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51

Eero R. Wallenius

# Control and Management of Multi-Access Wireless Networks

JYVÄSKYLÄN YLIOPISTO

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UNIVERSITY OF JYVÄSKYLÄ

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# ABSTRACT

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This work studies multiple network QoS pricing, control and management issues concerning the 3/4G and WLAN network environments. Most of the work is based upon analysis of the different simulations and the corresponding results.

The relationship between QoS and pricing has been studied widely, and it can feasibly be applied in a wireless networks and especially wireless telecom networks, as part of the subscriber billing rationale. Also the customer acceptance versus QoS and overall service pricing has been researched.

A model for a network featuring QoS based control - incorporating different network quality affecting factors such as throughput, delay and packet dropping - as well as providing for an optimized pricing of services in 3G networks, is presented.

Related to this, a Policy Based network management model for the management of 3/4G networks, is also introduced together with its underlying management language model, which is XML based.

This work will provide several answers to the questions, which often arise in connection with QoS dependent control, management and pricing of 3G and 4G networks. The most important items are the studies of the relationship between user acceptance of the services and the relations to service pricing, effects and model of Call Admission Control in QoS management, 3G and WLAN Interworking QoS model and simulation studies. Research about Policy Based Management of 3/4G networks reveals the future ideas and methods for the management of large tele- and data-com systems and networks.

Some of the provided answers should also however be viewed as intermediate results of currently ongoing research programs, which will continue after the publication of this research thesis.

Keywords: QoS, Quality of Service, Policy Based Management, XML, 3G networks, 4G networks, network traffic and service pricing.

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## ABREVIATIONS

| | |
|---|---|
| 3G | 3rd Generation cellular networks |
| 3GPP | 3G Partner Project |
| 4G | 4th Generation cellular networks |
| AAA | Authentication, Authorization, Accounting |
| AP | Access Point |
| AR | Access Router |
| ARP | Allocation/Retention Priority |
| BB | Bandwidth Broker |
| BER | Binary Error Rate |
| BTS | Base Transceiver Station |
| CAC | Call Admission Control |
| CAPEX | Capital Expenditure |
| CBR | Constant Bit Rate |
| CDR | Charging Data Record |
| CM | Configuration Management |
| COPS | Common Open Policy Service Protocol |
| CORBA | Common Object Request Broker |
| CS | Circuit Switched |
| DFSCP | DiffServ Code Point |
| DSL | Digital Subscriber Line |
| EDCF | Enhanced Distributed Coordination Function |
| EQoS | Experienced QoS |
| FM | Fault Management |
| GGSN | Gateway GPRS Support Node |
| GPRS | General Packet Radio Service |
| GSM | Global System for Mobile Communications |
| GW | Gateway |
| HA | High Availability |
| HCF | Hybrid Coordination Function |
| HDSPA | High Speed Downlink Packet Access |
| HPLMN | Home PLMN |
| KPI | Key Performance Indicator |
| LDAP | Lightweight Directory Access Protocol |
| LPDP | Local Policy Decision Point |
| MDAC | Multidimensional Admission Control |
| MIB | Management Information Base |
| MN | Mobile Network |
| MPLS | Multi Protocol Label Switching |
| MT | Mobile Terminal |
| NE | Network Element |
| NGOSS | Next Generation Operations Support System |
| NMS | Network Management System |

| | |
|---|---|
| NRT | Non Real-Time |
| NSIS | Next Steps In Signaling |
| O&M | Operations and Maintenance |
| OID | Object Identifier |
| OPEX | Operational Expenditure |
| OWLAN | Operator Wireless LAN |
| PB | Policy Based |
| PBC | Policy Based Control |
| PBM | Policy Based Management |
| PCF | Policy Control Function |
| PCIM | Policy Core Information Model |
| PCM | Pulse Code Modulation |
| PDP | Policy Decision Point |
| PEP | Policy Execution Point |
| PIB | Policy Information Base |
| PLMN | Public Land Mobile Network |
| PM | Performance Management |
| PS | Packet Switched |
| QoS | Quality of Service |
| RAN | Radio Access Network |
| RED | Random Early Detection |
| RR | Radio Resource |
| RSVP | Resource Reservation Protocol |
| RT | Real Time |
| RTP | Real Time Protocol |
| SGSN | Serving GPRS Support Node |
| SIR | Signal-to-Interference |
| SLA | Service Level Agreement |
| SMS | Short Message Service |
| SOAP | Simple Object Access Protocol |
| SOM | Self Organized Maps |
| SS | Supplementary Service |
| TDM | Time Division Multiplexing |
| TE | Traffic Engineering |
| THP | Traffic Handling Priority |
| TMF | Tele-Management Forum |
| TMN | Telecommunications Management Network |
| UE | User Equipment |
| UMTS | Universal Mobile Telecommunication System |
| USIM | User Service Identity Module |
| VBR | Variable Bit Rate |
| VOD | Video On Demand |
| VoIP | Voice over IP |
| VPN | Virtual Private Network |
| WCDMA | Wideband Collision Detection Multiple Access |
| WFQ | Weighted Fair Queuing |

| | |
|---|---|
| WLAN | Wireless LAN |
| XML | Extensible Markup Language |

# 1 INTRODUCTION

This research work contemplates the next generation of 3/4G networks and services and their quality, pricing models and management. In this thesis the different research problem issues have been discussed and viewed from multiple angles and perspectives to achieve the best possible view and understanding of the nature of the phenomenon and problem in 3/4G networks and service areas. This work has been divided into 4 sections:

- Quality of Service (QoS) and pricing
- Network, service and QoS management
- Policy Based Management and its applicability and future in 3/4G networks
- 3/4G, WLAN and wired broadband access inter-working and QoS

The reason for pricing research is based on the operators' desire for growth and increase in revenues. This can be achieved by the development of new network and customised services. Therefore a correct, efficient, robust, intelligent pricing and billing is essential for the whole systems existence. In the Circuit Switched (CS) voice era, QoS is always guaranteed by the switching technology without any special effort. Now when voice calls and data connections are moving towards network architectures, which are based upon Packet Switched (PS) technology, the network packet forwarding functionality must be designed and developed to offer at least similar properties and quality as the CS networks have offered. One of the main issues that has been raised is the Quality of Service (QoS) issue e.g. how to guarantee similar bandwidth, delay, error quality to PS connections as CS connections have had. CS connections have of course been slower, 64 kb/s maximum compared to the future PS type connections typically 2-10Mb/s in 3/4G. Thus the total bandwidth demand has also been lower in CS type networks than in PS type networks. On the technology side, CS core networks are mostly based on Time Division Multiplexing Pulse Code Modulation (TDM/PCM) links with fixed ATM backbones, whereas PS networks will be heavily reliant on IP-protocol on the network layer and TCP/UDP on the transport layer. Technologies like Multi Protocol Label Switching (MPLS) and Network Engineering are emerging and they will play a major role in the QoS enabled network architectures.

Quality of network services is the other hot topic within 3 and 4 Generation networks. Services will be the next big drivers for the network applicability and usage. Most of the services are still on the way but are yet to come, so the service penetration is still quite low and development is slow. The main reason for this is the limited speed of the connection, leading to unacceptable service quality, which nearly totally prohibits the most popular service usage; web browsing. The end user equipment properties are also still at a very low level, with too small screens and slow connection rates for proper streaming and video services. The level and restrictions still present with the current technology show clearly we are still along way from such a wireless service environment, whereby subscribers could themselves control the data and information received or sent by their wireless equipment. Policy Based Management (PBM) is an issue that is coming strongly into the large network environment control and management systems. The PBM is still in its infancy and research and standardisation are mostly just starting. In the beginning of the PBM standardisation, the goals were much more ambitious and the original target was to cover the whole network and system in its entirety. The present state of PBM research and development targets is much more modest. The goals have now been moved towards QoS, security management, the PBM Framework and towards the protocol direction leaving greater scope for remaining future challenges. One of the reasons to reduce the target levels is that a well-defined and standardised but restricted PBM would in fact delimit future control, management and system innovation inventions. It could also therefore be concluded that one reason behind the low profile state of PBM standardization, is the unwillingness of large equipment vendors themselves, to limit unnecessarily freedom to conduct their own research and development work, which might be curtailed by such a strong standardization of PBM. To start from this towards the original goal is to define a technology neutral upper level PBM Framework where the connecting object would be a commonly defined PBM language. It could then be used in all PBM enabled devices as such and what would contain freely defined content properties to be able to present any PBM hierarchy level and technology independent rules and refining processes that would be implemental in any sufficient performing control system in any technological field.

Inter-working between networking and IT technology has been a very important issue for a long time and as systems become more and more integrated inter-working and inter-operability become essential. In the network area inter-working with the main network areas 3/4G, fixed Internet and Wireless LAN technology is coming to final realization. A common claim has been that future WLAN technology will steal shares from future cellular technologies. The real truth seems to be more like that there will be a balance between the current fixed xDSL lines, WLAN technologies and future 3/4G wireless cellular networks, such that WLAN technology will likely rule in private homes and public “hot spots”, where a combination of mobility with high speed is essential, Future 3/4G cellular services and wireless connectivity will rule in areas where a wide coverage area, reliability and safety are all needed – for example business areas. Another reason for the usage differentiation is the current high price and low speed of 3/4G connections compared to the quite low and flat rate monthly prices of wireless WLAN and fixed xDSL connections. Therefore, in order to create a truly seamless inter-working environment between the business and home domains, all three technologies will need to be inter-connected to one another, to enable availability of the desired services with a given QoS for the lowest price possible, dependent upon location, and access technology utilised. The inter-working issue becomes even more interesting when the first multimode terminals capable of GSM, 3G and WLAN connections become available. When considering the hand-over mechanisms between these different technologies, it is obvious that the hand-over between fixed and wireless technologies does not seam feasible so the hand-over inter-working and inter-connectivity will only be between 3/4G and other wireless technologies. The most important concerns will be the quality of the connection, the QoS and ability to retain services, with fully seamless and errorless hand-over between any inter-working wireless technologies.

In this work, different solutions to the above inter-working and QoS challenges will be presented. The work proposes solutions for the 3/4G pricing model, starting from a basic tele-systems and network service pricing model to a fully optimized pricing model, with the needed constraints for support of multiple [access technology] and QoS concepts.

Future complementary access and 3G WLAN inter-working issues are widely covered by theoretical and simulation analysis enabling the study of fully inter-working 3G WLAN system and with support for the development and implementation of existing standardized functionality, as well as providing support for advanced features, which are the subject of future standardization.

In the Policy Based Management area, this thesis will offer the latest view on information related and other development innovations, in the PBM area, which can and most likely will form the basis used for the future development of both tele-systems and network management systems.

The structure of this thesis is as follows:

Chapter 2 discusses 3G Quality of Service (QoS) and pricing issues related to 3G, including the needed explanation of the basic underlying principles and idea, which are applicable to the pricing of services, as well as different network properties available to subscribers. Chapter 3 is dedicated to the network, service and QoS management issues, providing an overall and detailed description of the current (and future) 3/4G QoS and service management models and possibilities. Chapter 4 discusses Policy Based Management (PBM) issues and its applicability in the area of 3/4G networks, including a description of the coming PBM based control and management area, including the current research focus. Chapter 5 introduces the possibilities offered through end-to-end. QoS control and management in complementary access networks, featuring WLAN based connections.

# 2 SUMMARY OF PAPERS

This thesis includes fourteen research papers, which structurally follow the selected research approach:

[PI] T. Hämäläinen, E. Wallenius, ”Case study for 3G/UMTS services and billing methods”, Proceedings of the 17th International Teletraffic Congress (ITC17), pp.1201-1208, Salvador, Bahia, Brazil, 2nd- 7th December 2001

[PII] E. Wallenius, T. Hämäläinen, ”Fuzzy Logic Based Multidimensional Admission Control for 3G Networks” Proceedings of the 2002 World Wireless Congress (WWC’2002), pp.521-525, San Francisco, USA, 28th – 31st May 2002

[PIII] E. Wallenius, T. Hämäläinen, M. Wikström, ”QoS management by Call Admission Control in 3/4G Networks”, Proceedings of the 16th Nordic Teletraffic Seminar (NTS-16), pp.13-24 Helsinki, Finland, 21st - 23rd August 2002 21th

[PIV] E. Wallenius, T. Hämäläinen, ”Pricing model for 3/4G Networks”, Proceedings of the 13th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC2002), Volume 1, pp. 187-191, Lisbon, Portugal, 15th-18th September 2002

[PV] E. Wallenius, “End-to-End In-band Protocol Based Service Quality and Transport QoS Control Framework for Wireless 3/4G Services”, Proceedings of the 5th International Symposium on Wireless Personal Multimedia Communications (WPMC’2002), Volume 2, pp. 531-533, Honolulu, Hawaii, 27th – 30th October 2002

[PVI] E. Wallenius, “Policy Based Network and Service Management Model for 3/4G Networks”, Proceedings of the 10th International Conference on Telecommunications (ICT’2003), Volume 1, pp. 220-224, Papeete, Tahiti, 23rd February –1st March 2003

[PVII] E. Wallenius, T. Hämäläinen, T. Nihtilä, K. Luostarinen, J. Joutsensalo, "3G/4G Interworking with WLAN QoS 802.11e", Proceedings of the

IEEE Vehicular Technology Conference (VTC'2003Fall), Volume 3, pp.1803-1806, 6th – 9th October 2003, Orlando, USA.

