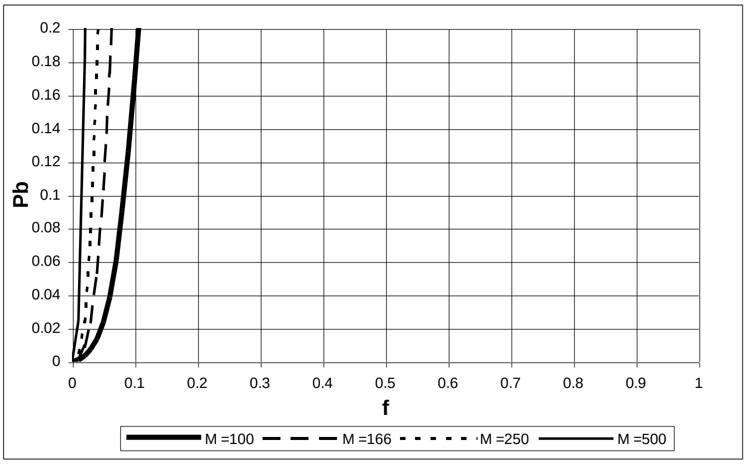
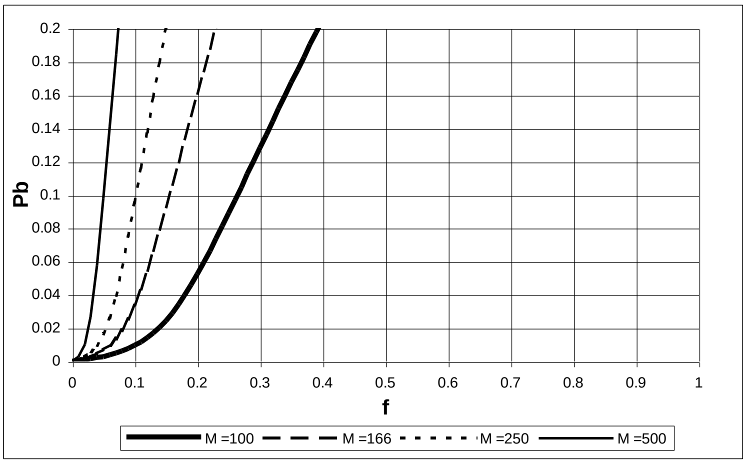


Figure A.1 Service components Blocking Probability in BCC environment – cont.

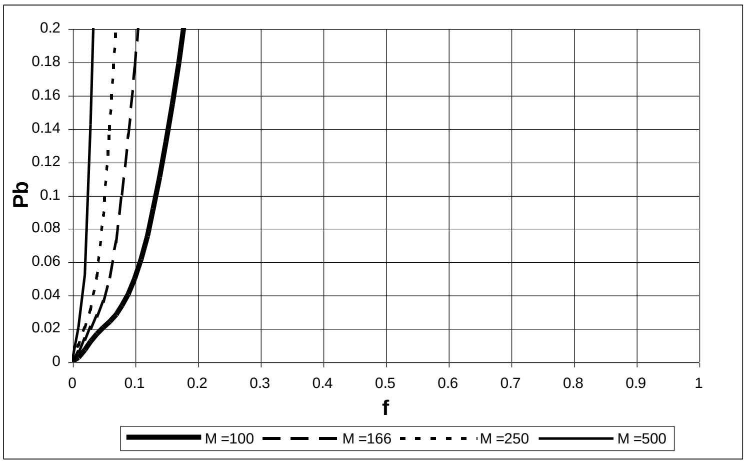
Environment: **BCC**

Downlink (108 ch.)

MED3



HDV



HID

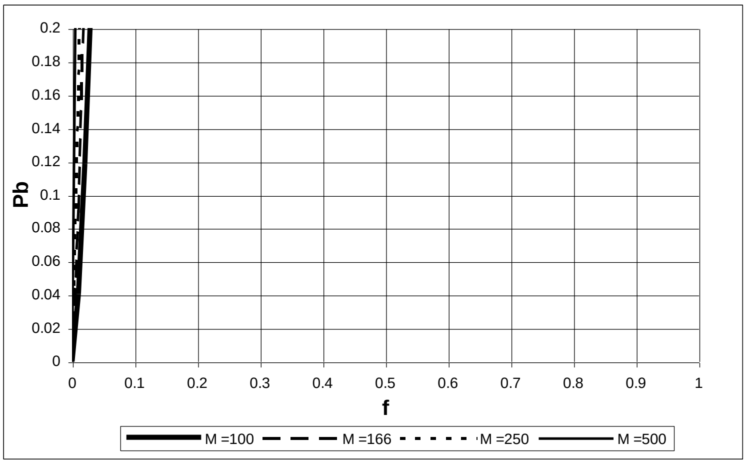
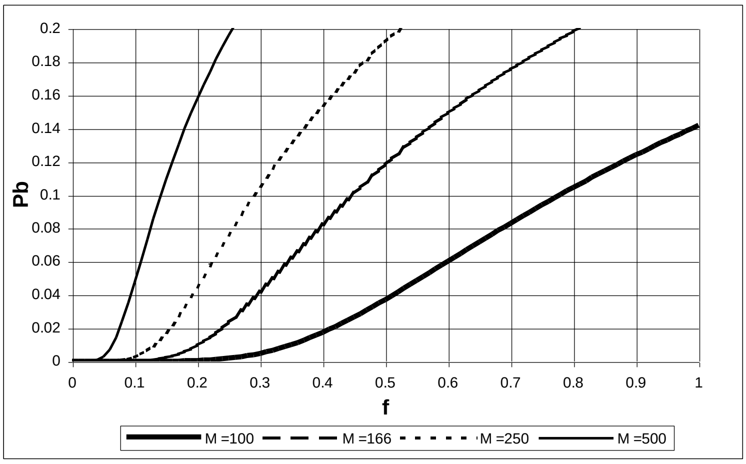


Figure A.1 Service components Blocking Probability in BCC environment – cont.

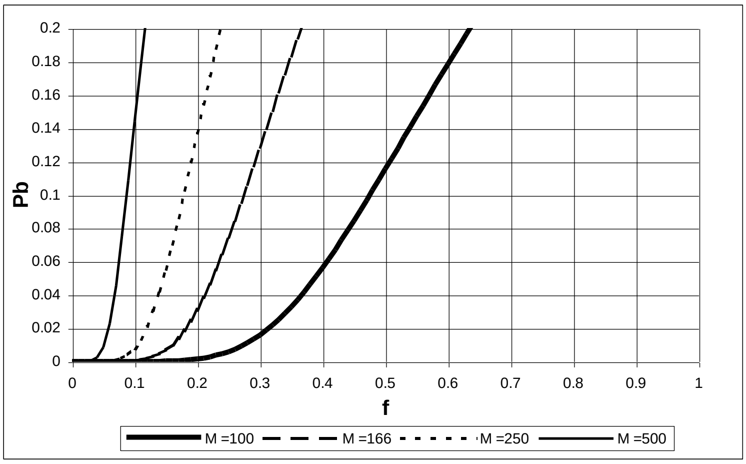
Environment: **BCC**

Uplink (76 ch.)

BAS



MED1



MED2

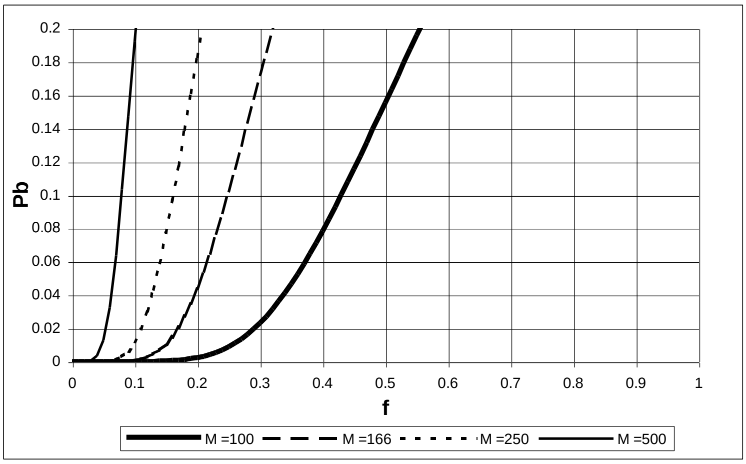
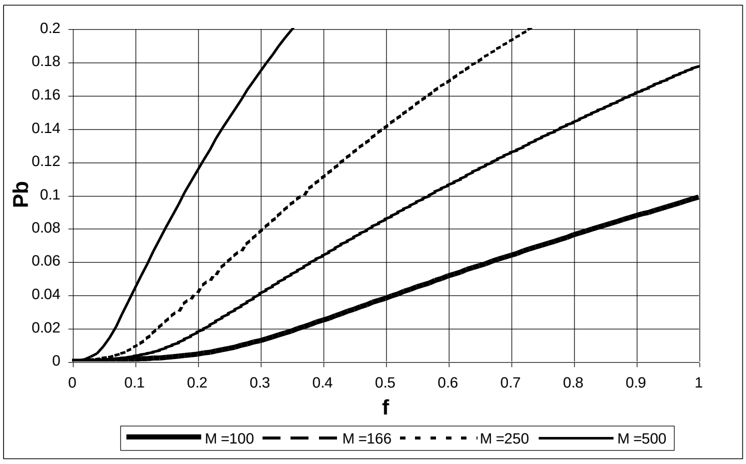


Figure A.1 Service components Blocking Probability in BCC environment – cont.

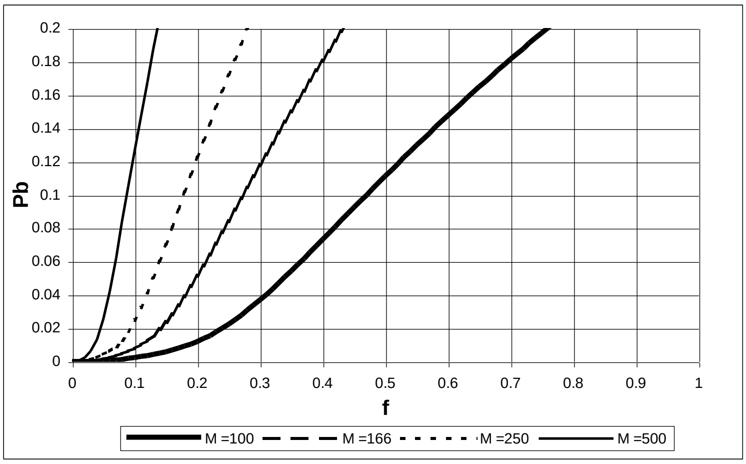
Environment: **BCC**

Downlink (140 ch.)