[PVIII] T. Hämäläinen, E. Wallenius, T. Nihtilä, K. Luostarinen, "Providing QoS at the Integrated WLAN and 3G Environments", Proceedings of the 14th IEEE International Symposium on Personal, Indoor and Mobile Radio Communications (PIMRC’2003), Volume 3, pp. 2014-2018, 7th-10th September 2003, Beijing, China.

[PIX] E. Wallenius, T. Hämäläinen, T. Nihtilä, J. Joutsensalo, "3G and WLAN Interworking QoS Solution", Proceedings of the 5th IFIP-TC6 International Conference on Mobile and Wireless Communications Networks (MWCN’2003), pp.29-33, Singapore , 27th – 29th October 2003

[PX] E.Wallenius, T. Hämäläinen, J. Joutsensalo, H. Koivisto, ”Service management model for integrated 3/4G and Wireless Lans”, Proceedings of the 10th IEEE International Conference on Electronics, Circuits and Systems (ICECS’2003), Volume 3, pp. 1022-1025, Sharjah, United Arab Emirates, 14th –17th December 2003

[PXI] E.Wallenius, M. Grosse-Kreul, T. Hämäläinen, ”Policy Language Based Management Model for Wireless Networks”, Proceedings of the 11th International Telecommunications Network Strategy and Planning Symposium, (Networks2004) ,pp.249-254, Vienna, Austria, 13th – 16th June 2004

[PXII] E. Wallenius, T. Hämäläinen, T. Nihtilä, J. Joutsensalo, ”Providing Qos in 3G-WLAN Environment with RSVP and DiffServ”, Proceedings of the 1st International Conference on E-Business and Telecommunication Networks (ICETE 2004), Volume 3, pp. 135-141, Setubal, Portugal, 24th – 28th August 2004

[PXIII] E. Wallenius, J. Joutsensalo, T. Hämäläinen, ”Revenue and Delay Control in 3G Service Network”, Proceedings on the IEEE 60th Vehicular Technology Conference (VTC2004Fall), Los Angeles, USA, 26th – 29th September 2004

[PXIV] E. Wallenius, T. Hämäläinen, T. Nihtilä, J. Puttonen, J. Joutsensalo, ”Simulation Study On 3G And WLAN Interworking”, Accepted to be published in Journal IEICE Trans. On Communications, 2005

## Contributions of the author

In paper [PI] the billing concept definitions and development work was done by author. The general model and simulations for publication [PII] were done by the author of the thesis. In the case of publication [PIII] the author of the thesis did the concept definition and simulations for the QoS control by call admission control. In [PIV] pricing models and simulations were done by the author of the thesis. In [PVII] the work was divided into the concept modeling of the system, actual simulation model and simulations and conclusions. The author has defined the basic 3G WLAN inter-working concept. Work for [PVIII] was divided as follows: The first and third authors defined the simulation scenarios and executed the simulations. The author has defined the basic 3G-WLAN inter-working concept and environment. In [PIX] the idea of using 3G and WLAN inter-working scenarios on environment definitions were made by the author of this thesis. The scenarios in [PX] were defined by the author of this thesis. The work for [PXI] was divided as follows: Basic XML procedures were developed by the second author, usage and definitions of XML in Policy Based concept was done by the author of this thesis. In the publication [PXII], the basic concepts of inter-working, RSVP and DiffServ usage was done by the author of this thesis. In the publication [PXIII], concept definition and adaptation to the 3G network from the theoretical pricing model was defined by the author of this thesis. The further development of the model for suitability in 3G network management and associated simulations were done by the author of this thesis. In the publication [PXIV], the concept of using 3G and WLAN inter-working was defined by the author of the thesis.

# 3 3/4G QUALITY OF SERVICE AND PRICING ISSUES

The new network technologies and service capabilities of combined 3/4G increase the billing and charging possibilities. In practice, this means a new way of being able to divide the available network capacity for use by the new types of services, is required. When all of the currently purely circuit switched (CS) based telecommunication networks are transformed into packet switched (PS) based IP networks, this will enable the availability of Internet based services through wireless subscriber terminals. This transformation has already started with the introduction of the IP packet switched GPRS/EGPRS services into GSM/EDGE networks, and will be accelerated further through the enhancements and higher speeds made possible through 3G technology.

The basic problem is to transform differently prioritized IP based packet switched traffic and services into operator revenues. A solid, robust and commonly applied pricing model is still partly missing. The problem can in practice be sub-divided into two separate [traffic] categories: purely IP based internet traffic, and traditional traffic carried on standard transport/ transmission technologies such as ATM /SDH, PDH (i.e. E1/T1 bearers), as used in the Radio Access Network (RAN), and the xDSL in the case of the WLAN based networks. This thesis tackles the problem, in a technology agnostic manner.

## 3.1 QoS in Business and Marketing

The present Internet and other IP based networks are mostly based on the principle of "best effort" traffic, meaning in practice that QoS can only be ensured by over dimensioning the networks to cope with the predicted worst case congestion scenarios. This solution method cannot be applied forever, and therefore the marketing of QoS will eventually both be needed, and strongly topical issue, especially as new wireless services, which required assured end-to-end quality in the network for their success, are introduced commercially.

In the initial development of QoS, it was planned to apply and charge QoS separately from the services in question. It has been realized recently that this marketing business model for QoS is not feasible. The current notation is that the only feasible way to market and charge for QoS, is to include it as an integral component of the overall service itself, in other words an essential component to ensure a *goodness* in the service itself, thus justifying it as a chargeable attribute of the service. This leads to the result that QoS charging has to be placed wisely and combined into future tele- and other IP service pricing models.

In the remaining sections of this chapter, a cross-section of solution alternatives are introduced, which explore different methods, and their effects, by which QoS can be placed into the policies for operator revenue and subscriber pricing systems. An example of a business policy model can be found in [96], where business level policies have been further refined into device level policies.

Three different views on the categorization of billing and pricing in 3/4G networks are presented in the tables, which follow next. (c.f. TABLE 1, TABLE 2). Finally, as presented in TABLE 3, pricing can be categorized to "market segments". Customers can be sub-divided into mass markets, technical/small business user, corporate or third party users. Each of these customer categories has their own special access, message and content related requirements, as shown in the TABLE 3. Firstly, as presented in TABLE 1, pricing can be categorized according to customer and application type. "End user" is a consumer of the service(s). "Third party" is a provider of the service(s) and "Other operator" is a provider of needed inter-connection and roaming services. Typical individual (i.e. private) end users are currently consumers of Voice and Internet browsing services, with demand growing in the future for streaming and video services. Typical preferences of corporate users are data connection services to corporate IT systems, as well as services supporting home office working (i.e. so called tele-computing). The third party (i.e. service provider) side can be typically divided into three main categories: advertising, content provider and e-commerce vendor. The first category, *advertising*, must always be a free service to the end user (i.e. individual or corporate subscriber). The final two categories, *content provider* and *e-commerce vendor*, are concerned with the provision of multiple content services, such as information, banking or pure sales transactions. These consumed services usually imply acceptance of the consequential costs by the end-consumer. Services provided by "Other operator" (i.e. a partner operator with an agreed commercial liaison relationship), are usually limited to the needed inter-connection or roaming services, but in future provision of more intelligent services, is also envisioned. For example one service provider might offer advanced services through a co-operating partner's network, for it's home subscriber base, when they roam to the partner's network. It could even be possible to provide such services also to the home base subscribers of the partner's, irrespective of whether such foreign subscribers are normally permitted or not to roam to the network, where the advanced services are actually based. Thus an exiting hit service could be sold to the home subscribers of another partner operator etc. TABLE 1 presents the various pricing dimensioning model that can be used in the 3/4G networks.

TABLE 1 Pricing by customer categories

| **Customer** | **Category** | **Application Type** | **What is Billed** |
|---|---|---|---|
| End User | Individual | Telephony, Internet Access, Messaging Information & Entertainment Value Added Services (VAS) | Voice & Data Transport Content |
| | Corporate | Corporate Intranet Machine to Machine Direct Access | Transport, security, application development and hosting Transport, closed user groups and applications Interconnect |
| 3rd party | Advertiser | Visits or responses Pushing targeted Advertisements | Hits, exposure, hosting, and transport Customer information and transport |
| | Content Provider | Content placed on portal or in walled garden, retail outlet Delivery of push content, share price information | Hosting & content, customer data management, transport, secure transactions, and billing & collection Transport |
| | E-Commerce vendor | Sales transactions Targeting information at individuals who fulfill certain criteria | Hosting & billing and collection, secure payment and transport User profile information, transport |
| Other operator | | Interconnect Networking capacity Roaming | Terminating traffic on operators network Transport |

Secondly, as presented in TABLE 2, pricing can be categorized according to a "network-pricing dimension", which depends upon the application in question. Here, the pricing is based upon the application, which is mapped in turn to a specific "network-pricing dimension".

TABLE 2 Pricing by network pricing dimension

| | | **Network Pricing Dimension** | | | | | |
|---|---|---|---|---|---|---|---|
| **Application** | **Example** | **Access Bandwidth** | **Bit Rate Guarantee** | **Data Volume** | **Per Event** | **Free to End-User** | **Content** |
| Web-Browsing Intranet Access | Looking up Web-pages | Highly Relevant. 1 | Relevant. 2 | | | | |
| Time Sensitive Information | | | Highly Relevant. 1 | | Relevant. 2 | | |
| Streaming Media | | Highly Relevant. 1 | Highly Relevant. 1 | | | | |
| Messaging | | | | Relevant. 2 | | | |
| File Transfer | | | | | | | |
| Shopping | | | | | | Highly Relevant. 1 | |
| Information/ Entertainment | | | | | Relevant. 2 | | Highly Relevant. 1 |

From TABLE 2, it can be seen that data volumes and number of events are important dimensions for messaging and as mentioned earlier advertising and e-shopping related advertising should be free for customers, being paid instead by the advertisers or e-commerce vendors.

Finally, as presented in TABLE 3, pricing can be categorized according to "market segments". Customers can be sub-divided into mass markets, technical/small business user, corporate or third party users. Each of these customer categories has their own special access, message and content related requirements, as shown in the table.

TABLE 3 3G Pricing by market segments.

| Customer | Internet & Intranet Access | Messaging | Content |
|---|---|---|---|
| Mass Market Consumer | Internet Café mode, pay per day when you use the service. Internet access with limited messaging features, monthly subscription | Pay per message. Bundle of messages per month. Free to user, 3rd party pays, commercials, instructions to services. | Subscription based content. Pay per event. Pay per use per pulled content. Free to user, commercials, product information, bank balance. |
| Tech/Small Business | Monthly subscription. | Bundled number of messages per month. Unlimited messaging. | Same as for mass markets |
| Corporate | Negotiable annual subscription. | Negotiated annual subscription. | Negotiable annual subscription |
| Third Party | Negotiated annual subscriptions per user. Wholesale: Negotiated based on overall usage. | Negotiated subscription | Negotiated, based on usage. Revenue sharing. |

Each of the pricing models can be applied separately, but usually the pricing schema used by operators or Internet Service Providers (ISP) is mixture of one or more of the models.

## 3.2 Pricing and Billing Issues

Network and service usage can be priced and billed in several different ways. Sections 0-0 present a composite overview of different possibilities and ways in which pricing and billing can be executed, including a description of the attributes and phenomena, which may be used as a basis for pricing.

### 3.2.1 Admission control based pricing

Admission control based pricing means that in cases of service and/or network congestion, the price of the connection or service is increased in direct proportion to the amount of the state of congestion state, or for example by simply applying different pricing rates for business hour usage, compared with a non-business hours. This pricing principle has already been applied in call pricing, from the beginning of the GSM era.

Admission based pricing could be applied also for Internet access, but this is not usually done due to the lack of suitable billing and charging systems, whose associated CAPital Expenditure (CAPEX) and OPeration EXpenditure (OPEX) would be too high to justify. In 3/4G systems intelligent billing and charging systems will -indeed must- be available by default, because this is the only way by which subscribers (i.e. end users) can be billed and thus revenue streams assured for the connections and services that are actually used and consumed. The future billing and charging of 3/4G systems will be capable to differentiate QoS on a single user flow and per each service or sub-service level. Admission for the Internet case is thus (currently) usually charged by means of a flat rate monthly connection fee, whereas 3/4G connections are charged by connection admission, consumed service and are time based.

Admission control based pricing has been studied widely because of the basic nature of admission control and its clear need in cellular networks. As in [25] a dynamic method for pricing is suggested. More recently the common view no longer favors very dynamic pricing schemas, because of the unpredictability of generated pricing results and the lack of transparency for such pricing. In [26] a model, for revenue optimization incorporating pricing with guaranteed QoS for multiple service classes, is presented. The approach is based on a slightly different definition of QoS, taking into account call blocking, which is the main consequence of operational admission control, in a running cellular network. In [27] the admission and QoS problems are seen in terms of the wireless transceiver power control and associated interference problems and are dealt with by means of an interference-based criterion. In [28] a dynamic admission control technique is used to provide adequate QoS level, by limiting the maximum threshold of 'hand-off connection dropping probability' for real-time traffic, as well as by periodically adjusting the size of reservation pool - according to rapidly changing network load conditions. In [29] QoS and pricing is considered in terms of call-acceptance conditions, which depend on the behavior of the system over the lifetime of accepted calls. The model also considers the case of dynamic pricing, which allows connections that pay more to get larger shares of the bandwidth, and investigate the trade-off between quality of service and the size of the acceptance region.