BAS



MED1



MED2

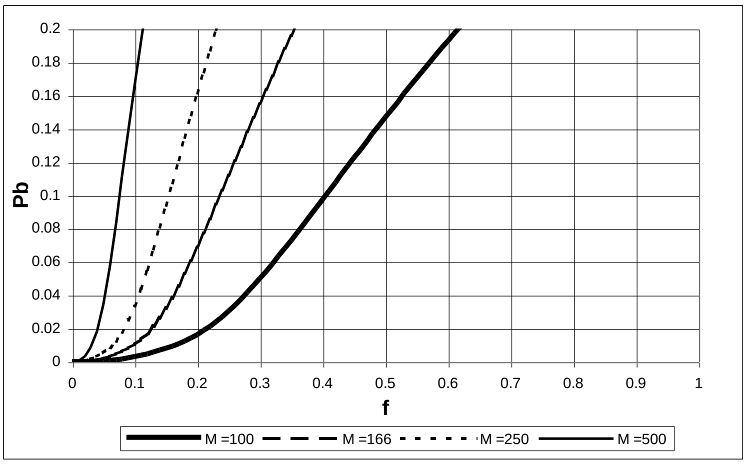
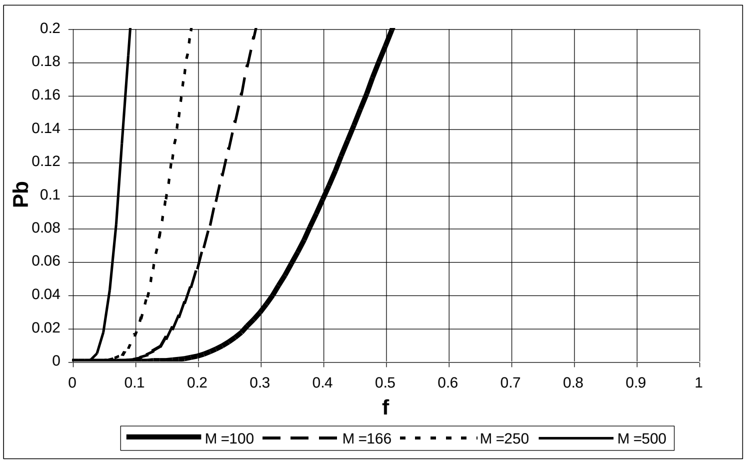


Figure A.1 Service components Blocking Probability in BCC environment – cont.

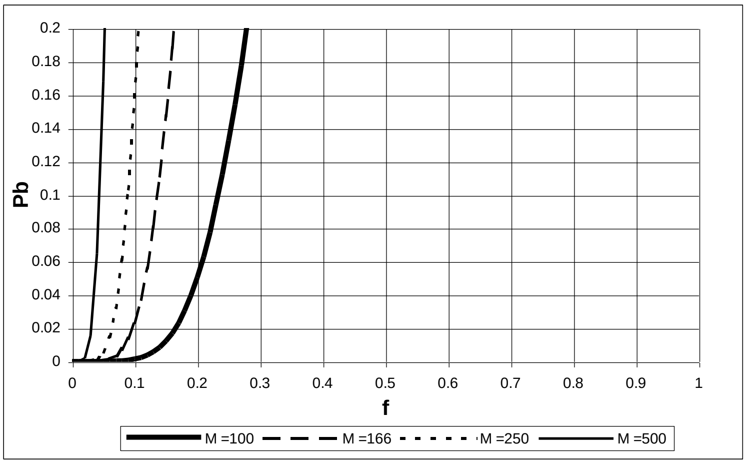
Environment: **BCC**

Uplink (76 ch.)

MED3



HDV



HID

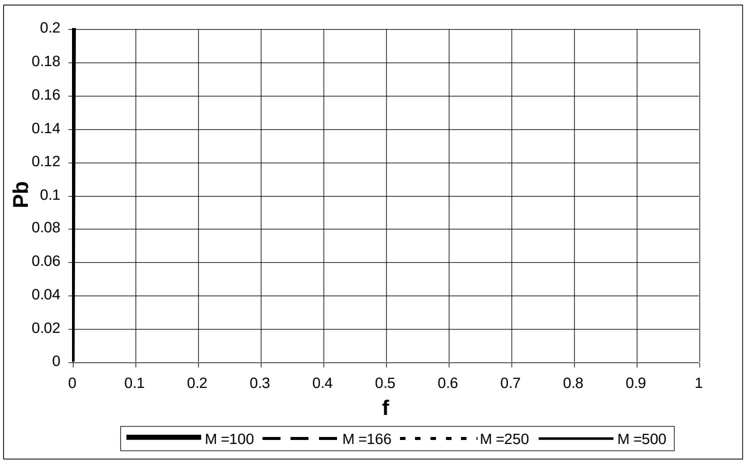
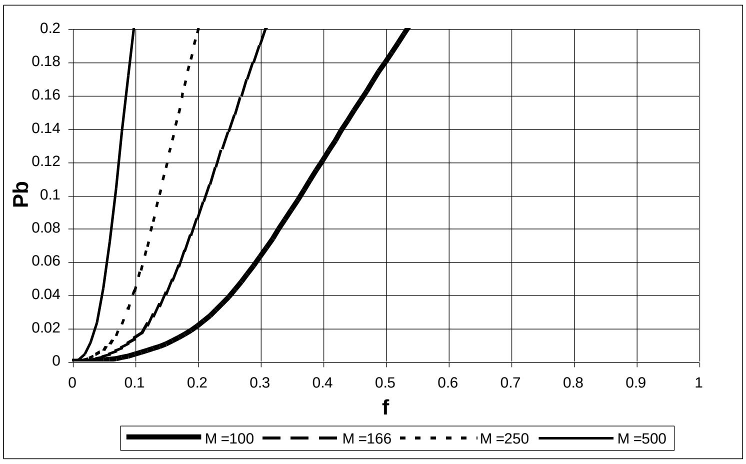


Figure A.1 Service components Blocking Probability in BCC environment – cont.

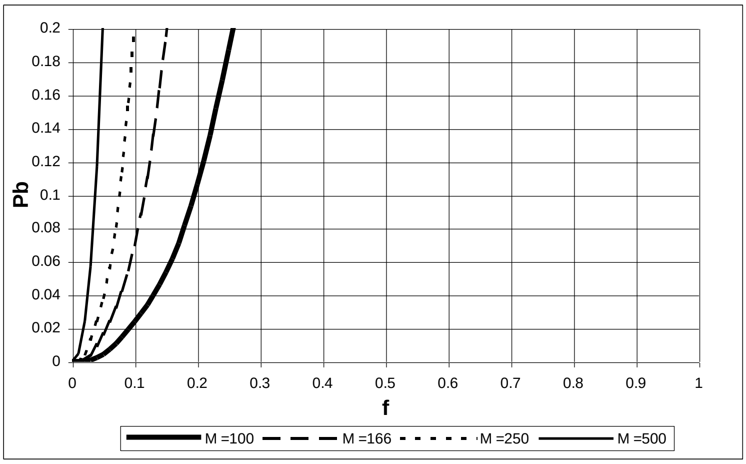
Environment: **BCC**

Downlink (140 ch.)

MED3



HDV



HID

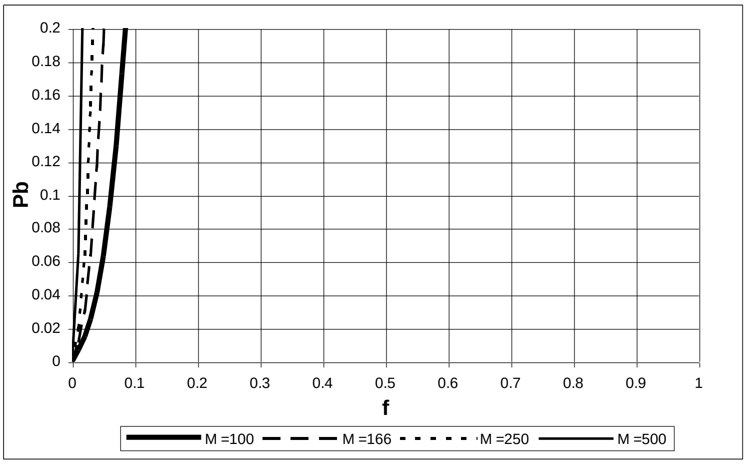
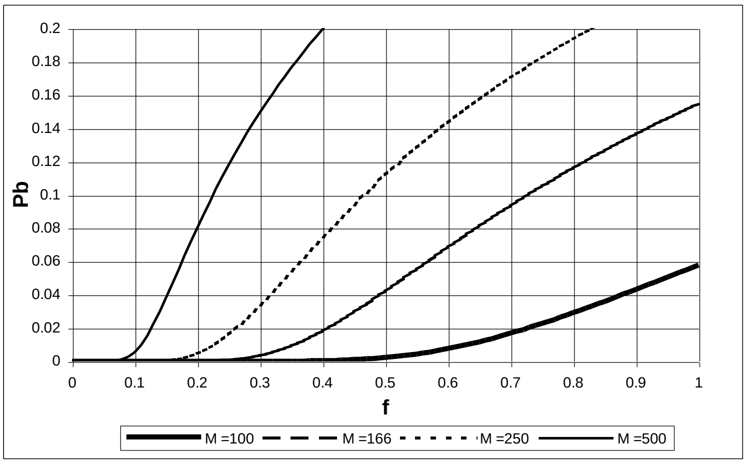


Figure A.1 Service components Blocking Probability in BCC environment – cont.

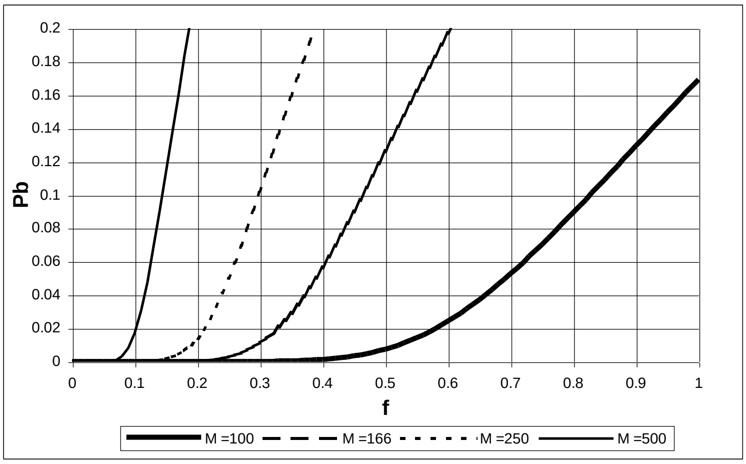
Environment: **URB**

Uplink (108 ch.)

BAS



MED1



MED2

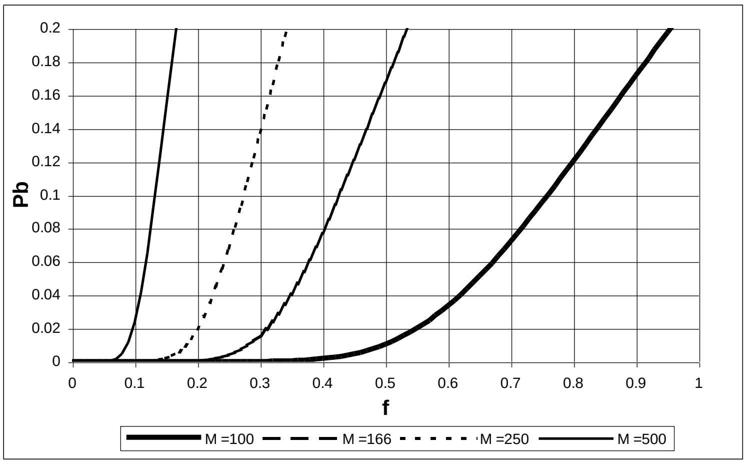
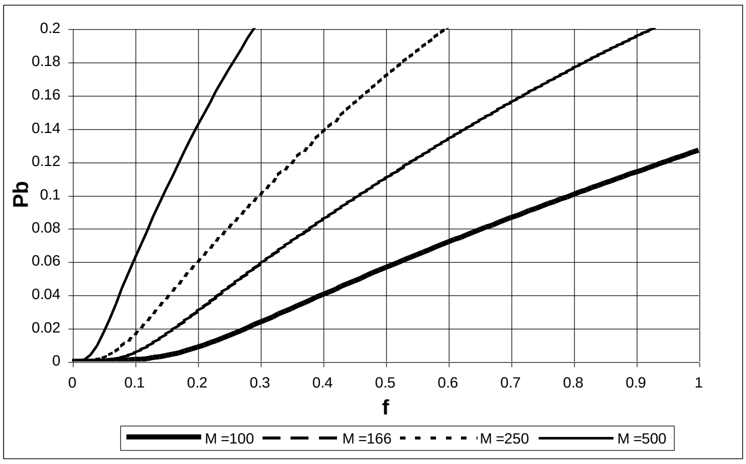


Figure A.2 Service components Blocking Probability in URB environment.