All of the latest admission control studies show that QoS and price and are very much tied together and the main goal for most of the studies has basically been to study how to achieve the maximization of revenue, through optimization of pricing, whilst keeping QoS on an acceptable level.

### 3.2.2 Congestion based pricing

Congestion based charging is usually applied indirectly using higher prices during business hours. This model can be used for both network connections and network services. In the past when Internet connections where done by usual telephone call connections with modems the business hour pricing was applied in the telephone connection charges, but in the era of xDSL, flat rate pricing has taken over and the variable prices have become variable QoS and bandwidth issues in best effort networks. In 3/4G networks, congestion situations can be experienced as 'call blocking' and usually no QoS decrease can happen, as such, just as is currently the case with purely Circuit Switched (CS) connections. In the case of Packet Switched (PS) data calls, some delay and bandwidth downgrading can indeed happen, but as no voice calls are yet passed through the network -in pure PS mode-, the effect of decreased QoS in the PS data side is still very unnoticeable. From the research perspective congestion and pricing issue can be looked at from various point of views. In [30] a basic packet differentiation method is presented and in [31] an elastic user model for congestion, which resembles or is actually the same as the 'subscriber acceptance concept', is presented. In [32] the congestion pricing is solved with an auction method on long-term basis. In [33] a congestion pricing that resolves the TCP RTP unfairness dilemma with different Round Trip Times (RTT) is presented.

### 3.2.3 Auction based pricing

Auction based pricing is a form of congestion based pricing where, the highest bidder gets the connection or service in congestion situations. This method is not very usable in single user cases, because the requirement for the pricing transparency is difficult or even impossible to implement. A system where subscribers should constantly follow ever-changing call or connection charges is not very applicable, nor is this method used with any typical simple subscriber services, in practice.

At the larger scale where tele- and network operators typically buy and sell and buy bandwidth for foreign country connections, or even for big corporate connection cases, bandwidth and connection auctioning can be a very good solution for all parties. Tele- and other corporations can buy bandwidth they need "Just On Time" (JOT), as and when they need it and similarly network operators can sell any possible surplus capacity, which arises, very quickly and at the prevailing market price.

In the 3/4G area the Service Level Agreement (SLA) type connections and automatic management systems are being developed at the moment. From the Internet side the SLA connections can be seen as a bandwidth pipe for multiple best effort connections, but similarly they can be controlled automatically as in 3/4G cellular operator cases. A suggestion of using COPS-SLS for SLA negotiation has been proposed in [72].

The auction methods described in [35] is based on a flexible pricing schema, defined by a customer supplied budget schema, with the maximum price resembling the current prepaid subscriptions but without flexible pricing. By accepting flexibility in pricing the subscriber gets substantially, “more than paid for”, better quality than with a fixed price situation. In [36] the auction method is used to maximize operators revenue in differentiated service network, by using client bids to determine the final admission price for a specific QoS connection.

### 3.2.4 Service based pricing

In a simple service based pricing schema the price is usually based on flat rate connection and fixed or transaction based service charging. The QoS pricing is then included into the flat rate that is based on the used bandwidth (e.g. different xDSL speed categories and GSM/GPRS bandwidth classes). This model is very simple and easy to implement and is already in use for most of the QoS pricing cases, at the moment. With the flat rate connection case, the revenue is highly dependent upon the service prices and the flat rate connection does not usually change the acceptance or usage of the service (i.e. the service usage is highly dependent upon the service price itself). Reference [37] clarifies the issue in a VPN service environment by optimizing the connection, specifically using *routing optimization*, thereby maximizing the network capacity, which has the result of achieving maximum revenue. The *routing optimization* in multi-service networks is applicable for any type of service.

### 3.2.5 Revenue based pricing

Revenue based pricing is a method where the operator can optimize their revenue and network characteristics to a point where the quality of the network (e.g. according to some QoS metrics [delay, bandwidth, BER etc]) are tuned to the minimum and the revenue from the network is maximized.

In different environments and countries different level of QoS are required, based on the different service offerings. Revenue maximization based pricing is the basis for every network service operator, so this issue has been solved for every operator system in one-way or another.

### 3.2.6 Pricing based on resource allocation

Network and system resources are the main costs (CAPEX) of the operators and therefore pricing based on the resource allocations can be considered reasonable. However there exist some problems, because the notion of cost of services is deceptive. SMS messages are experienced to be cheap but in fact they are most expensive services in the cellular network. Another example would be video conferencing versus voice call. Whilst video conferencing consumes 100-1000 times more resources that voice calls, the price ratio cannot be in the same proportion. Likewise, many similar problems of disproportion shall arise as new services evolve. Therefore the resource based pricing can mainly be used in cases where the subscriber himself decides on the resources to be used, with advance knowledge of the effect on the final price, such resource usage decision shall cause. The main use of this type of pricing could be for example in streaming or in other services which make use of interactive resource reservation.

## 3.3 Policy based pricing control and management

Policy based management (PBM) is one of the future enhancements to the network management area. This means that the PBM is also applied in pricing control and management. Mainly if no real-time pricing schema is used, then the PBM would be applied to subscriber and service management. In case that the same operator maintains the network and other services the integrated PBM system could be used for all PBM domains.

PBM is still quite in its infancy and therefore inter-working with different management domains is not usually possible. This means that for network operators and service operators, there is no overall common PBM management yet available, which would include pricing management and co-operation.

## 3.4 Results

On the one hand, price changes will be based upon the current service and network capabilities of the Operator and their network but on the other hand the market situation in the operator's market area is also relevant. Price predictability is one key principle for subscriber satisfaction. Many of the aforementioned connection and service-pricing schema lack this vital price predictability principle. Any lack of transparency or ambiguity in pricing can be strongly considered to be detrimental to the subscriber and thus eventually to the operator too. When the operator business was government controlled, based upon clearly established state monopolies, the pricing principles applied had to be accepted per-se. In the current de-regulated and more free market environment, where states are even forbidden to support the old monopoly type arrangements (e.g. EU commission regulations), and also in the ever tightening future market situation, *price level* and *price transparency* to end subscribers will become increasingly meaningful and vital differentiation factors for different operators to compete in a free market situation.

The most likely future pricing scenario currently visible is one based on a connection type (3GPP traffic classification and QoS), with duration-based billing supplemented by additional service fees such as transaction fees in the case of query type services or per view fees in the case of streaming type services. Also a flat rate (3GPP traffic class based) Internet connection pricing scenario, through the ¾G cellular bearer connections will grow, due to the available speeds matching critical take-off thresholds. In any case, for the moment, the QoS will be bundled to the traffic class pricing and a scenario whereby a single subscriber can freely change their connection QoS settings (and thus related pricing) has still to emerge.

The basic pricing model used in the ¾G environment is a mixture of the old Circuit Switched (CS) pricing and service model, to which have been added new network properties such as QoS and connection security, as well as new services such as streaming videos or e-mail.

### 3.4.1 Legacy billing model

Tele and voice services are the oldest form of telecommunications. Usually these services have been billed by call, call time or both with the addition of long-distance operator's fees. Billing of these old services will remain mainly the same, with the addition of an optional QoS requirement charge. A QoS requirement can either be predefined for all calls, or else it should be adjustable by some means ~~of~~ from the UE/TE, function keys or through a separate numbering plan for High QoS call etc. QoS can be seen as a multiplier (from 1 to 3…4) applied to the time based cost of the call. Also a certain set-up fee for a QoS call can be applied depending on the network configuration. This can be expressed as follows:

$$C_{cs} = T_c * (P_{lo} + P_{ld}) * Q_{c(1\text{-}4)} + C_s + Q_s \qquad (1)$$

$$C_{cip} = B_t * P_b * Q_{c(1\text{-}4)} + C_s + Q_s \qquad (2)$$

Where:
$C_{cs}$ = Charge of the Call (charged by time duration as in CS)
$C_{cip}$ = Charge of the Call (charged by bit flow as in IP-networks)
$P_{lo}$ = Unit price of a call minute (local)
$P_{ld}$ = Unit price of a call minute (long distance operator costs)
$P_b$ = Unit price for an amount of data (voice)-bits
$T_c$ = Duration of the call
$B_t$ = Amount of bits transferred during the call
$C_s$ = Call setup unit price
$Q_s$ = Unit price for QoS setup by call
$Q_{c(1\text{-}4)}$ = *Charge for QoS time by Class* $_{(1\text{-}4)}$

A combination of these formulas can also be used in a case where a part of the network does not have capabilities to support appropriate CDRs. There can also be supplementary services (SS) in the network, which will be charged separately, and their costs are usually added to the basic service charges. These services can be charged according to previous principles by time, by unit, by amount of transferred bit or by any combination of them. The total charge will then be:

$$C_{tot} = C_c + SS\ fees \qquad (3)$$

Where: SS fees is Supplementary Service fees

### 3.4.2 Multimedia services

Multimedia services will be the new service ‘conqueror’, which will eventually displace old tele and voice telephony services, bringing a new dimension, *real time video images*, to the services. These real time services are more complex in nature and require a more complicated billing schema. All services are IP based, which means that all signaling/routing will be based on IP. Call and service signaling will be done by SIP protocol in 3G networks and connections and in some cases also by using H.323 (e.g. in older VoIP networks). Signaling will probably use different routes in the network due to the fact that the signaling load is much lighter than the actual real-time connection stream. Signaling can be seen as a call set-up event and can be charged separately. However only successful calls can be charged, even if unsuccessful calls should still be detected. The actual real-time call is formed through an RTP stream and is carried by the operators along the path from the caller to the called party. This part of the call can be seen as a resource reservation from the network operators, for the time that the reservation is active (reservation time of an active RSVP path etc.), qualified by the amount of data bits delivered and the bandwidth that is consumed during the call. The reservation of the path and QoS can be charged as a part of the Call set-up for a successful call and the reservation time as part of the actual time, bit or both based bill as a multiplier as in the telephony case. Multimedia service billing can be done as follows:

$$C_c = B_t * P_b * Q_c + Q_s + C_s \quad (4)$$

Where:
$C_c$ = Charge of the Call by bit-flow
$P_b$ = Unit price for an amount of data (voice) bits
$B_t$ = Amount of bits transferred during the call
$C_s$ = Call set-up unit price
$Q_s$ = Unit price for QoS set-up by call
$Q_c$ = Charge for QoS time by Class

Usually multimedia services are available only in IP networks so only bit flow and call duration time are relevant for billing. In particular, CS based variables are no longer needed. Billing in the packet-based tele, voice and multimedia services can also be divided to uplink and downlink parts, which can be charged differently [116]. Downlink can be a push type transmission, which could be in some cases free for the customer (e.g. local advertisement etc.).

### 3.4.3 Public or private group-services

Due to the nature of 3G core and IP networks, new types of services can be developed. Public and private group-services mean that the same content of a service can be broadcasted in a local area (one BTS, SoLSA etc.) to several simultaneous receivers, without wasting radio capacity. These services fall into three different categories; 3G Home operator-services which will be supplied by the customers home PLMN/operator, Visiting 3G operator services which will naturally be supplied by the visited PLMN/operator and 3rd-party services which can be global to all users in the global PLMN net or which can scale down to one BTS or private SoLSA services.

Basic cost (operator cost) for these can be calculated by the consumption of resources they allocate from the network as a whole. Usually they need only one down-channel to TE/UE/MS as per normal voice or multimedia services (multiparty games, conferences etc.). These connections can be billed as per any of the previous cases or alternatively a special rate for the service can also be applied. Charging of content in the group services (radio, TV broadcasts, News, weather services etc.) depends on the individual service provider, their costs, cost structures, legal and copyright entitlements to the published material and this is beyond the scope of this study. From this fact, it follows that the basic rate for this call will be higher, but because of the multiple users the single connect fee can be much lower for this type of service. There can also be upstream connections to the group- services (multiparty games, conferences etc.). These connections can be billed as per any of the previous cases or alternatively a special rate for the service can also be applied.