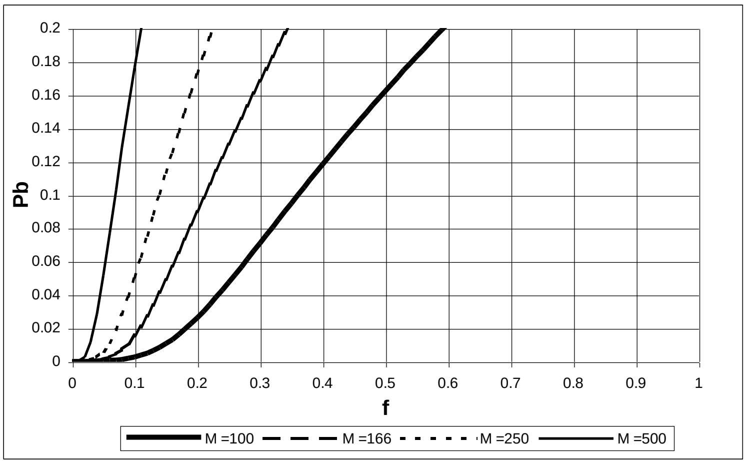
Environment: **URB**

Downlink (108 ch.)

BAS



MED1



MED2

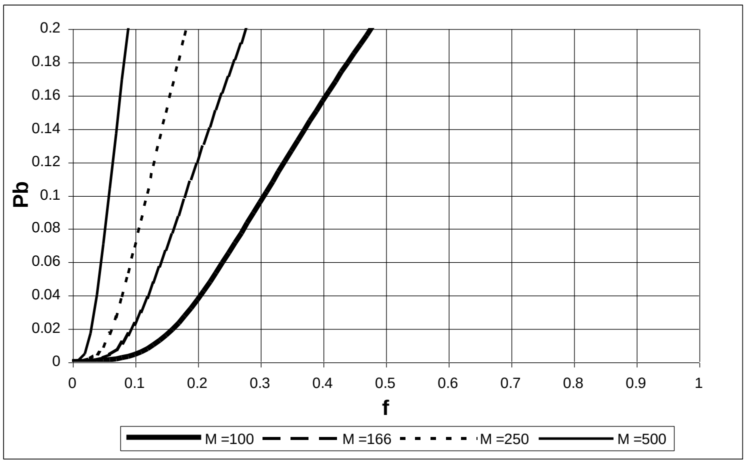
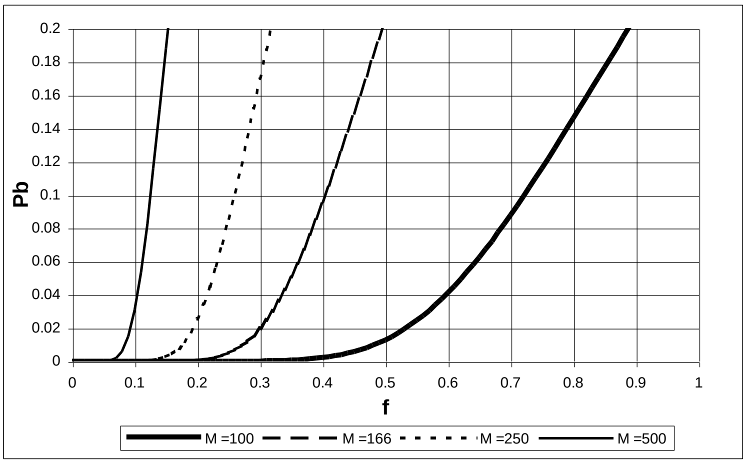


Figure A.2 Service components Blocking Probability in URB environment – cont.

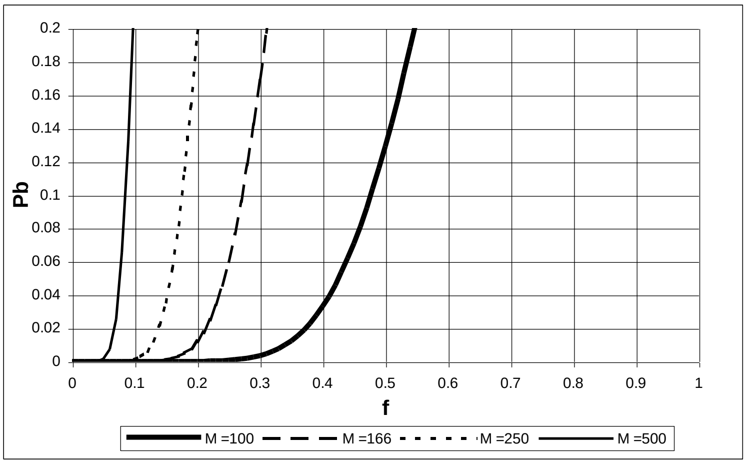
Environment: **URB**

Uplink (108 ch.)

MED3



HDV



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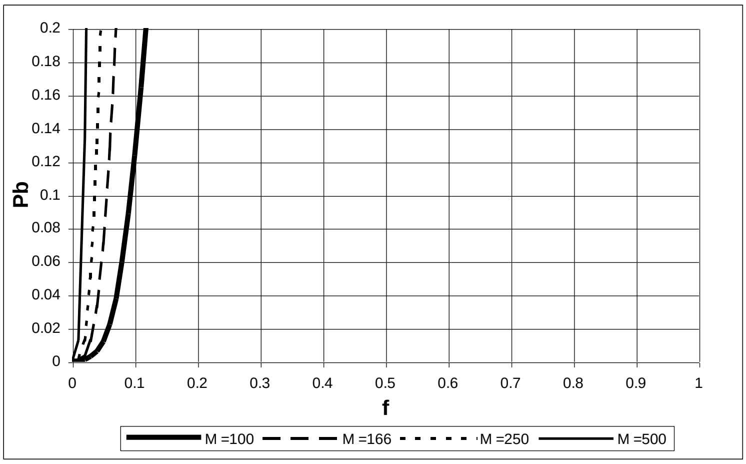
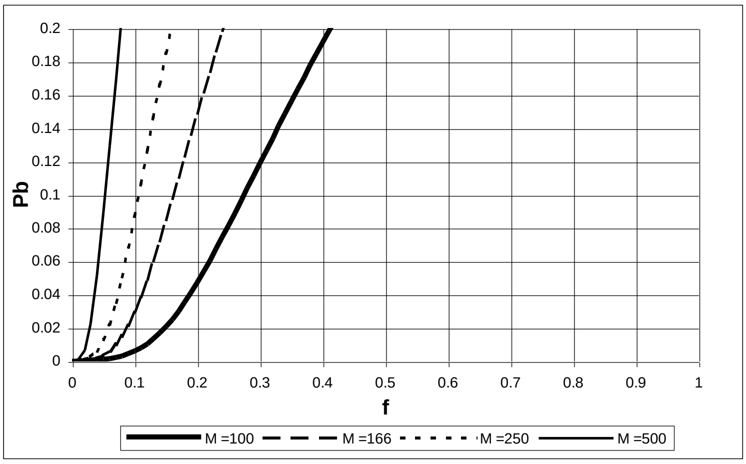


Figure A.2 Service components Blocking Probability in URB environment – cont.

Environment: **URB**

Downlink (108 ch.)

MED3



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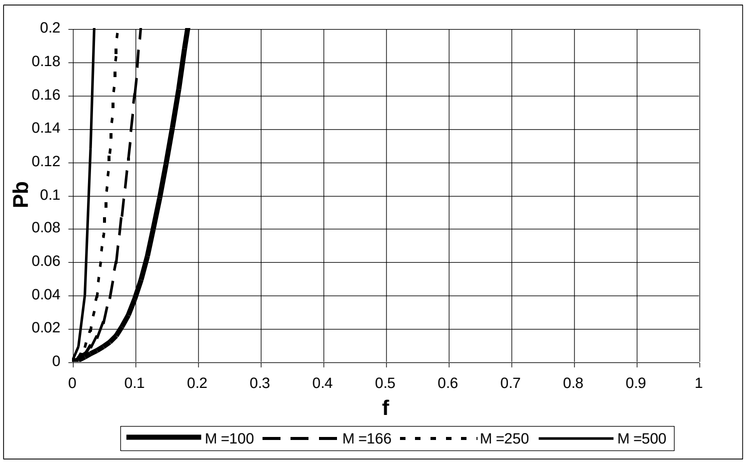

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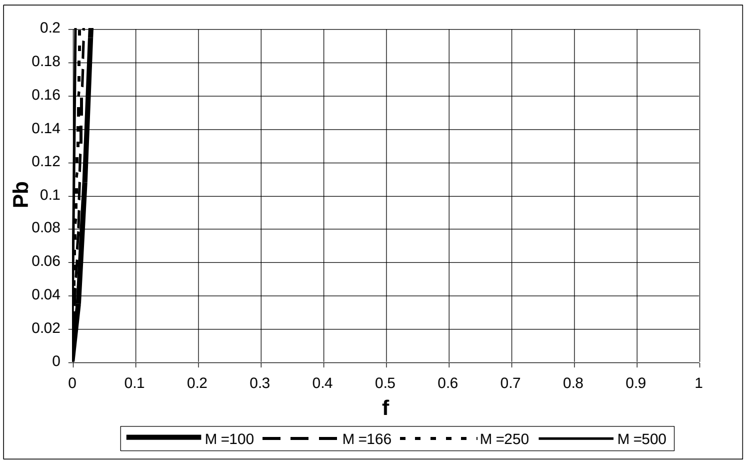
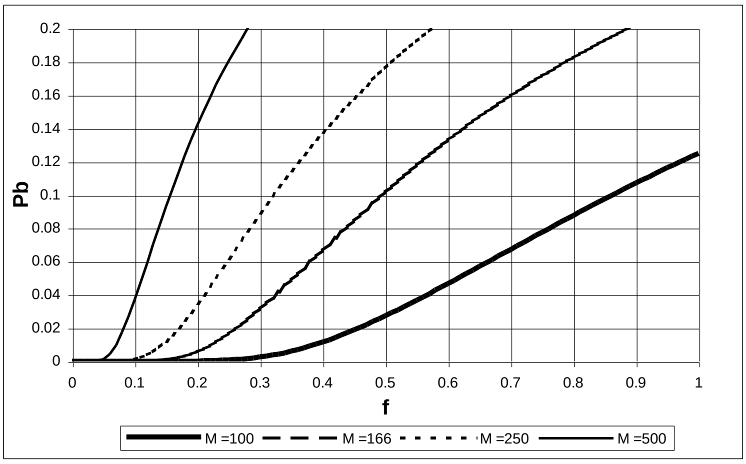


Figure A.2 Service components Blocking Probability in URB environment – cont.