### 3.4.4 Network Quality of Service (QoS) billing

QoS is a new separate feature in the 3G network. The QoS feature will have major relevance for billing in 3G/UMTS [109]. In the beginning, there will only be 4 different QoS-classes: real-time conversational, real-time streaming, interactive and background classes, enforced by DiffServ in 3G core and edge routers. However, in the future there will be ways to achieve end-to-end QoS by using of RSVP, MPLS or ATM protocols. From the charging point of view, QoS classes represent a resource reservation and consequential reduction of the operator's available network capacity, which is therefore billable from the customer. Because of the nature of the QoS, it is only a resource reservation, not always the use of the resource. Therefore the billing of QoS should be some or far less dependent of the nature of the customer traffic in question. It should be based on the actual reserved bandwidth when in use. (This only applies when using end-to-end QoS reservations and it is thus not yet applicable to 3G Rel4. networks). Using a simple coefficient, according to the QoS class from CDR, one can currently implement a form of QoS based charging in the 3G Rel4. networks. From the operators point of view the coefficient ratios between different classes are straightforward depending on the costs of the network bandwidth and the usage of it by individual QoS class. The real ratio between traffic amounts in different QoS-classes cannot be predicted yet, because of the lack of the All-IP network and services. One earlier proposed (and interesting) charging method is dynamic pricing of bandwidth per connection [110]. The price for a connection will be calculated from the network utilization and acquired bandwidth for the connection, compared to the bandwidth load of the network and the amount of connection demands. This leads to a situation that the price of the connection is higher during business hours and lower during out of office hours. To mathematically analyze this situation, we can use the

Markov-modulated traffic model [111], (e.q. 5), for the probability ($P_k$) of a call during a specified duration of time (t) and arrivals (k).

$$P_k(t) = t^k / k! * e^{-t} \qquad (5)$$

The bandwidth demand for a call has been divided by 3GPP into four classes, Conversational Class, Streaming Class, Interactive class and Background Class. The actual percentages of demand for certain class are still unclear due to lack of real working 3G systems. Using Markov's formula, (e.q. 6), we get a probability model for total probability

$$P_k(t) = \sum_{i=1}^{4} t^{ki} / k! * e^{-t}, \text{ where i=1 to 4} \qquad (6)$$

The network load (E) is expressed in e.q. 7.

$$E = P_k(t)*T \text{ Erlangs} \qquad (7)$$

The price elasticy, [112], ($P_e$) can be estimated as a simple equation between the change of demand ($Q_c$), total quantity (Q), price (P) and a change of price ($P_c$), (e.q. 8).

$$P_e = (Q_c / Q) / (P_c/P) \qquad (8)$$

The bandwidth for all 3GPP defined QoS classes can vary from 0 to 2Mb/s. If we use sliding dynamic varying pricing, we must expand the price elasticity for a specific connection speed ($P_{ei}$) (e.q.9):

$$P_{ei} = \sum_{i=1}^{4} (Q_{ci} / Q) / (P_{ci}/P_i) \qquad (9)$$

And where i present the QoS classification factor.

Here $Q_{ci}$ (demand for bandwidth) is the same as the network load E, so we can express the price elasticity as in e.q. 10.

$$P_e = \sum_{i=1}^{4} (E / Q) / (P_{ci}/P_i) \qquad (10)$$

By using different kinds of price elasticity scenarios, we can resolve the price of a separate call (e.q. 11).

$$P_i = P_{ei} * Q / E \text{ ,where i=1 to 4 (3GPP case)} \qquad (11)$$

The total demand for the bandwidth ($B_t$) is then a sum of all separate bandwidths of all simultaneous calls ($N_c$, number of simultaneous calls) at any given moment, (e.q. 12).

$$B_t = \sum_{j=1}^{Nc} Q_j \qquad (12)$$

The total income of the network at any given time can be estimated by summing all separate simultaneous connection charges and estimated call duration, (e.q.13).

$$C_{tot} = \sum_{j=1}^{Nc} P_j \qquad (13)$$

To be able to estimate the cumulative income of the network, we need an estimate of call duration distribution for all separate call types. We can now use the c.d.f. of hyper-Erlang distribution [113, 114, 115], (e.q. 15), to estimate the lengths of the calls.

$$E_h(t) = 1 - \sum_{i=1}^{M} \alpha_i \left( \sum_{i=1}^{M} \underline{\left((m_i \eta_i t)/k!\right)}^k * e^{-m_i \eta_i t_i} \right) \qquad (14)$$

Factors $m_i$ are non negative and $\eta_i$ positive numbers. The estimate for total income $C_{Ti}$ of one service/call-type $i$ during time period $\Delta t$ is then

$$C_{Ti} = P_i * E_{hi}(t), \ t = \Delta t \qquad (15)$$

and the estimate for total income $C_T$ would then be

$$C_T = \sum_{i=1}^{N_c} C_{Ti} \qquad (16)$$

This basic pricing model is presented in the author's publication [PI].

The most important issues that arise when new properties/services are developed and offered to end subscribers are the price of the property/service and the subscriber acceptance ratio for the property/service itself. If the subscriber perceives the price too high compared to the received benefit, the acceptance ratio will consequently be poor meaning that the service/property will in practice not be used. In every service and property combination case there may be more than one service and property combined together. A poor combination of services and properties will invariably ruin even the best and most innovative of services; very rapidly after it's launch. The usual custom of the Operator's of deliberately overcharging for new services and properties, just to see what could be the maximum attainable (but still sustainable) price level is a quite risky approach! It's likely that at least several good services may be lost, at least for the moment, due to this pricing strategy. By developing an on-line monitoring system for service billing with in-built support for exploring the service use data, to reveal the real acceptance versus pricing ratios, operators will be able to maximize their revenues and optimize their CAPEX investments.

### 3.4.5 QoS aware pricing

In case a subscriber makes a QoS change or the network requires a QoS downgrade due to HO (Hand Over) or for some other reasons, the price and QoS factors can be combined together by using the e.q. 17.

$$P_{cci} = P_{rij} \pm PQ_{pijk} \qquad (17)$$

Where: $P_{cci}$ = Total price for a call with known QoS. Parameterization, $P_{rij}$ = Basic rate for a default parameterized call, $PQ_{pijk}$ = Change of the price due to a QoS property change, *I* = Subscriber class (Gold, Silver, Bronze and Economy) and *j* = 3GPP traffic class.

TABLE 4 shows QoS attributes and their values for each 3GPP traffic class. This table also includes price factor/quantity change ($PQ_{pij}$) that can be expressed as in eq. 18.

TABLE 4 Pricing of QoS attribute change

| **QoS Attribute** | **Conver-sational class nominal/ change quantity** | **Streaming class nominal/ change quantity** | **Inter-active class nominal/ change quantity** | **Back-ground class nominal/change quantity** | **Price factor/ quantity change* ($PQ_{pij}$)** |
|---|---|---|---|---|---|
| Band-width | 1 kb/s | 1 kb/s | N/A | N/A | 1±x/2000* $P_B$ * L(x) kb/s |
| End-To-End delay | 1 ms | 1 ms | N/A | N/A | 1±x/350* $P_B$ * L(x) ms |
| BER | $10^{-6}$ | $10^{-6}$ | $10^{-7}$ | $10^{-7}$ | 1 ± x/$10^{-6(-7)}$ * $P_B$ * L(x) errors |

$$PQ_{pij} = (1 + x / Q_{bij}) * P_{Bij} * L(x) \qquad (18)$$

Where: *x* = amount of increase or decrease of a specific QoS attribute value, $Q_{bij}$ = Nominal value of the QoS attribute in operators network, $P_{Bij}$ = Basic price of a call or connection in specific traffic and subscriber class, *I* = 3GPP traffic class, *j*= subscriber class indicator and *L(x)* = linearity factor.

### 3.4.6 Linearity factor

The linearity factor *L(x)* defines the pricing as linear function with respect to changes of the QoS parameter. The dividers used in the calculation correspond to the maximum value of the single QoS attribute. The maximum value for the

bandwidth is 2Mb/s, the maximum delay is 350ms and BER is $10^{-6 \text{ (or } -7)}$ depending on whether the traffic is RT or NRT.
Usually, e.q. 19 produces very high prices at the top end range with correspondingly very low prices at the bottom end range, meaning that the voice call to multimedia call price ratio can be as high as 1:100, which should be considered to be too much. The linearity factor can be expressed as eq. 19:

$$L(x) = A*(e - e^{-B*x}),\ -1 \le x \le Maximum\ QoS\ attribute\ value \quad (19)$$

Where: $x$, $A$ and $B$ are linearity parameters and they should be defined so that the price ratio between min and max QoS does not rise to unreasonably high values. The factor $A$ sets the base level of the price and the factor $B$ adjusts the slope of the curve, which determines the deduction of the price when using high bit rate or volume transfers. The relation to the customer classification can be expressed in the same way. The assumption has been that the quality steps can be equal in each traffic and customer class. In real life, however some justification of this assumption may be needed. Values presented here are merely estimates for 3G/4G network blocking and dropping properties and they have not been verified yet in a real operating environment. However, they represent a good basis for a prioritized network quality.

### 3.4.7 Price factor

The price factor is the variable, which is used for optimizing the admission control functionality. The goal is to optimize the income of the network system with the predefined threshold values for:

- Maximum price for each subscriber class
- Minimum bandwidth for each subscriber class in congestion situations. Bandwidth price change step ($\pm PQ_{Baij}$) will be assumed to be ± 10% of the original minimum bandwidth and base price.
- Maximum delay for subscriber class. Delay price change step ($\pm PQ_{Dij}$) will be assumed to be ± 10% of the original maximum delay and base price.
- Maximum BER for subscriber class. BER price change step ($\pm PQ_{Beij}$) will be assumed to be ± 10% of the original maximum BER and base price.

Pricing unit in the simulator will tune the admission control according to these values, maximizing the total income.

### 3.4.8 Network load dependent price changes

In different load situations load dependent price changes can be classified, as discrete or continuous.

The continuous call pricing (bandwidth or volume based) can be expressed as eq. 20:

$$P_b = A_{ij} * (e - e^{-x*B}) * T_l / 100 \qquad (20)$$

Where: $P_b$ = Unit price of the call or connection, $A_{ij}$= linear price factor for each traffic and subscriber class, $(e - e^{-x*B})$= linearity factor and $T_l$ = Traffic load.

The classified call pricing can be expressed as equations 21a and 21b:

$$P = 1/(A_{ij} * (e - e^{-x*B}) * T_l / 100)\text{, } A_{ij} = C_1 \text{ when } 0 < T_l \leq T_{h1}\ \% \qquad (21a)$$

...........

$$P = 1/(A_{ij} * (e - e^{-x*B}) * T_l / 100)\text{, } Aij = C_N \text{ when } 0 < T_l \leq 100\ \% \qquad (21b)$$

$$\text{and } x = 1 \text{ to } 9 \text{ and } B = 1$$

Where: $P$ = Unit price of the call or connection, $A_{ij}$ = Constant price factor per subscriber and traffic class, $(e - e^{-x*B})$ = linearity factor, $T_l$ = Traffic load, $C_N$ = Constant price per subscriber and traffic class and $T_{hl}$ = Traffic load threshold value for price change.

The linearity factor can also be included into the $C_N$, but for clarity it is shown here separately. The utilized pricing method should be at the choice of the operator. However, from the subscribers' point of view, the classifying method could be somewhat clearer with fixed threshold values for each traffic load classes. The price of the call could then be predefined at the beginning of the call. The price *–optionally shown to the subscriber in the beginning of the call-* should remain the same during the whole call to avoid uncertainty of the total price of the call.

### 3.4.9 Volume based pricing

In the future networks, connections are planned to be charged according to the amount of bits transferred during the call, connection. Actually, the connection can even be called *a session* because of the similarity to the computer connections. In 3G/4G network there will be always open primary PDP context connection, which can be used for call signaling and also for other shared channel transmissions. It is probable that this primary connection will be *free*, (i.e. the cost of usage is included in the subscriber's monthly subscription fee).

The secondary PDP context connections will however be charged. The charging can be divided into two different categories, depending on the nature of the transmission. Real Time connections, Conversational and Stream-class traffic, can be charged by the call duration and the volume of bits transferred during the call. The reason for this is that a RT-connection always occupies a whole traffic channel due to the strict delay requirements of such calls. No shared channel can be used. Non-Real-Time, Interactive and Background can use shared channels and therefore even the primary PDP context channel can be shared for these connections, provided that the QoS flow templates are compatible.

In the 2G and 2.5G networks pricing is still based on the duration of the call and services used. The only exception is GPRS data traffic, which uses GSM timeslots but is charged by the quantity of transferred bits during the connection or session.

In the case that the traffic volume during a connection rises to a very high level, there must be a volume discount method built-in to the charging system, which prevents charges to rise excessively. This can be achieved by using same linearity factor, $(e - e^{-x*B})$, for flattening the highest end of the volume pricing. Volume pricing formula can be expressed in the same form as the bandwidth based pricing,. The main difference in the pure volume based case is that the traffic load factor is missing or here it equals 1 ($T_l$ % /100 =1), eq. 22

$$P_v = A_{ij} * (e - e^{-x*B}) \qquad (22)$$

Where: $P_v$ = Unit price of the transferred bits, $A_{ij}$ = Constant unit price for a subscriber and traffic class traffic and $(e - e^{-x*B})$ = linearity factor.

### 3.4.10 Price optimization

Price optimization can be viewed from two different points of view. The investment view is concerned with the amount of capital, which is invested into the network, and the income view is concerned with the income derived by the network, during a specified duration of time. The ratio between investment and income must be such that the basic interest rate of the investment and the profit expectations will be covered. To be able to calculate the price optimization parameterization to the network there must be basic knowledge of the ratios between the total price and capacities (bandwidth, throughput, edge-to-edge delay, BER etc.) of the network. From these basic factors, we are then able to calculate the basic unit price for each network resource.