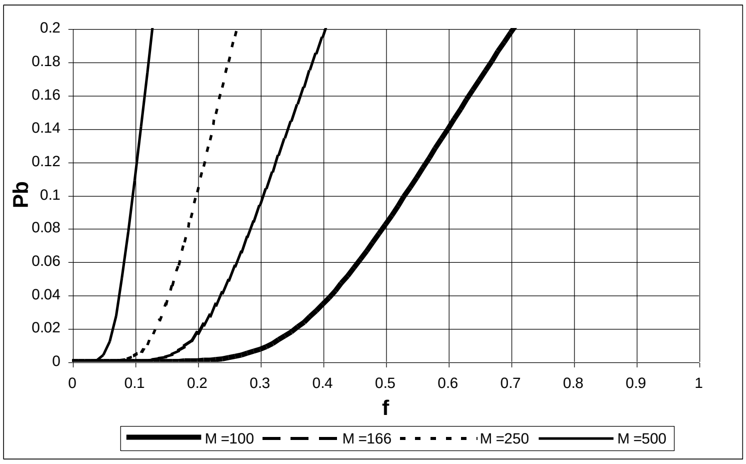
Environment: **URB**

Uplink (77 ch.)

BAS



MED1



MED2

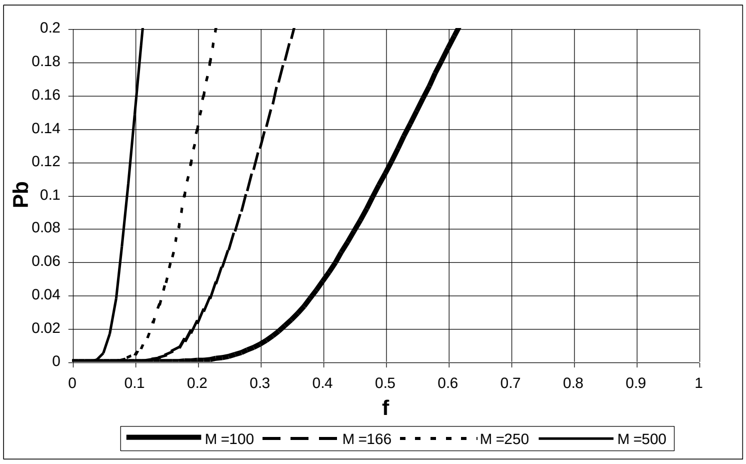
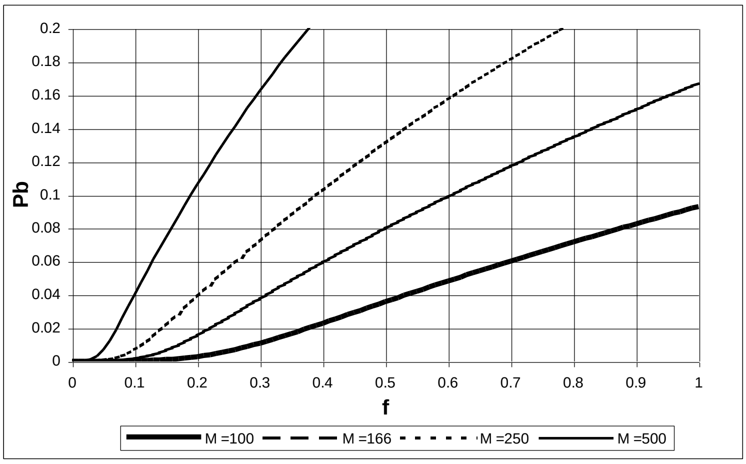


Figure A.2 Service components Blocking Probability in URB environment – cont.

Environment: **URB**

Downlink (139 ch.)

BAS



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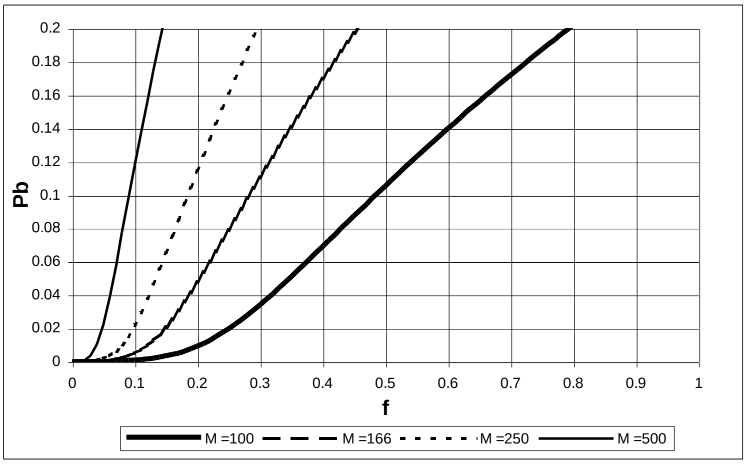


MED2

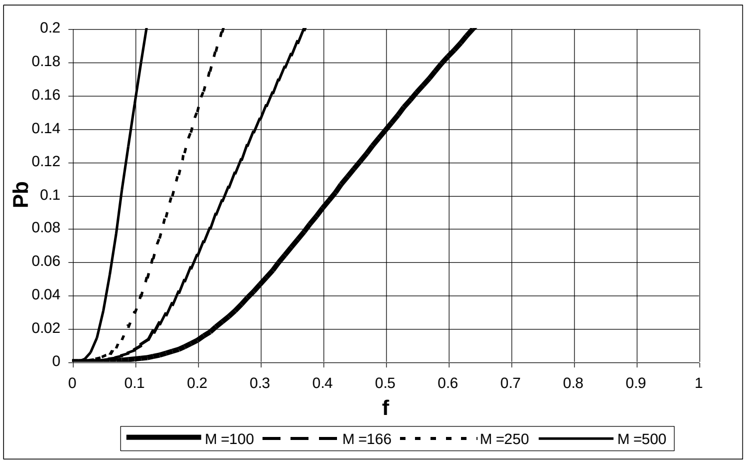
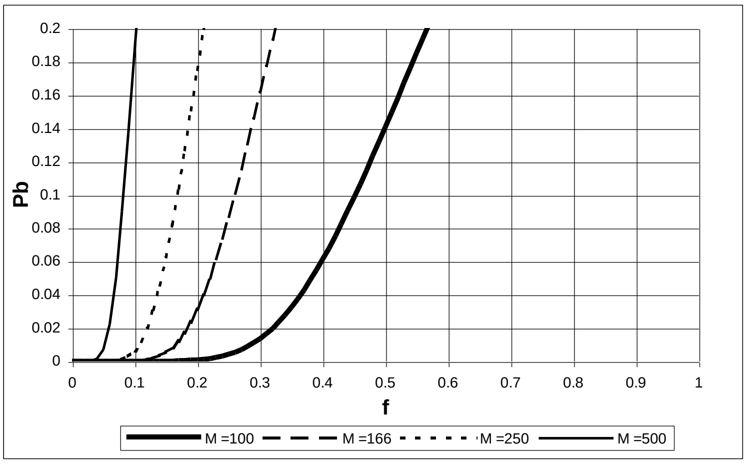


Figure A.2 Service components Blocking Probability in URB environment – cont.

Environment: **URB**

Uplink (77 ch.)

MED3



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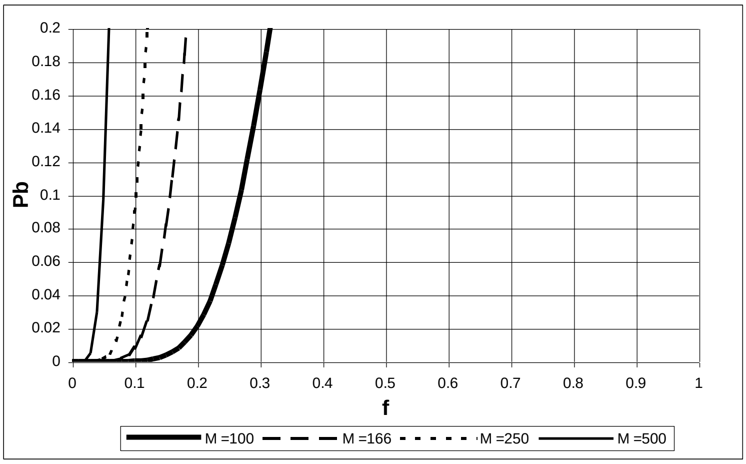

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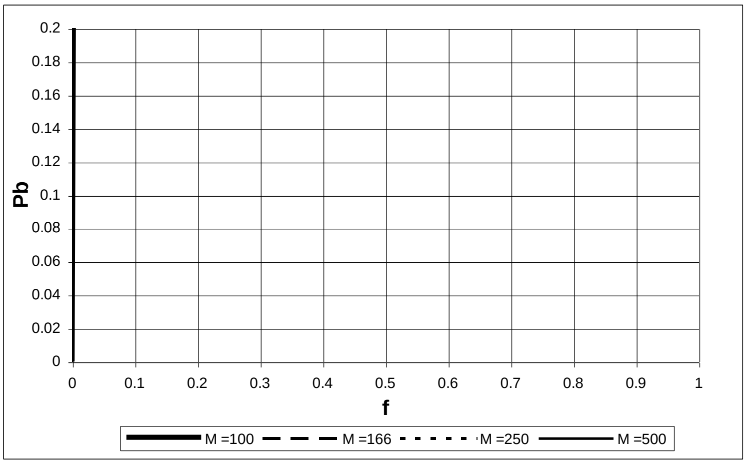
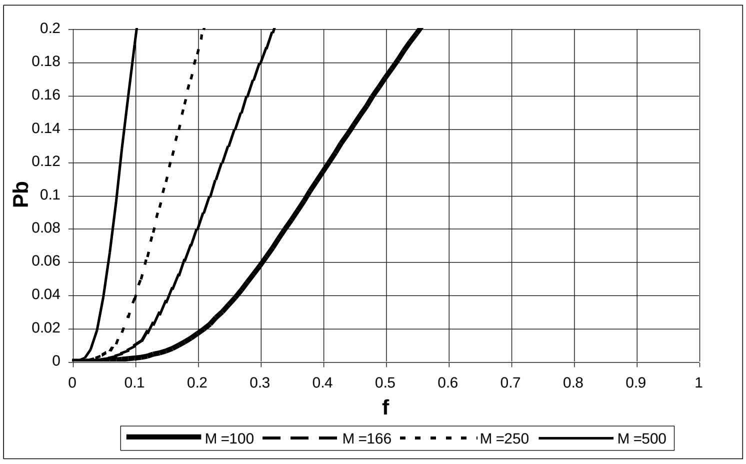


Figure A.2 Service components Blocking Probability in URB environment – cont.

Environment: **URB**

Downlink (139 ch.)