### 3.4.11 Price elasticity

There must be also knowledge of the subscriber behavior or demand ratio to the price of the network resource. (Price elasticity). Eq. 23 shows estimation for the price elasticity, $(P_e)$.

$$P_e = (Q_c / Q) / (P_c / P) \qquad (23)$$

Where: $Q_c$ = change of demand, $Q$ = total quantity, $P_c$ = change of price and $P$ = price. The estimated price elasticity will be in the range of -1.3 and -1.7 for future 3G networks calls and connections.

### 3.4.12 Subscriber acceptance and maximizing the total revenue

As the price of the call is raised the acceptance level of the service decreases. The acceptance (and usage) of a service is highly dependent on the pricing of the service. When the service is cheap all subscribers needing the service will also use it and there will be no price-based limitation of the usage. At the other end of the price range, there is a different situation. If the price of the service becomes higher than it's perceived usefulness to the subscriber, it will finally reach the situation whereby the price is so high that nobody uses the service! The optimal price range would be in the middle of the acceptance curve where the ratio of acceptance change and price change are maximized, e.q. 24.

$$\max \frac{\Delta A_s}{\Delta P_s} \tag{24}$$

Where: $A_s = F(P_s)$ = Acceptance factor, $P_s$ = Price of the service and $\Delta$ -denotes change. Maximizing the product of $P_c * Q_c$

$$\max\left[P_c * Q_c\right] \tag{25}$$

and taking the corresponding $P_s$ and $Q_s$ values we get the maximized total revenue eq. 26.

$$\max R = A_s * P_s * Q_s \tag{26}$$

Where: $R$ = total revenue for a service and $Q_s$ = Service quantity (Priced unit of a service). There is also the question of the investments in capacity to provide the service, which rises along with the usage of the service and it must be taken to account when estimating the total profitability of the system and service.

Price elasticity and acceptance factors can also be studied together by comparing how much acceptance increases or decreases when the price changes. This can be expressed with the following eq. 27.

$$A_s = F(Q^*P_e^*P_c/Q_c) \tag{27}$$

There are two sub-optimal areas and views how the optimization process can be done. The first sub-optimal operating area can also be expressed as the area where the maximum price elasticity factor is achieved. This means that the network load control by pricing is the most effective. This may be desirable in cases where the operator specifically wants controllable demand for their service; for performance reasons.

The second sub-optimal can be found near the maximum acceptance factor. Coming downwards the acceptance there can be found a point where the total revenue $R$ will be maximized, eq. 26. The area above this point is actually a waste of network resources and it should be avoided by keeping the pricing slightly above that point. Bearing in mind these two sub-optimal points in mind, the obvious operating area (pricing) would be between these points. Then the operators have the good (if not exactly maximum) control over the network resources and at the same time the revenues are near optimized.

### 3.4.13 Acceptance and price elasticity dependency

The shape of the 3G service acceptance curve actually depends on the price elasticity factor of the service. As a conclusion we can determine that the lower end of the curve produces more profit per change due to the lower acceptance ratio.

### 3.4.14 Optimized price parameterization

For parameterization we have used the price elasticity model with predicts the demand change compared to the price change. By using the correct model for the acceptance curve, we can predict quite accurately the behavior on the income of the network. However, there are no studies yet available for subscriber behavior in 3G networks, therefore some assumptions have to be made about the subscriber behavior and the price elasticity factors.

### 3.4.15 Use of Linearity factor for adjusting the acceptance curve

There is one interesting possibility to adjust the Linearity Factor to match the acceptance curve as in equations 28 and 29.

$$L(x)=A_{ij}/F(P_s)= A_{ij}/A_s= A_{ij} * (e - e^{-x*B}) \quad (28)$$

And

$$L(x) * A_{ij} / F(P_s) = A_{ij}\text{, constant} \qquad (29)$$

These customer behavior and acceptance model has been presented in [PIV].

In publication [PXIII] we present an advanced optimizing algorithm to control the QoS and at the same time optimize the revenue of the operator. The basic model optimization model is based on the following algorithm, which is presented here in a simplified form.

Let $d_0$ be the minimum processing time of the classifier for transmitting data from one queue to the output in eq. 30. For simplicity, the assumption is that data packets have the same size. The number of service classes is denoted by $m$. In WFQ, the real processing time (delay) is

$$d = N_i d_0 / w_i, \qquad (30)$$

where $w_i(t) = w_i$, $i = 1, \ldots, m$, are weights allotted for each class, and $N_i(t) = N_i$ is a number of customers in the $i^{th}$ queue. Here time index $t$ has been dropped for convenience. The constraints for the weights are

$$w_i > 0 \qquad (31)$$

and

$$\sum_{i=1}^{m} w_i = 1. \qquad (32)$$

If some weight is $w_i = 1$, then the other weights are $w_j = 0$, $j \neq i$, and class $i$ is served by minimum processing time $d_0$, if $N_i = 1$. For each service class, a revenue or *pricing function*

$$r_i(d) = r_i(N_i d_0 / w_i + c_i) \qquad (33)$$

(euros/minute) is decreasing with respect to the delay $d$. Here $c_i(t) = c_i$ includes insertion delay, transmission delay, etc., and here it is assumed to be constant. A goal is to maximize revenue criterion

$$F(w_1, \ldots, w_m) = \sum_{i=1}^{m} N_i r_i (N_i d_0 / w_i + c_i) \qquad (34)$$

under the weight constraint 1 and 2. As a special case, consider *linear* revenue model. The function

$$r_i(t) = - r_i t + k_i,\ i = 1, \ldots, m, \qquad (35)$$
$$r_i > 0, \qquad (36)$$
$$k_i > 0, \qquad (37)$$

is called a linear pricing function.

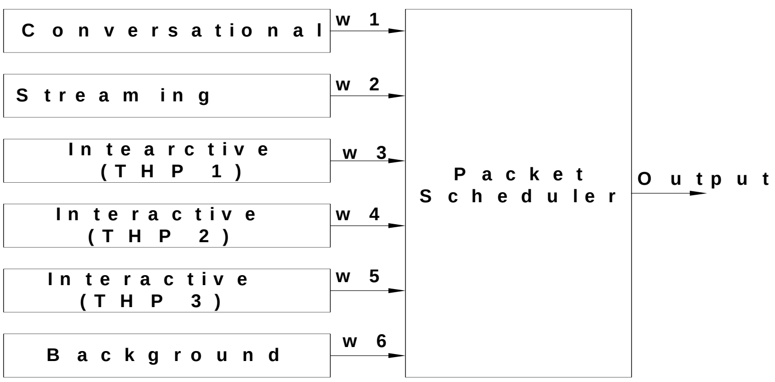


FIGURE 1 Traffic classification at the output buffers.

*Theorem 1*: Consider the linear pricing function (35) and the corresponding revenue function

$$F(w_1,\ldots,w_m,N_1,\ldots,N_m)=\sum_{i=1}^{m}N_i\left(-r_i\frac{N_i}{w_i}+k_i\right) \quad (38)$$

where $d_0 = 1$ and $c_i = 0$ for convenience. Then upper bounds for buffer sizes are

$$q_i=\left\lfloor\frac{1}{2}\frac{k_i}{r_i}\right\rfloor, i = 1, \ldots, m, \quad (39)$$

where $y = \lfloor x\rfloor$ denotes maximum integer $y$ satisfying $y \le x$.

*Theorem 2:* In the case of linear pricing model (35), the upper bound for revenue is

$$F\le\frac{1}{4}\sum_{i=1}^{m}\frac{k_i^2}{r_i}. \quad (40)$$

*Theorem 3: When*

$$N_i=\frac{1}{2}\frac{k_i}{r_i}, \quad (41)$$

*revenue is*

$$F=\frac{1}{2}\sum_{i=1}^{m}\frac{k_i^2}{r_i}\left(1-\frac{m}{2}\right). \quad (42)$$

It is clear that in practice the buffer sizes must be selected smaller than in Eq. (38). As a special case, when there is only one class, i.e., $m = 1$, upper bound (43) can be achieved, but not for the other values of $m$, if the buffers are full.
The following theorem gives sufficient condition for achieving non-negative revenue as well as an other upper bound for revenue:

*Theorem 4: If weights are selected by*

$$w_i=\frac{N_ir_i/k_i}{\sum_{l=1}^{m}N_lr_l/k_l}, \quad (43)$$

*and a constraint*

$$\sum_{i=1}^{m}\frac{N_ir_i}{k_i}<1, \quad (44)$$

*is used in the call admission control mechanism, then*

$$0\le F\le\sum_{i=1}^{m}N_ik_i. \quad (45)$$

### 3.4.16 Summary

Pricing and QoS research goals have been gathering old developments and defining some new model to estimate and actually define pricing models for combined QoS and network and user services. With these models operators can evaluate different models and use one that best suits their business and technical environments.

# 4 QOS AND SERVICE MANAGEMENT

In this and the future era of the developing new 3/4G networks and their environments, the most important challenges for success are Services and QoS. At the moment the development of new 3/4G service core needs the most development effort, compared to any other part or development areas in cellular systems. QoS is very tightly tied together with services by guaranteeing their usability for the subscribers and this is why the control and management of this functionality must be developed as fast and with as high quality as possible for the present 3G environment.

FIGURE 2 shows the layered management model from the Tele Management Forum (TMF) [108]

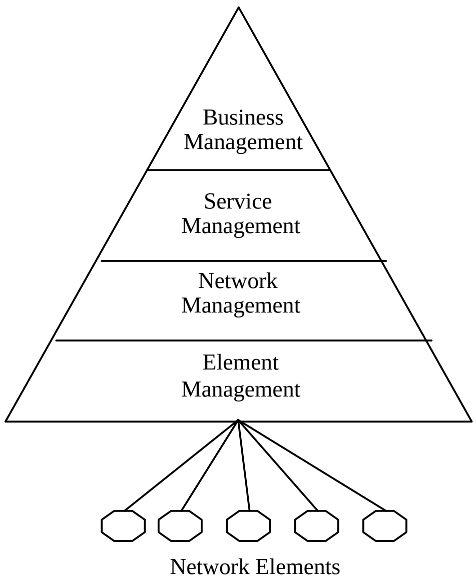


FIGURE 2 TMF Model

TABLE 5 Scope of the TMN logical layers

| Layer | Functional scope |
|---|---|
| BML | Covers aspects of management relating to high-level planning, budgeting, goal setting, executive decisions, business issues related to SLAs, etc. |
| SML | Uses information presented by NML to manage contracted service to existing and potential customers; this is the basic point of contact with customers for provisioning, accounts, QoS, and fault management. The SML is also the key point for interaction with Service Providers and with other administrative domains. It maintains statistical data to support QoS, etc. |
| NML | The NML has visibility of the entire network, based on the NE information presented by the EML. The NML manages individual NEs and all NEs as a group. In other words, the NML has the first managed view of the network. The NML coordinates all network activities and supports the demands of the SML. |
| EML | Manages each network element; the EML has element managers each of which are responsible for the TMN–manageable information in certain NEs. In general, an element manager is responsible for a subset of the NEs. An element manager manages network element data, logs, activity, etc. |
| NEL (Network Element Layer) | The NEL presents the TMN–manageable information in an individual NE. In other words, the NEL interfaces between the proprietary manageable information and the TMN infrastructure. In practice, the NEL acts on commands filtered from higher layers and initiates alarm reports. |

The highest level, business management layer defines the operator side business goals and management actions to achieve them.

The service management layer defines goals for services derived from business goals and actions on service level how to control them. T5 explains TMN layers in more detail.

## 4.1 Research and Standardization

QoS management can be divided into 2 main categories based on the aggregate level of the managed network traffic flows. DiffServ type QoS management is targeted to multiple combined traffic flow management, with a simple non-signaling based pre-reconfigured management solution. DiffServ is very well standardized and is also the main QoS method in the 3G networks. On the flow based management side, RSVP is similarly well standardized and usable and on the service side standardization comes from other than the IETF direction, due to the fact that network services and especially 3G network services are out of the scope of the IETF. The main actor for services is TMF defining the big-picture and management framework for 3/4G services in their NGOSS programs [57, 58, 59, 60, 61, 62].

QoS research has been very active in recent years because of the rising congestion in the Internet. Along with the new 3/4G services, the same congestion and bottleneck problems are becoming a threat to the cellular society as well.

On the research side, a great number of management models for telecom system have been defined, simulated and tested, some of these directly borrowed from the datacom world [89]. The most interesting studies then are the ones focusing on the combination of the problem areas.

## 4.2 QoS and Service management

QoS is a functionality that can mainly be handled internally inside the operator's networks. In cases that the connections are passing through an intermediate operator's network or going straight to an other operators network, QoS can be maintained by a Service Level Agreements (SLA) in the border of the two networks. An SLA between two operators can be seen as a simple QoS management and monitoring task where all passing traffic through the home and visited PLMN inter-working interface in one single aggregated traffic flow.

Usually, when we speak about QoS, we mean a single user experienced QoS, which means how a subscriber perceived the QoS of his services to be. Very seldom do individual subscribers have any real means to verify the actual QoS there are receiving, so it is somehow more important to measure the subjectively experienced QoS and this has been seen as more important than the objective and real QoS.