MED3



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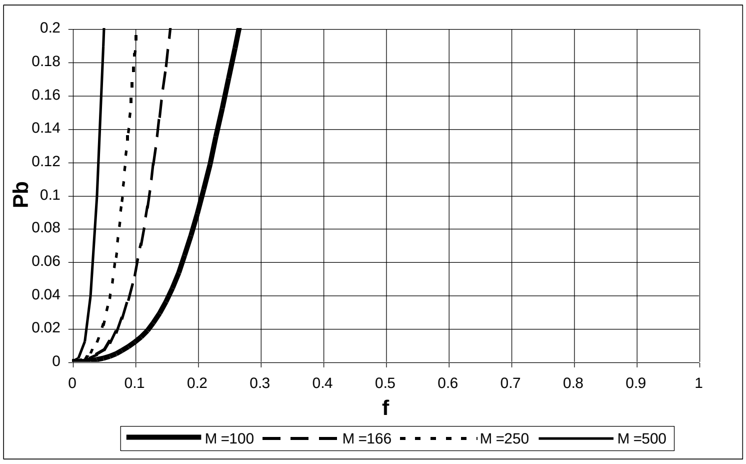

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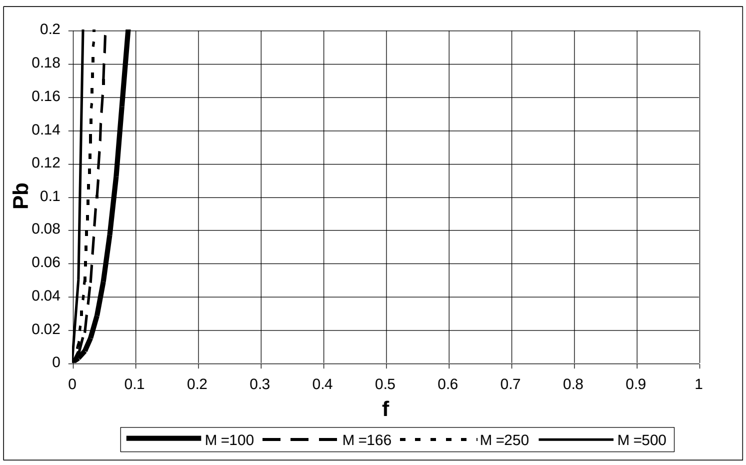
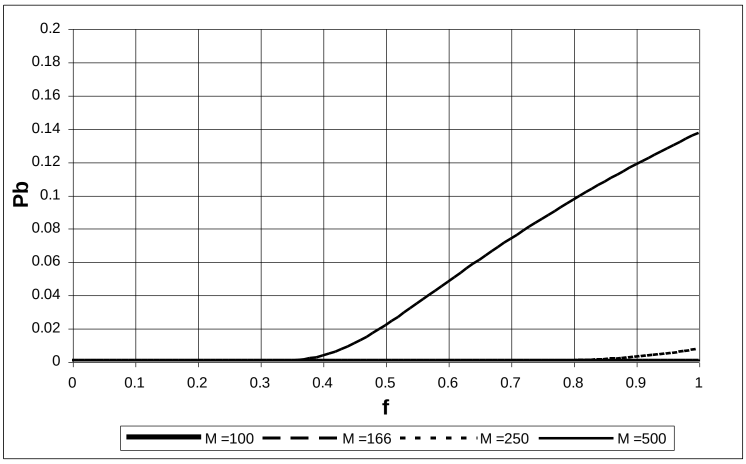


Figure A.2 Service components Blocking Probability in URB environment – cont.

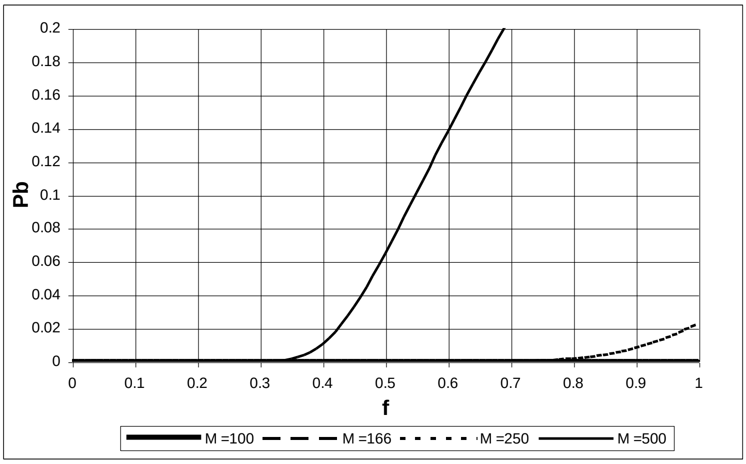
Environment: **ROA**

Uplink (432 ch.)

BAS



MED1



MED2

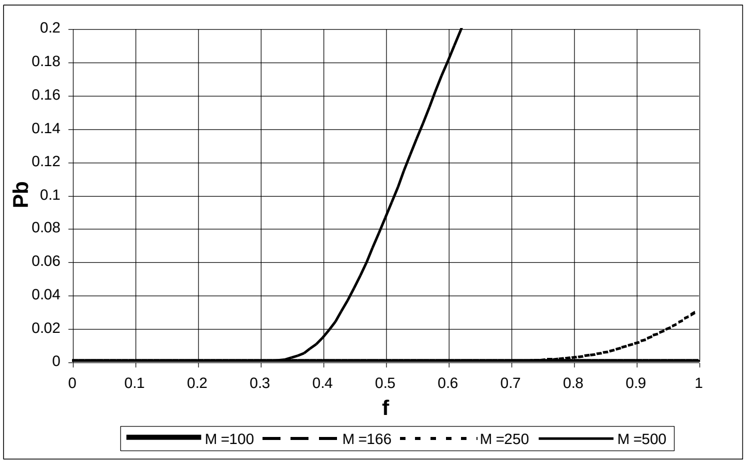
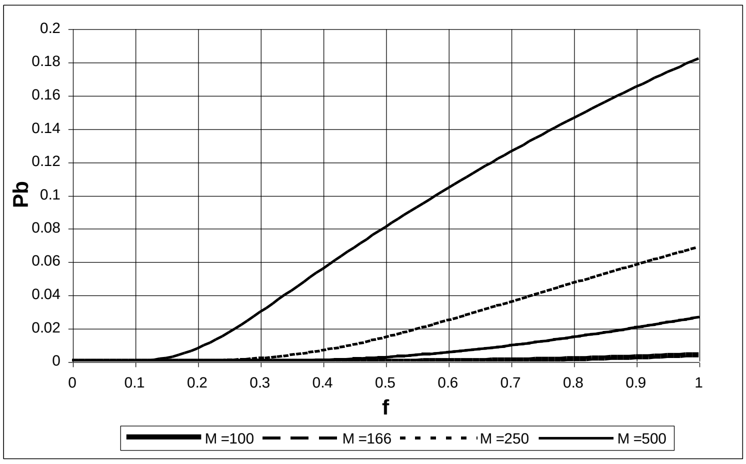


Figure A.3 Service components Blocking Probability in ROA environment.

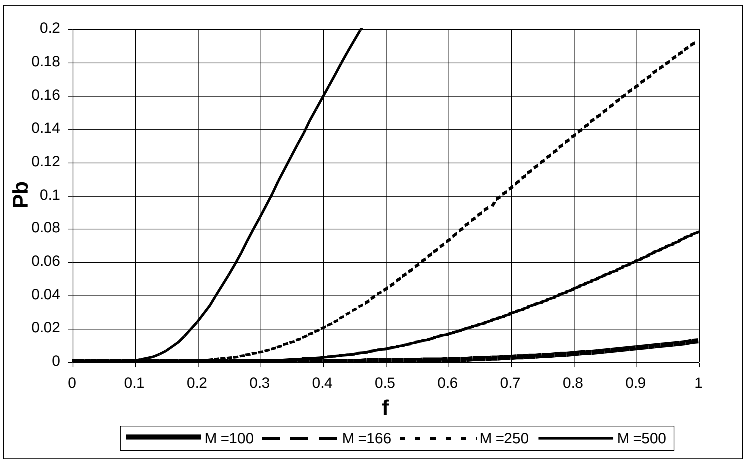
Environment: **ROA**

Downlink (432 ch.)

BAS



MED1



MED2

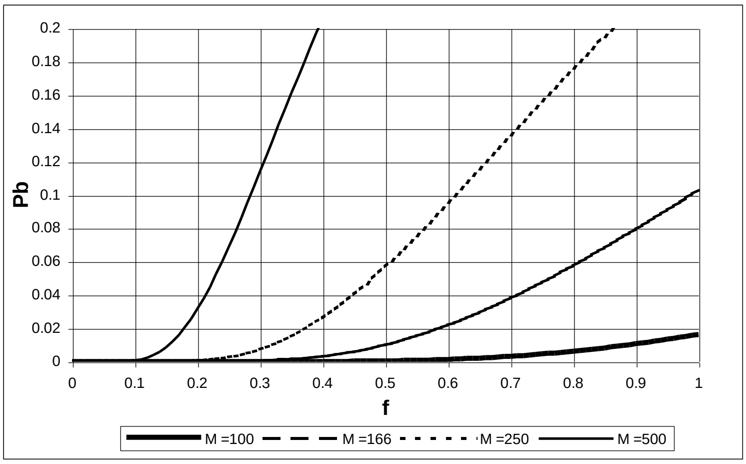
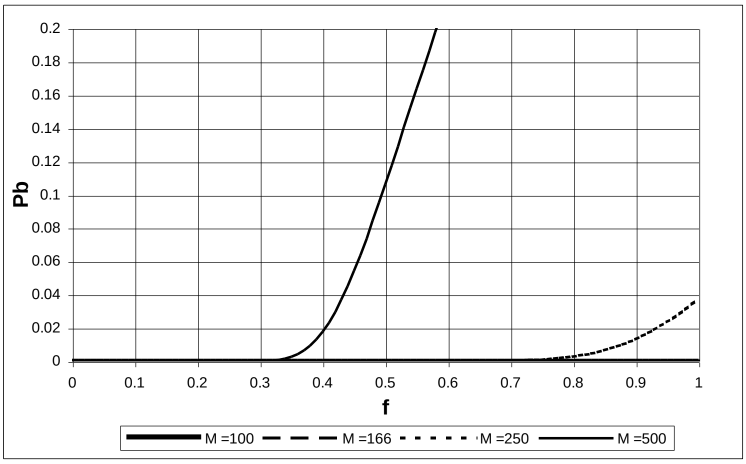


Figure A.3 Service components Blocking Probability in ROA environment – cont.

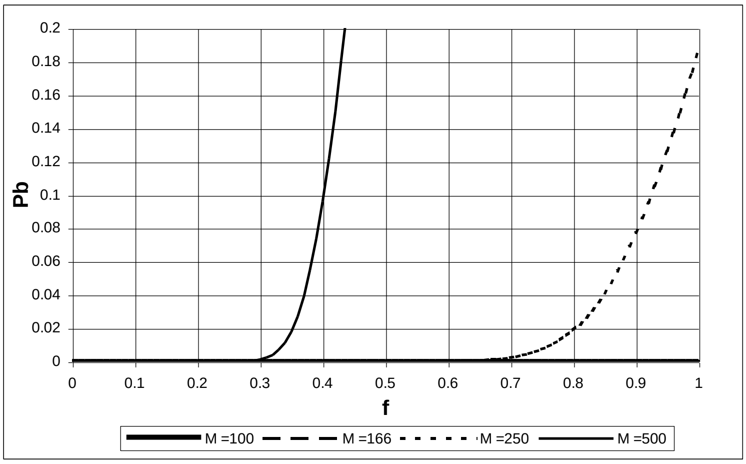
Environment: **ROA**

Uplink (432 ch.)

MED3



HDV



HID

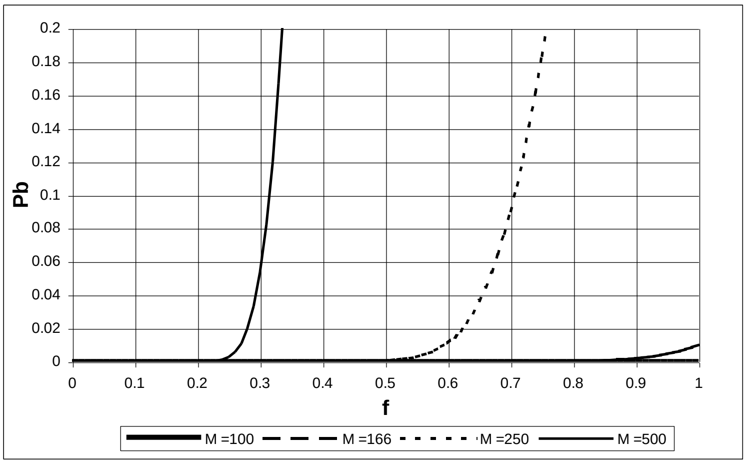
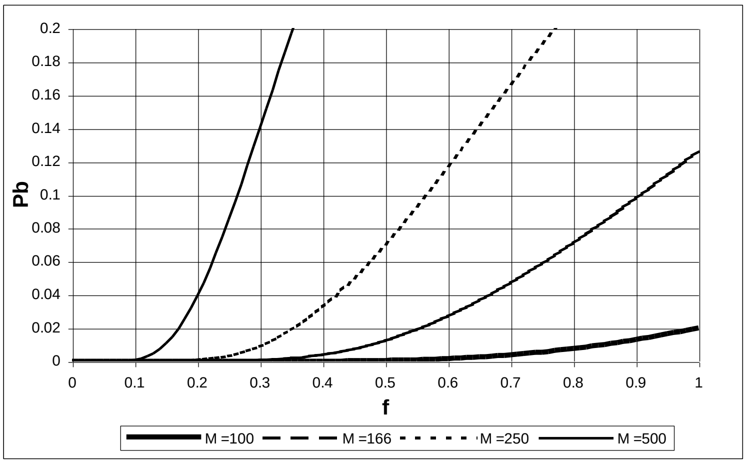


Figure A.3 Service components Blocking Probability in ROA environment – cont.

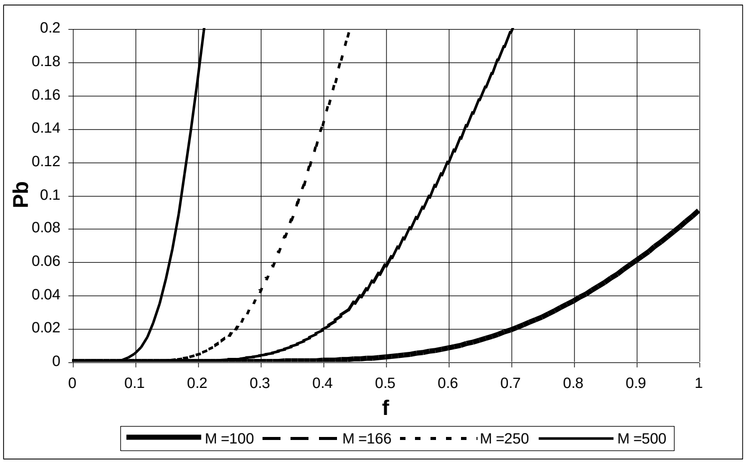
Environment: **ROA**

Downlink (432 ch.)

MED3



HDV



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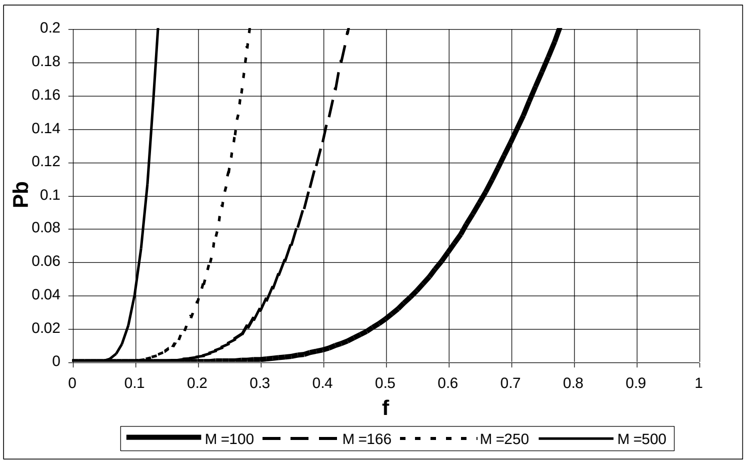
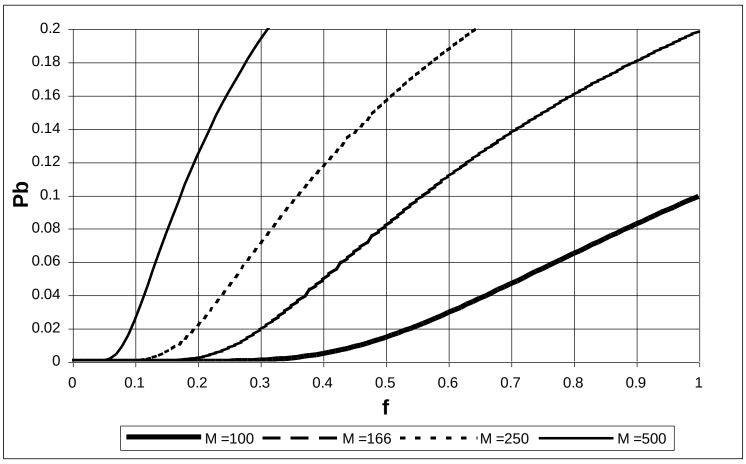


Figure A.3 Service components Blocking Probability in ROA environment – cont.

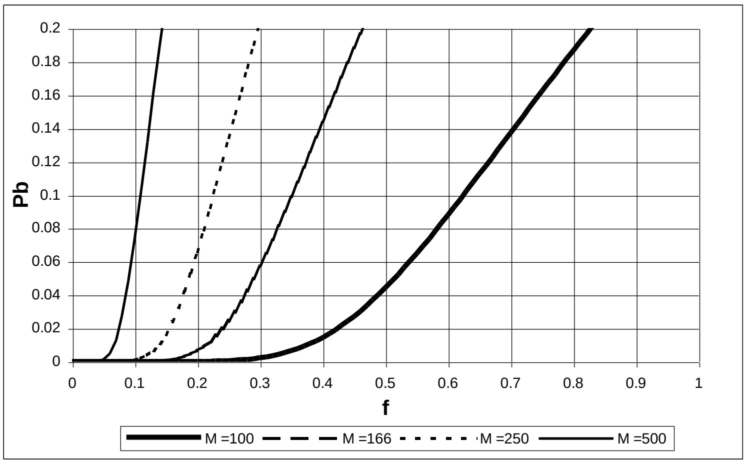
Environment: **ROA**

Uplink (108 ch.)

BAS



MED1



MED2

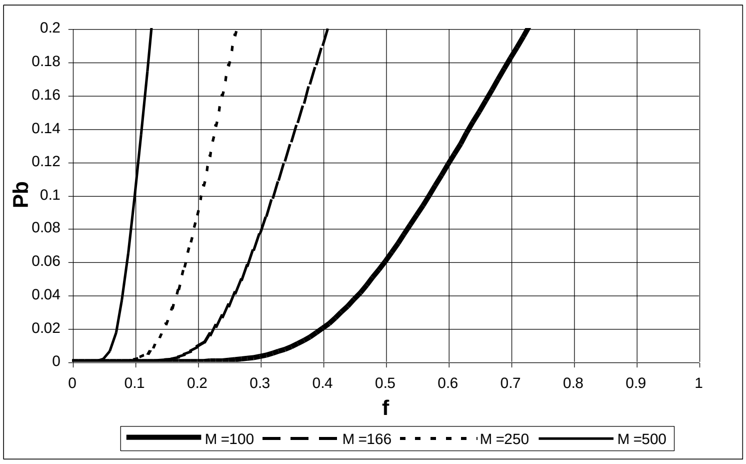
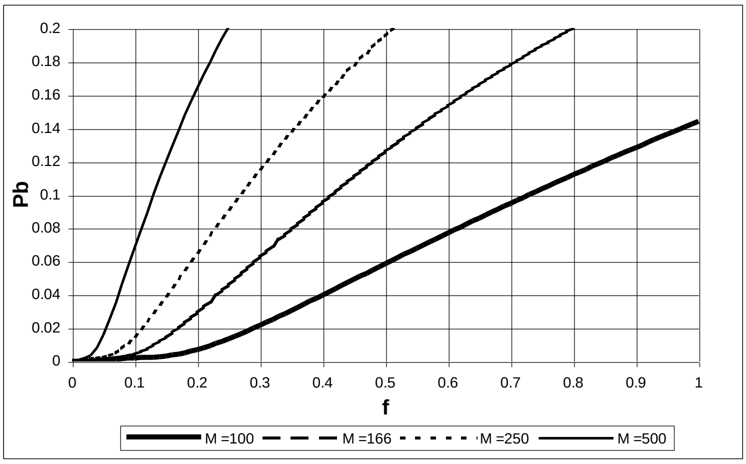


Figure A.3 Service components Blocking Probability in ROA environment – cont.

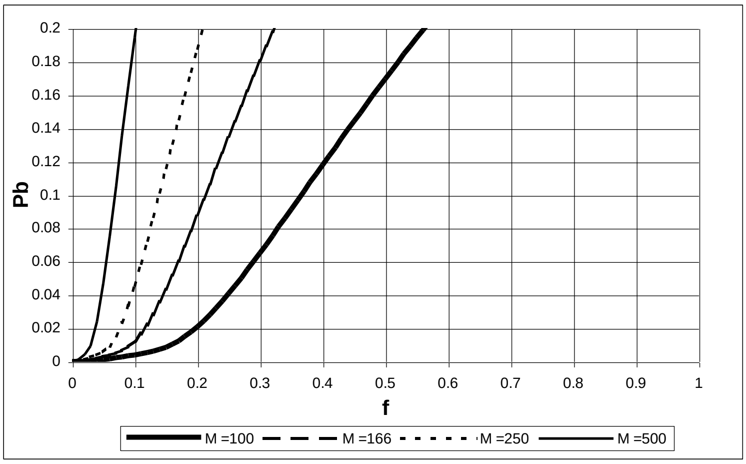
Environment: **ROA**

Downlink (108 ch.)