In FIGURE 2 the QoS management layer can be seen to be in the service and network management layers. On the other hand, the business requirements and attributes for QoS come from the business management layer. Usually the QoS management layer is also considered to be on OSI layer 3 but in some cases and network environments the management layer can be in the OSI layer 2 (i.e. MAC/LAC). In the Ethernet transport layer 802.11p/q queuing can be used to define QoS in the network and by a proper mapping from 3GPP traffic classes to 802.11p/q this is a feasible solution [74].

## 4.3 Admission control based QoS and service management

QoS is an elementary and integral part of service quality and cannot be isolated from this context. This offers a possibility to look at the matter from a combined QoS and service point of view. When we consider how to improve QoS, service quality and subscriber experienced service quality, we can combine the control of both under a common management feature called admission control. Admission control can estimate both network QoS and service load and service server performance when making admission decisions to the service in question.

There are also multiple other admission control points that can be used for CAC mechanisms. We can place CAC to the very edge of the RAN to make observations on the congestion in RAN part at cell level or Signal to Interference Ratio (SIR) [75]. Also bare call or service priorities defined for example by ARP can be used for CAC decisions [76, 81]. Different kinds of capacity measurement based CAC systems can be developed [77].

One very important aspect is blocking and dropping percentages that are used as a basis for CAC [78, 79]. Service management is the other dimension, when we define the means and methods of user experienced quality of their services. In the beginning, when services are mainly maintained and offered by the network operators, the problems with the service quality may not be a very big issue, because operators have always better means and possibilities to tune their networks and service environments to deliver an adequate level of quality of services to their subscribers.

The problems start when external service provider start offering their services through wireless and cellular operator networks and connection services. There is now standardized model for external service providers to manage and maintain or even measure their service quality in the inter-working environment. This is the reason why TeleManagent Forum (TMF) is targeting strong efforts to the service management definitions and development at the moment [38].

Multiple models have been developed since 1999, when the service boon began. The current official model and definitions can be found in 3GPP Technical Specifications [7, 8] which are concentrating however on the bare QoS side, but which still defining the necessary quality metrics and their constrains. TMF is concentrating on developing a Service Quality Management Framework that enables custom oriented service measurements like COPS-PR related methods in [82].

## 4.4 Results

As services are the most central part of the ¾G network offerings, the QoS is the main differentiator of the operators offering these services. This is the reason why there must be a reliable robust model and methods for operators to be able to tune their network and service properties, in the way they want them to be seen by the subscribers, specifically in terms of service offering and service quality. Some operators may want to sell their services cheaply with low CAPEX and OPEX and accordingly offer lower quality than their competitors, clearly trying to catch the most price sensitive subscribers, while some other operators may want to offer best quality to the most demanding and highest paying customers.

When speaking of the quality control with restricted resources, the main method for controlling the quality of network and services is call admission control (CAC). A basic study of the QoS management by CAC is presented. It shows that the QoS can be completely handled and controlled by a simple CAC mechanism. By using connection blocking, or even in some extreme cases using connection dropping, a very simple and robust CAC system can be implemented.

Publication [PII] describes a patented multi-dimensional Fuzzy logic relation based CAC system that can be used in the new ¾G systems. It takes care of the multiple selected QoS criteria to optimize the network quality according to pre-defined parameters. This method has been designed to be used as a part of a Policy Based Management Call Admission Control (PBM CAC), where the criteria and the relational model can be executed in the same rule/decision engine.

### 4.4.1 Traffic model

In our simulations, incoming call probability $P(t)$ can be estimated by Poisson distribution with a rate $n$ of incoming calls to a cell during time $t$.

$$P(t) = t^{n} / n! * e^{-t} \qquad (46)$$

For each 3G traffic class and subscriber class the equation is:

$$P_{ij}(t) = t^{n_{ij}} / n_{ij}! * e^{-t} \qquad (47)$$

Where: $i$=1 to 4 (Conversational, Stream, Interactive, and Background) (This is only for information, and is not covered in this study. All simulation can be considered to be done in any RT-traffic class, Conversational, or Stream.), $j$=1 to 4, (Gold, Silver, Bronze and Economy subscriber classes)

The call duration of each subscriber class can be estimated by exponential distribution with mean $1/n$ and time spent with all base stations (eq. 48).

$$D_{ij}(t) = n_{ij} * e^{-n_{ij} t} \qquad (48)$$

### 4.4.2 Probability of call blocking

The probability of call blocking can be resolved from the overall load in the network. The probability of blocking is the same as the probability of traffic load exceeding the admission threshold value (eq. 49).

$$Bl_{ij}(t) = \sum_{i=1}^{4} \sum_{j=1}^{4} [P_{ij}(t) * D_{ij}(t)] \qquad (49)$$

Where: $Bl_{ij}$ is the probability of call blocking for a subscriber and traffic class combination, $P_{ij}(t)$ is the call probability distribution function and $D_{ij}(t)$ is the call duration probability distribution function.

### 4.4.3 Probability of call dropping

The probability of call blocking is similar as the call blocking except for the threshold value.

$$Dr_{ij}(t) = \sum_{i=1}^{4}\sum_{j=1}^{4} [P_{ij}(t) * D_{ij}(t)] \qquad (50)$$

Where $Dr_{ij}$ is the probability of call dropping for a subscriber and traffic class combination, $P_{ij}(t)$ is the call probability distribution function and $D_{ij}(t)$ is the call duration probability distribution function.

### 4.4.4 Multidimensional admission control fuzzy logic implementation

Multidimensional admission control can be implemented in various ways. We have made a fuzzy logic based implementation using max-min composition. The multidimensionality is based on the following factors Edge-To-Edge delay, BER, Price factor and $Mload_{KPI}$ parameter. The main principle for multidimensional admission control is shown in FIGURE 3.

Each of the factors mentioned earlier are measures of the network quality. Each of those factors represents a certain portion of resource load, e.g. network bandwidth, and overall delay budgeting and jitter. By defining how these factors correlate to the total or specific load (bandwidth, delay, etc.) we will come up to a series of crossing curves where **y** presents $Mload_{KPI}$ and each $x$ presents one of the admission control dimensions. By using fuzzy logic min-max composition we can easily and quickly define the admission load parameter $Mload_{KPI}$, meaning actually which curve to follow when defining a $Mload_{KPI}$ admission decision value.

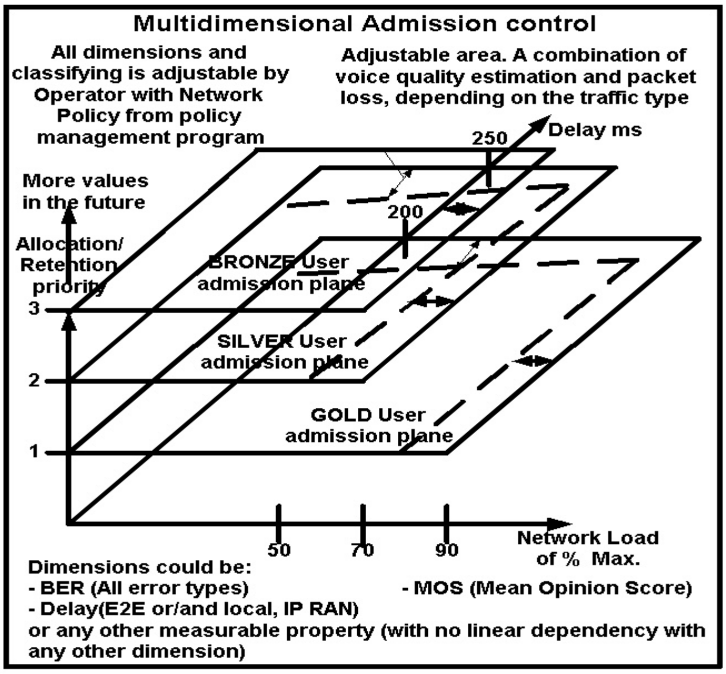


FIGURE 3 Basic principle of the Multidimensional Admission Control.

Mathematically MDAC system can be based on classical fuzzy logic max-* or max-min deductions:

For max-*

$$R_1 * oR_2 = \{((x,z), \max((\mu_{R1}(x,y) * \mu_{R2}(y,z))) \mid x \in X, y \in Y, z \in Z \} \quad (51)$$

and for max-min case

$$R_1 * oR_2 = \{((x,z), \max(\min(\mu_{R1}(x,y) * \mu_{R2}(y,z))) \mid x \in X, y \in Y, z \in Z \} (52)$$

Where *x, y* and *z* can be any three dimensional combinations. The maximum number of dimensions is not limited to three but for convenience used here as an example.

Publication [PIII] describes the requirements and functionalities needed to implement a full functional CAC system for 3/4G networks.

This study also includes CAC simulations to tune the CAC system in various blocking and dropping situations.

### 4.4.5 Simulation model

FIGURE 4 depicts the simulation model that has been used to test the MDAC CAC system in [PIII].

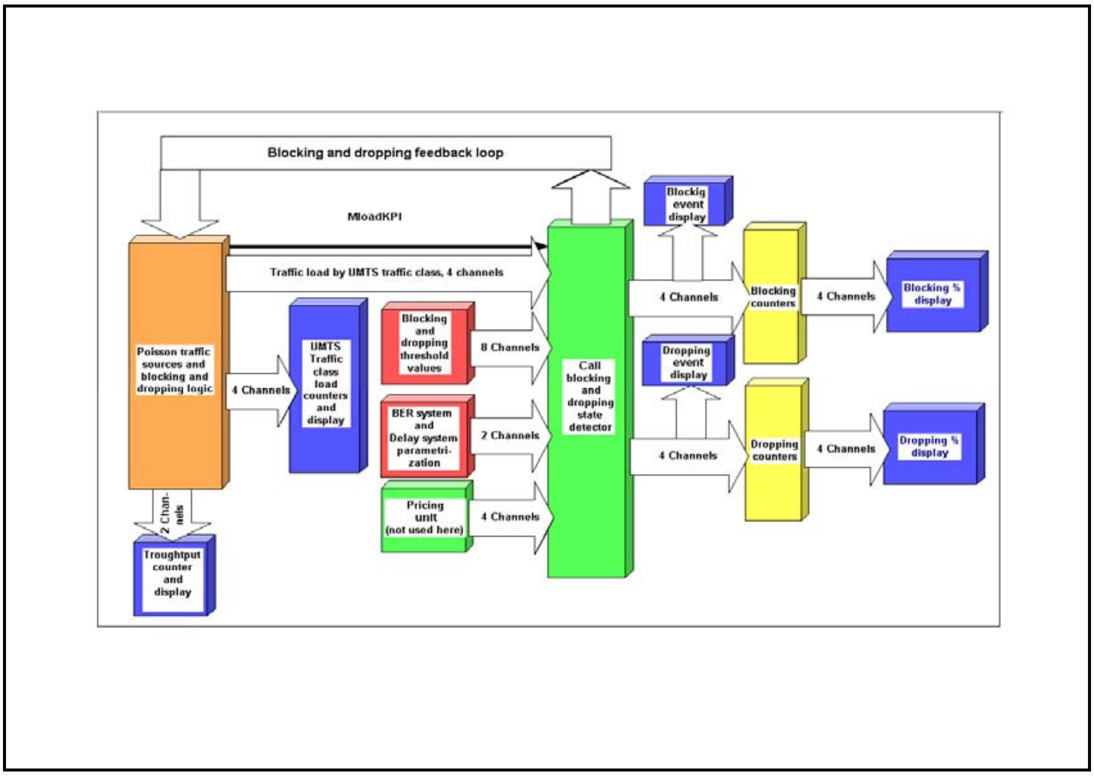


FIGURE 4 Simulation model

### 4.4.6 Call blocking

Call blocking percentage per traffic class and subscriber class is the main point of interest to observe, because it is the main measure for the subscriber service satisfaction. There have been studies on the required call blocking values to achieve good, satisfactory and bad network services. FIGURE 5 shows the blocking properties of the system for different subscriber classifications.

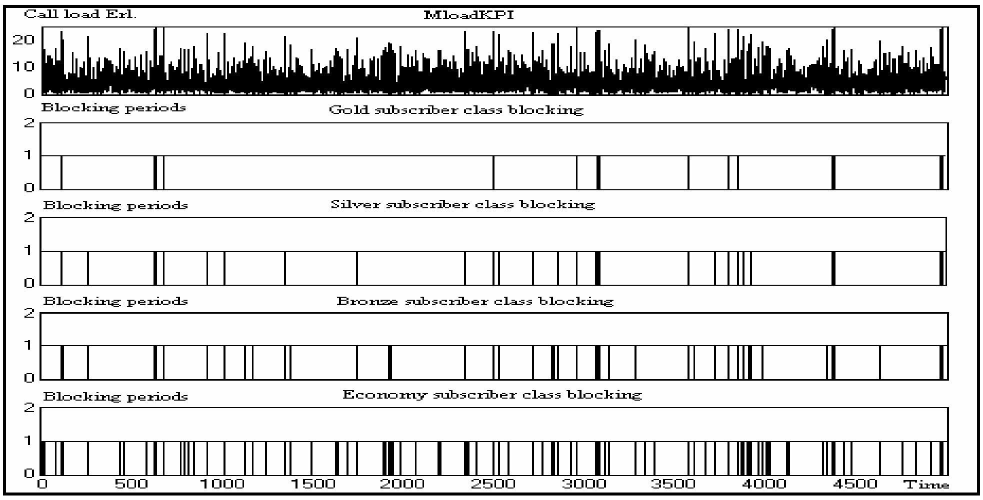


FIGURE 5 $Mload_{KPI}$ and call blocking events by subscriber class

At the top of the picture there is the combined Poisson distributed traffic load, which is fed to the admission control unit. The admission control unit makes decision based on the $Mload_{KPI}$ and the class based load limit, which have been given to each of the subscriber classes.