BAS



MED1



MED2

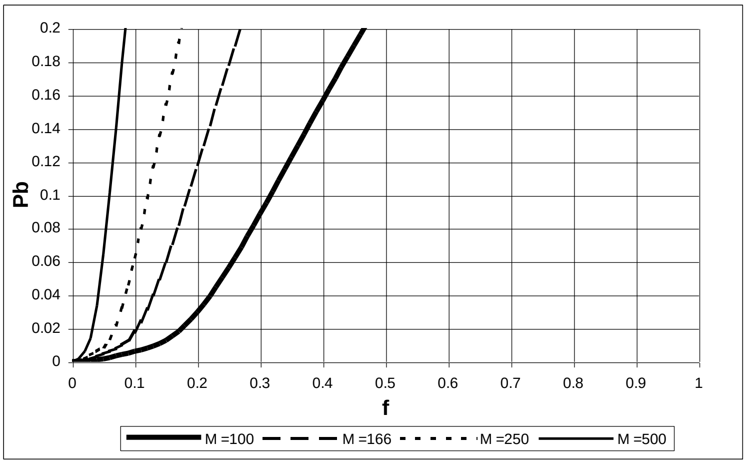
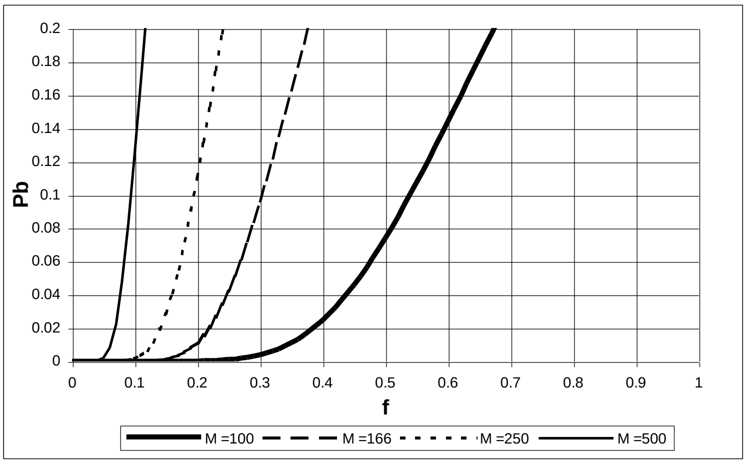


Figure A.3 Service components Blocking Probability in ROA environment – cont.

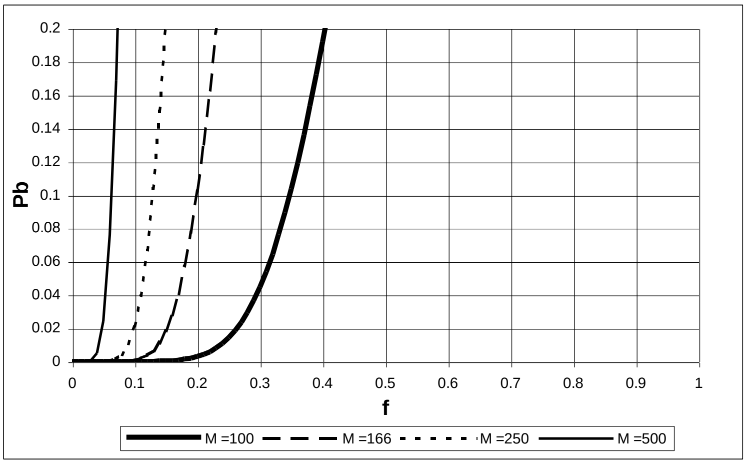
Environment ROA

Uplink (108 ch.)

MED3



HDV



HID

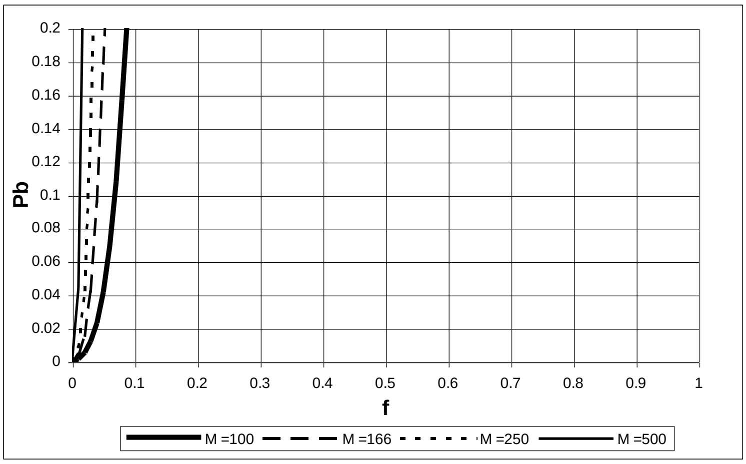
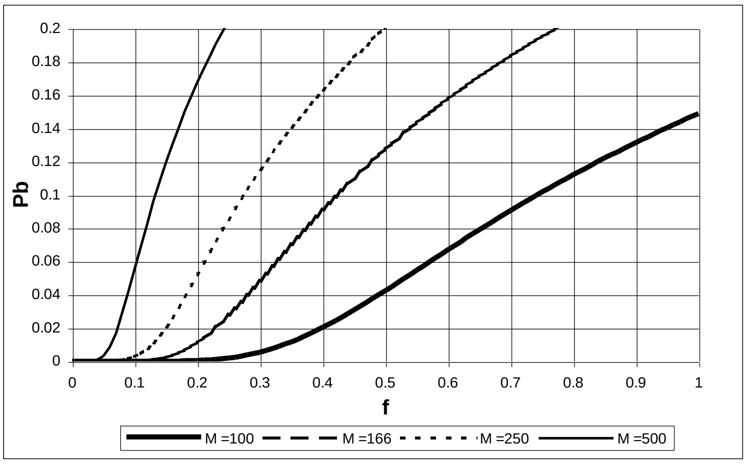


Figure A.3 Service components Blocking Probability in ROA environment – cont.

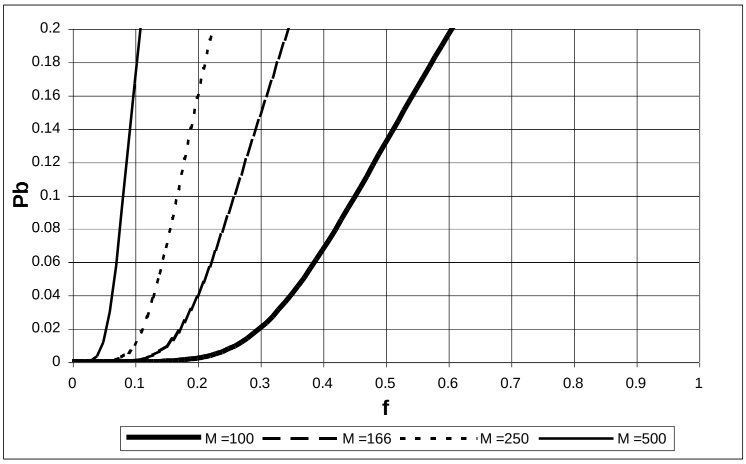
Environment: **ROA**

Uplink (85 ch.)

BAS



MED1



MED2

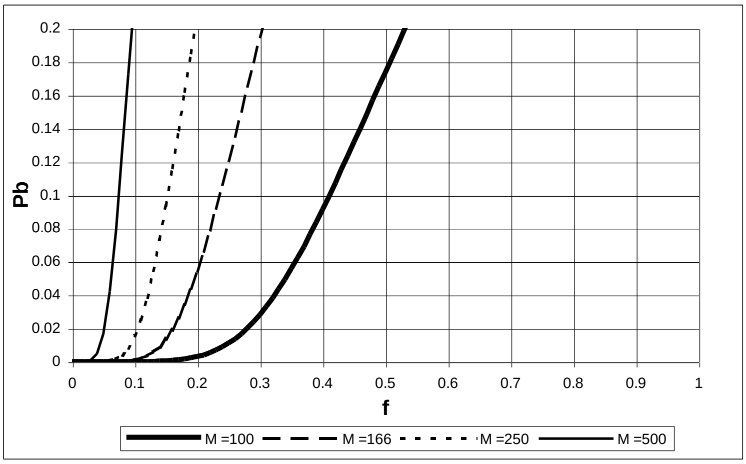
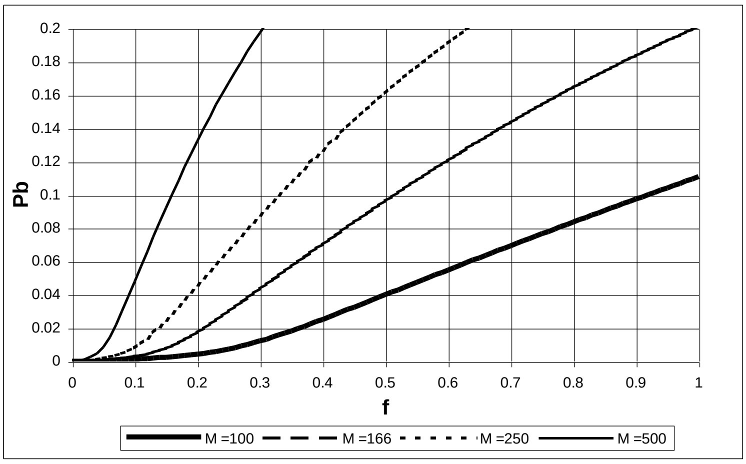


Figure A.3 Service components Blocking Probability in ROA environment – cont.

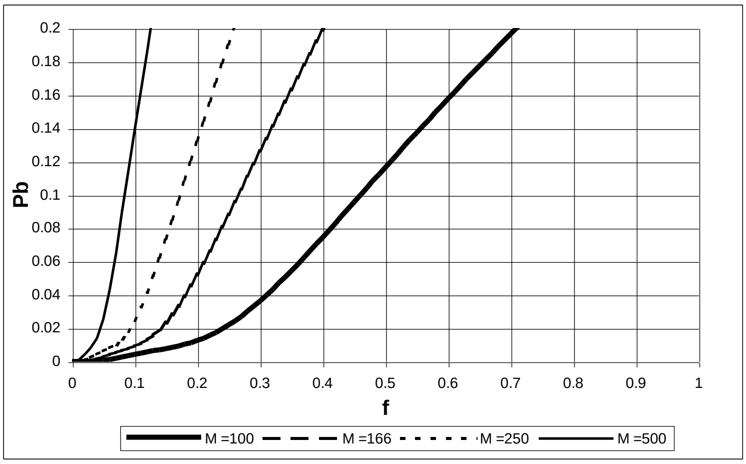
Environment: **ROA**

Downlink (131 ch.)