FIGURE 5 shows the functionality of the admission control. It can be seen how the admission control cuts the traffic for the lower classes without disturbing the highest two classes. This functionality of course can be parameterized and controlled by configuration or by call admission policy if Policy Based Management is used.

Publication [PV] concentrates on solving the invisibility of the network QoS to the independent Internet Service Provider (ISP). The problem in this area is that ISPs have no standardized way to directly measure the connecting networks QoS. The only way to be able to monitor and control the QoS of the connecting network is through the QoS API located in the cellular phone. This is a very convenient and natural way to deal with the problem, as a subscriber has paid for their right to use and control the QoS of their connections. The ISP receives the mutual benefit of being able to measure the experienced quality of their service, through the cellular handset, as well as adjust it to the subscribers' liking. The method used is a simple SOAP based In-band protocol to negotiate about the quality of the service between the client and server parts of the service. Based on this information, the server can set the speed of the service and the properties of the network to best suit the operators and subscriber's service quality requirements.

### 4.4.7 Basic functionality of the framework

FIGURE 6 depicts the basic functionalities and modules needed to control the quality of service.

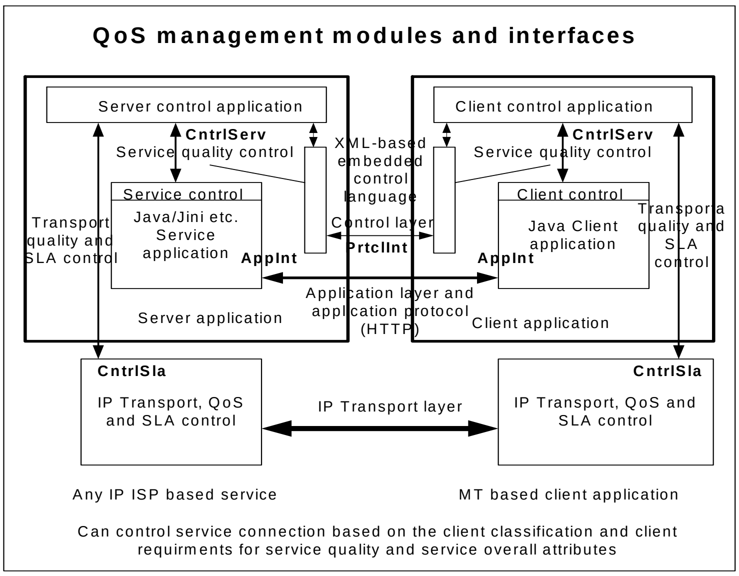


FIGURE 6 Basic functionalities, modules and interfaces, for End-to-End service control

### 4.4.8 In-Band Concept

The In-Band control protocol solution provides a synchronized way to inform both ends of a service of the quality factors related to the network and service functionalities.

To be able to combine quality control more tightly to the user plane traffic and service qualities the control plane signaling has been tunneled in the user plane traffic. As XML language has rapidly been adopted as the most used application language, it is very natural to make the control plane definition as an extension to XML. All control actions, QoS and service quality monitoring, tuning etc. can be considered to be executed through XML-language tagging and carried on top of HTTP-protocol. A control model can be constructed from the capabilities and monitored objects.

### 4.4.9 A Practical Solution

FIGURE 7 depicts the practical application and connection through the access network.

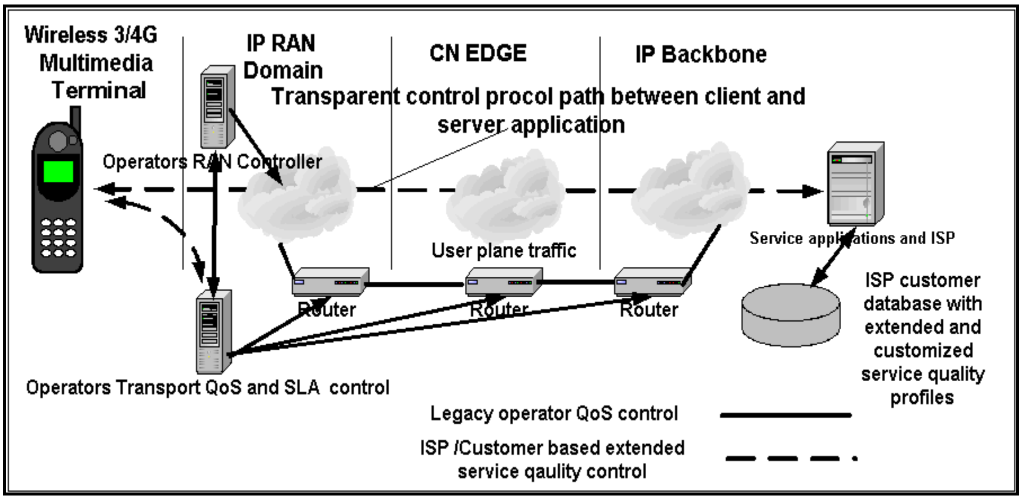


FIGURE 7 A practical solution

The basic idea is that the application and control planes are invisible to the transport network and the transport network properties will be controlled through signaling from the service application not straight through the terminal operating system and it's interfaces.

The advantage of this solution is that the wireless network domains (restricted operator domain) would be visible to the MT and ISP through the MT QoS monitoring and adjustment interface. The QoS attributes acquired from the operator's network can then be transferred to the ISP quality control. ISP can calculate the complete service quality for each of the quality attributes. This also enables the wireless network operator to take advantage of the extended quality monitoring and the overall quality of the network can then be improved.

#### 4.4.10 Summary

QoS and service research goals have been to find a basic model and practical solutions for combined QoS, service control and management. QoS and services form a unified combination that form the term Experienced QoS EQoS. EQoS is the final metric on how a customer experiences the quality of a single service. QoS or service quality alone cannot be used when evaluating EQoS, they must be combined and evaluated together.

# 5 POLICY BASED MANAGEMENT AND CONTROL

Policy Based Management (PBM) means a totally or partially autonomous and self-managed system where the whole system is managed by predefined rules in a completely known and controlled environment.

Policy Based management can be widely understood and applied to the whole system in it's entirety, from the top-level business model and rules right down to a single network element and its management. There has been variety of studies on the highest level, policy based business management [56], which can drive in turn the lower layers of a policy based management hierarchy, from the interpretation and mediation middle layers to the device dependent lower layers.

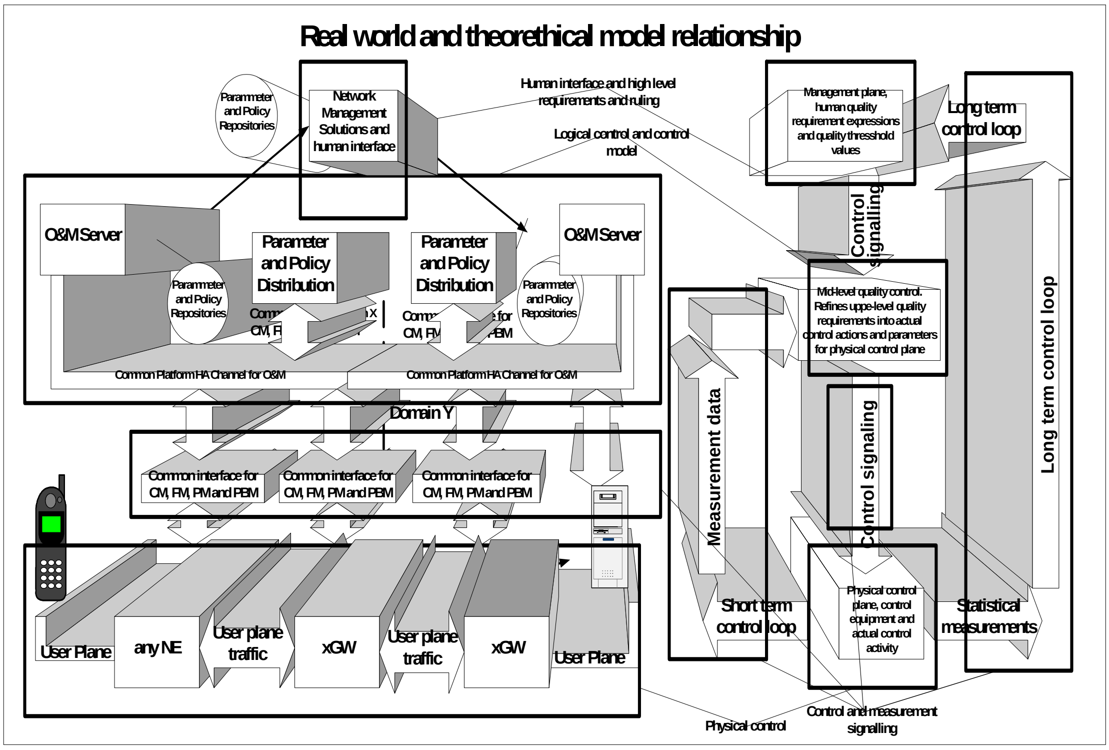


FIGURE 8 Real world and theoretical relationships

## 5.1 Comparisons between theoretical and real world control and measurement models

FIGURE 8 depicts the relationships between the theoretical and the real world control and measurement concepts. Starting from the lowest layers from both worlds, we find the physical user plane and control plane, which carry the associated user and control plane traffic, and we also have here the physical devices used to execute the traffic flow control and management. Moving upward in the abstraction level, we then have the interfaces for the basic control and measurement entities, Performance Management (PM), Configuration Management (CM) and Fault Management (FM).

The purpose of both models is to interpret and inter-change information between higher-level control layers and the lower level execution layers. They both contain same basic high components at the high, middle and low levels, which can be directly mapped from theoretical and scientific models into a real world full functional management system. In most cases, the real world management system is a multiple combination of different kinds of system, operating together. Each real system is not even necessarily connected to each other. In some cases, the decision layer comprises a human making decisions manually, based upon an interpretation of different network, system or service metrics, which are converted into new lower level rules or eventually even to a specific parameterizations value set in the system configuration.

The right side of the picture is a simplified model of the short term and long term control systems, which are both rule based and inter-connected to each other in a feedback control loop arrangement. The long-term control loop is concerned with the highest-level management layer of the real world system, whereas the short-term control loop is concerned with the corresponding Network Element internal *real-time control* and tuning processes. Both of the loops can be implemented making use of the same PBM rule and rule engine technology, independently from the hardware and software technologies used in the implementation of the upper level management system or the lower level network elements.

## 5.2 Scope of Policy Based Control and Management

To be successful, an environmental study and thorough research is needed to determine all the main controllable and measurable items and the relevant details for the self-controlled environment. It is very often preferable that in the majority of cases, systems are designed to be only partly Policy Based Controlled (PBC), and some of the most difficult tasks are handled by manual intervention of a human, or by some other non-PBM based control scheme.

In real life terms control and management typically have slightly different meanings. Control usually means a Real-Time (RT) activity, whereas management usually means more Non Real-Time (NRT) tasks done in the background, to ensure the future fitness of the network. Therefore system and network measurements, observation methods and actions are also slightly different.

Control needs fast real-time measurement functionalities, which are very close to or embedded into each Network Element (NE), to perform the actual measurement and monitoring work.

The time requirements in a real-time measurement control loop can be as fast as 20 ms. The upper level Network Management System (NMS) must also have some RT capability to handle faults and system tuning requirements originating from the lower level systems or network elements.

## 5.3 Standardization and Research

Policy Management standardization has reached a point where PBM can be safely exploited in QoS, DiffServ and RSVP based QoS management areas. The 'Policy Core Model' [40] and 'Policy Quality of Service Information Models' [48] have been defined for the management purposes. On the DiffServ side, 'QoS service Policy Information Base' [41], 'Framework Policy Information Base' [49], and 'Structure of Policy Provisioning Information (SPPI)' [50] have all been defined. On the RSVP side, 'Extensions for RSV Policy Control' [42], 'COPS protocol usage for RSVP' [43], 'Framework for Policy Usage Feedback for COPS-PR' [44], 'COPS usage for Policy Provisioning' [45], 'Managed object definitions for Policy Provisioning (COPS-PR)' [46] and 'COPS protocol' [47] have also been defined and standardized. In the recent decade the Policy Based Management has been the subject of extensive research on 'Policy Hierarchies' [2], 'Policy Driven System', 'Network Management [3, 4, 5] and 'Policy Languages' [39].

Recent studies on Policy Based Management can be divided into the following (but also constantly evolving) categories from the tele-, network- and system management points of view:

- Upper level business and organizational associated policies, used mainly by operators in their traffic, service pricing and billing strategies.
- Policy Based QoS Management (DiffServ & RSVP) and Traffic Engineering (TE)
- 3G Service and QoS management (Go and Gq) interfaces [15, 16].

IETF has two working groups, who are currently working on the PBM area. Resource Allocation Protocol (RAP) Working Group, which is targeted to establish a scalable policy control model for RSVP and to define a protocol for use among RSVP-capable network nodes and policy servers.