BAS



MED1



MED2

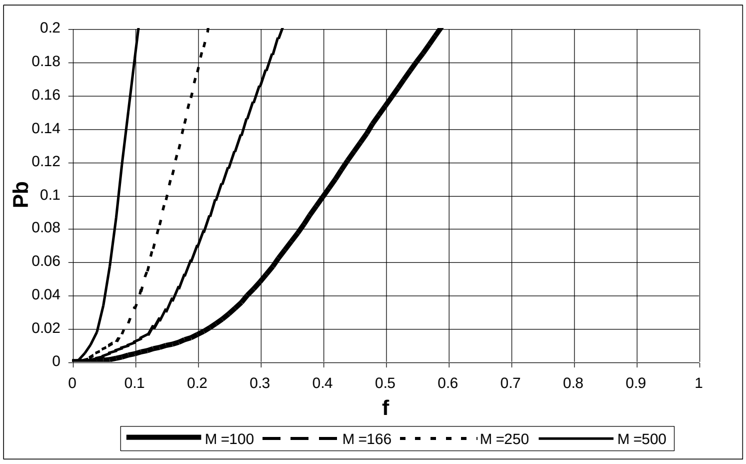
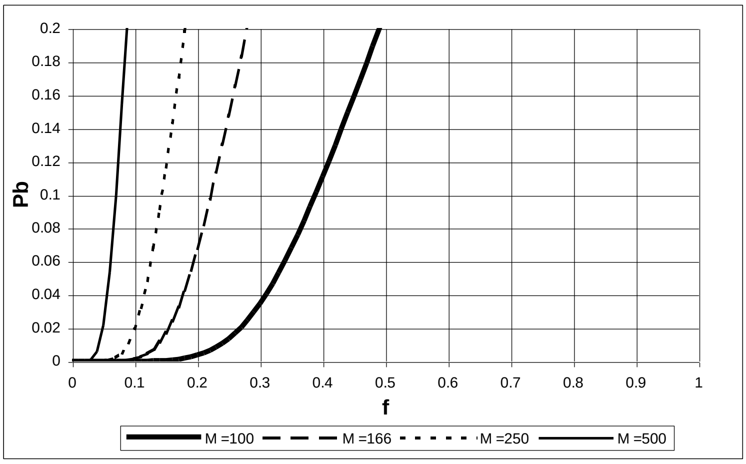


Figure A.3 Service components Blocking Probability in ROA environment – cont.

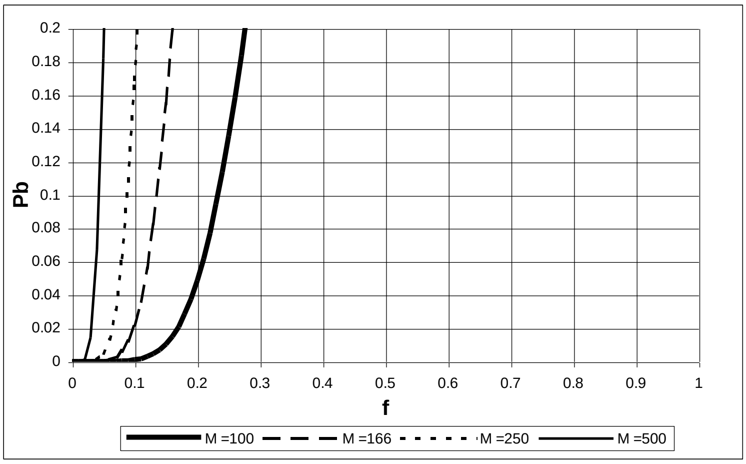
Environment: **ROA**

Uplink (85 ch.)

MED3



HDV



HID

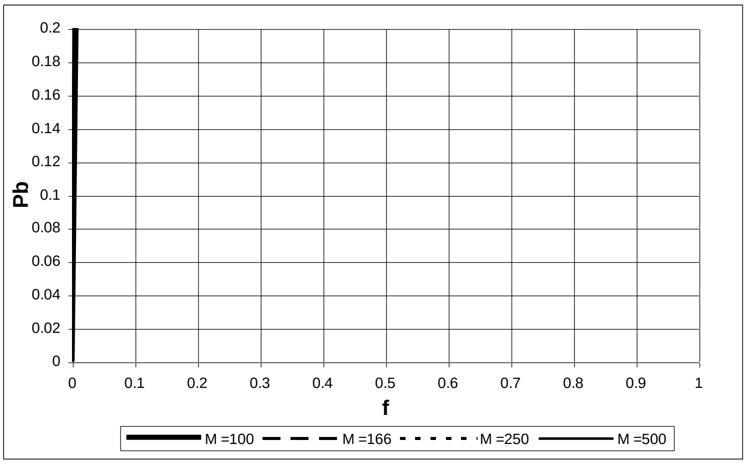
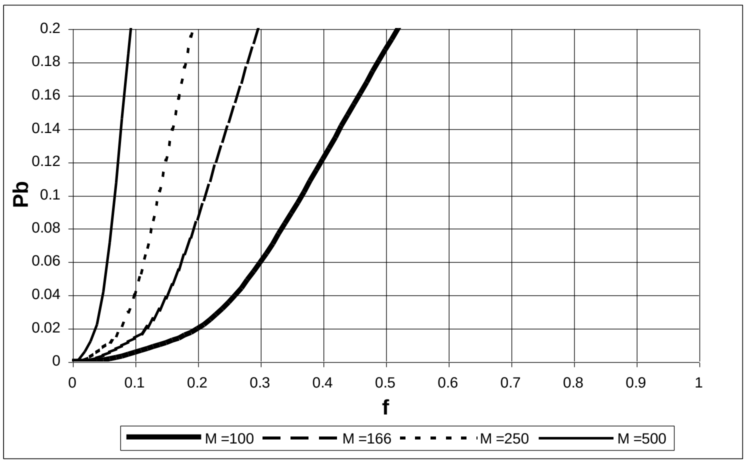


Figure A.3 Service components Blocking Probability in ROA environment – cont.

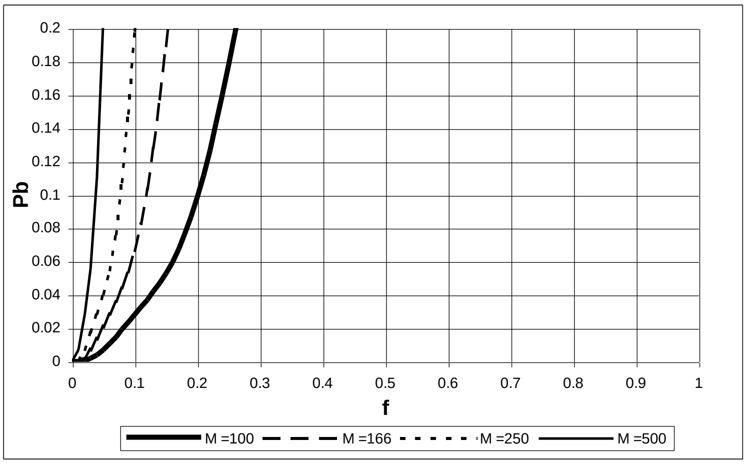
Environment: **ROA**

Downlink (131 ch.)

MED3



HDV



HID

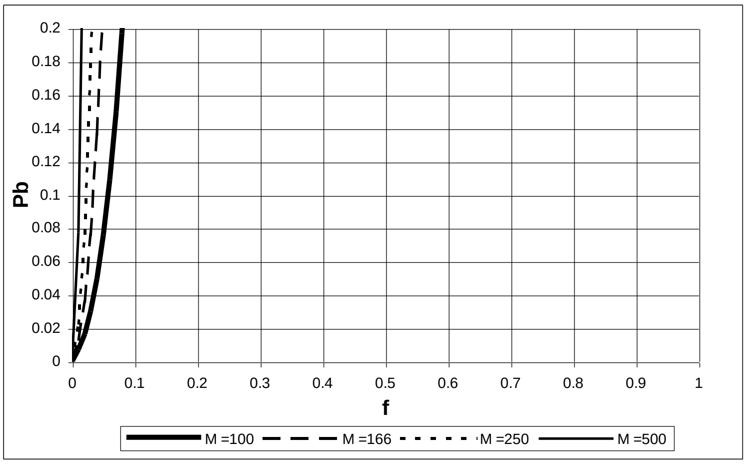
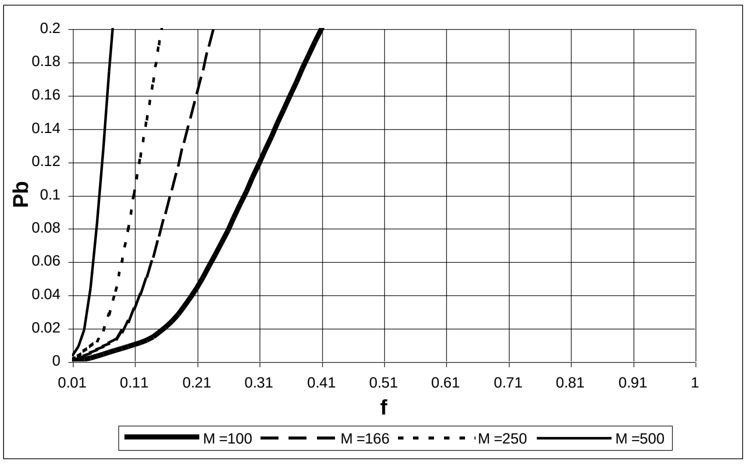


Figure A.3 Service components Blocking Probability in ROA environment – cont.

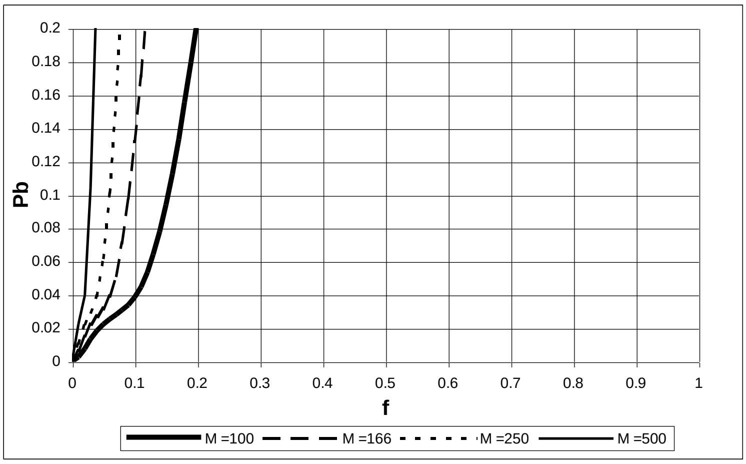
Environment: **ROA**

Downlink (85 ch.)

MED3



HDV



HID

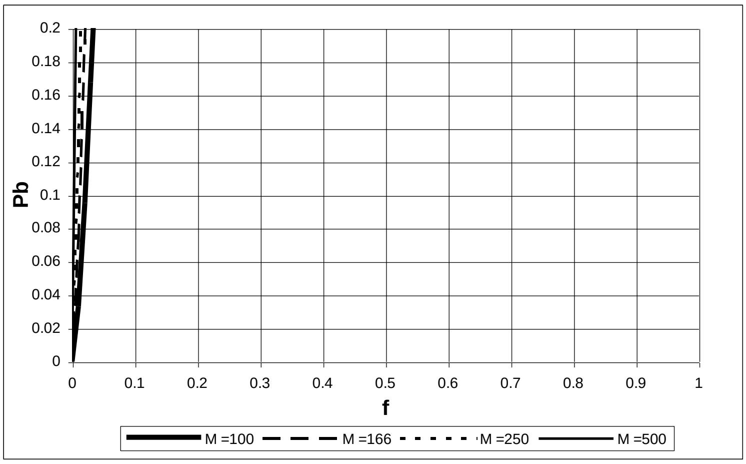


Figure A.3 Service components Blocking Probability in ROA environment – cont.

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