The other the Policy Framework Working Group [21] is concentrating on defining a general *vendor independent* framework for PBM, reusable policies, extensible information model, Policy Information Base [PIB] -plus an extension to it- for QoS management needs.

The RAP Working Group has also defined a Framework for Policy Based Admission control and it's main elements (i.e. the Policy Enforcement Point (PEP), the Policy Decision Point (PDP) and the Local Policy Decision Point (LPDP) [6]).

The most common policy repository access protocol is the Lightweight Directory Access Protocol (LDAPv3) [22], and the mapping of Policy Core Information Model (PCIM) [23, 24] to LDAP schema has also been defined in [25].

Policy Based Management issues has also been widely discussed in the author's papers [PVI, PXII].

## 5.4 Control and Management Hierarchies

In principle, the control and management hierarchies are not specifically limited in any particular way. In practice, the hierarchy levels should and must be limited and grouped or divided according to some management property of the system, network or service. FIGURE 9 depicts the control and management hierarchy. Policy Management hierarchies have been widely studied by the standardization community and are also available.

### 5.4.1 Human interface

The human interface – depicted in FIGURE 9 is the highest-level interface to the system. It is the way to express the business requirements and related rules to the system. These rules can be expressed in any form related to the specific domain to which the rules in question concern.

The top-level human interface for a policy based management system should be located in the Business Management Systems (BMS), where the business rules for the whole system are managed. Additionally, there must be lower level management interfaces for each Policy Based Managed domain, so that the rule refining process and rules themselves would be completely and unambiguously defined to the lowest level of the management system. These interfaces are distributed throughout the system, but there must exist a common functionality, in order to keep the whole PBM system consistent.

### 5.4.2 Rule refiner (compiler)

Rule refiner in FIGURE 9 is functionality, which is itself based on rules defining how to refine higher hierarchy rules into the equivalent and related lower hierarchy rules. The next lower level rule produced by the rule refiner can be an Ln-1 or 1 level rule, meaning that the rule is the actual control point rule e.g. control element parameterization or element policy.

### 5.4.3 Rule level Interface

In FIGURE 9, the term ‘interfaces’ is a common name for entities that connect two functionalities together, thereby passing information between them in both directions. An interface can be comprised of a protocol, multiple protocols or some other proprietary interfacing methods e.g. Corba. The network element layer is the lowest functional entity in the network domain. It carries out the actual network traffic transportation and enforces control actions and policies on itself. In Policy Based Managed, the Policy Information Base (PIB) controls the enforcement environment on the network element layer.

The rule hierarchy follows the same logical framework that forms the Policy Based Managed environment e.g. physical (HW) or a logical network domain with single elements included into that domain. The same hierarchical model has been also presented in a more practical way in [1], where the policy domain and it’s associated layer has been located into a specific Common Management Layer between the management applications and distributed processing services.

### 5.4.4 Network elements and system components

The lowest policy based managed level in FIGURE 9 is a network element or a system component. They are managed by changing their configuration parameterization. A network element, or system component, can still have multiple internal functionalities, which are not managed by a policy-based scheme, because they are not directly visible to the measurement or control system.

An example of this is that router routing functionalities are often configured through direct signaling between routers without any upper management system intervention, whatsoever.

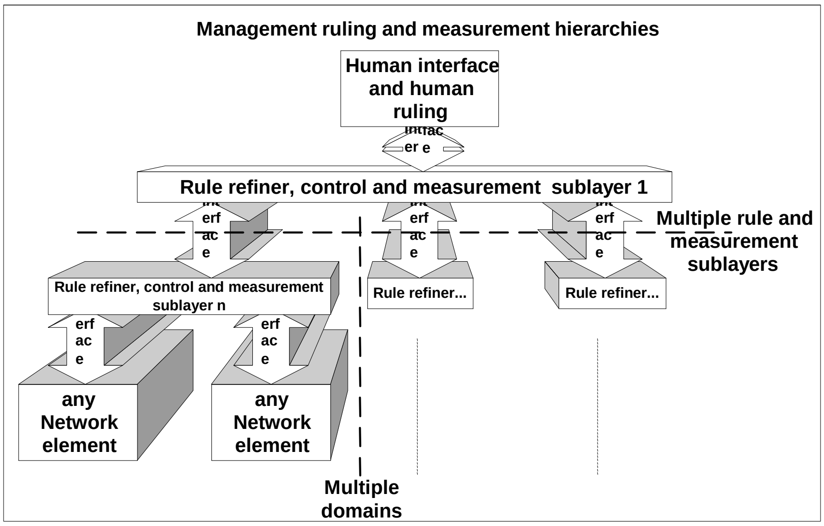


FIGURE 9 Management rule, control and real time monitoring hierarchy

The hierarchy presented in FIGURE 9 can be easily mapped to the policy continuum example [64], as presented in FIGURE 10. The business view can be seen as a human view to the trouble domain, while lower sub-layers can be mapped to the rule definer sub-layers in the control and management hierarchy model. The lowest level in both models is the same; device dependent layer.

The multiple domains presented in FIGURE 9 represent horizontal sub-domains, which in-turn present technology dependent sub-domains, inside any given *technology independent* domain.

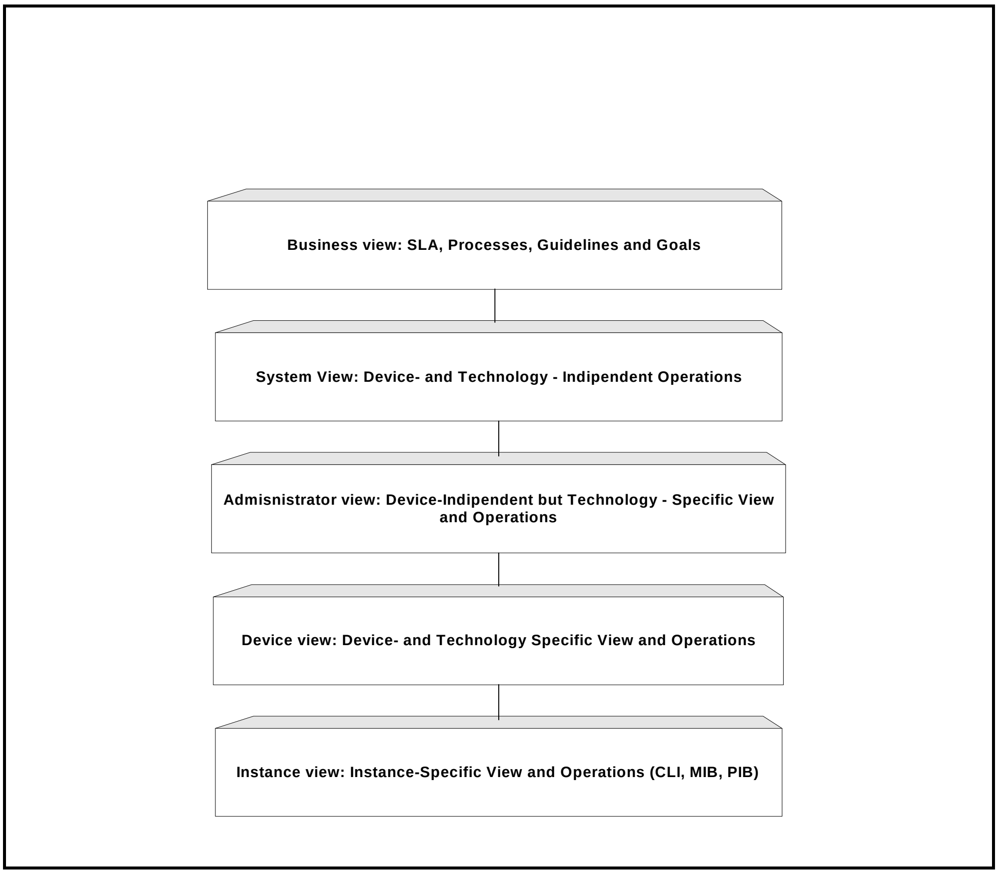


FIGURE 10 Policy Continuum

## 5.5 Location and Center of the Control and Management Systems

The highest machine operated (i.e. computer executed rules) management layer is the heart of the control and management system. It can be called the Network, System or/and Service Management System, which internally creates the overall picture of the state of the system, including views to all resources available in the system and network. A typical NMS system includes basic a Operation and Management[1] (O&M) server, which can be a single unit in smaller networks or a distributed clustered system for a larger managed system like the 3G network and the service production system usually are.

In both the theoretical and real worlds, the highest management authority is a human making decision on how the system should behave, in various situations. From the theoretical point of view, the decision phase is made based on RT measurements from the live system and the NRT trend is analyzed, based on KPI data from a series of various measurements. On the real world side, the human interface UI should be able to reflect the state of the system and give advise how to operate the system and networks. The real system can also be fully or partially automated, to pass only system state information towards a human and only in situations that cannot be automated or solved by automated action orders given through a suitable interface.

In practice, tele- and data-com systems can be seen as classic examples of real time process automation systems, thus the same design and policy definition rules and practices can be applied on both of them. Therefore, a new path towards better controlled and managed tele- and data-com systems, can come from the automation research and development directions.

## 5.6 Policy Management Languages

Policy Management languages can help when managing large and complicated system, by bringing the management tasks to an upper level of abstraction, which is easier to understand and which is closer to both human understanding and to the human trouble domain.

Any executable language, available at runtime, can be used in a policy based management system and can be considered to be policy management language candidates. Typical examples are the Perl language or even operating system command languages such as Unix or Linux scripts. In addition to this, there are some specialized policy management language projects such as Ponder [39] and it's applications [92, 93, 94, 95], PAX [51], SRL [52], Network Path Policy Definition Language [53] and RPSL [54], which represent efforts trying to develop a domain specific policy language for the network management area. Ponder has also been proposed to be standardized in IETF, but at the moment no positive decision have yet been reached.

As the XML language has reached a common acceptance for use as a common intermediate language platform, it could be used as a carrier and development tool for special Policy Based Management areas such as Radio Network Management.

Extensive work has been done on the research of Policy Based Management languages, where the goal has been to define a proper approach to the problem, as well as to define the basic requirements for a common and widely acceptable language model [39].

## 5.7 Policy based management systems in Telecom networks

Most of the Telecom networks are modeled and managed according to Telecommunications Management Network (TMN) model. The basic configuration and reconfiguration actions are made through element managers. These managers are orchestrated by a logically centralized but physically distributed network manager [17].

In the telecom area system management architecture is based on Element Management Model (EMS) where each element is managed by them selves and alone. The concept of a common Network Management System (NMS) has to defined and developed by each operator by them selves because tele-equipment vendors provide only basic tools to management the Network Elements, not the systems. This is a future challenge that tele management Forum is targeting with it's NGOSS system definition. Some earlier policy based management models and framework studies exist like in [91]. The manager can have a network-wide policies and it is implemented through an automated logic supervising the network elements and their reconfigurations. The new TeleManagement Forum's (TMF) Next Generation Operations Support Systems (NGOSS) has taken the Policy Based Management as one of its main targets [20]. PBM is believed to be one of the key elements of the new NGOSS management system model and later the key element in the implemented management systems.

Current research has defined several similar management models for the 3G networks [84, 86, 88].

## 5.8 Policy Based QoS, Charging and Service Control and Management Systems

All lower level Policy decisions are based on the operators business case decisions and so therefore the operators business control system would be the best strategic location point for the top-level Policy Based Management system. All rules and decisions based on those rules should then be reflected to the network, system and service levels in the operator's entire tele-service production system. Usually, at this stage of the PBM evolution, operators' business systems do not have any interfaces to the network and system level PBM and consequently the business requirements are interpreted and taken into use by some other way, which is usually manual in nature.

A very popular approach to the combined QoS, charging and service control has been a Resource Broker type of solution, where a control entity called a broker shares the service and network Resources, based on some optimization or maximization schema. In these cases, operator revenue with some other QoS constrains have been successfully used in these types of scenario [72].

## 5.9 Policy Based QoS Management and Traffic Engineering

The easiest and the most popular PBM subject, in recent years, has been Policy Based network QoS management, which was followed a little later by Traffic Engineering. PB QoS management is probably the best-defined PBM item. IETF has made comprehensive definitions for both DiffServ and RSVP management as well as the basic framework definition for PBM.

The difference between Traffic engineering (TE) and real-time resource control and reservation is that TE is based on the fixed routing and traffic constrains along the routed path. Dynamic resource reservation like RSVP is actively changing the properties of the routed network path constantly, thereby causing continuous fluctuations to the network resources and traffic QoS properties.

## 5.10 Policy Based 3G QoS and Service Management

The basic network and transport technology of the present 2G, 2.5G and also in the near future 3G, is and will remain ATM. Therefore any All-IP based QoS and policy management scenarios and research is partly now outdated, due to the fact that earlier planned implementations of All-IP, have been postponed and will be considerably delayed, compared to the earlier time schedules. [71]. The most popular solution proposal had proposed to use DiffServ in the network level and to map the wireless 3GPP traffic classes into Per Hop Behavior (PHB) classes with the help of DiffServ Code Point (DSCP) as described in [90].

In the future, when the All-IP architecture finally materializes, All-IP based QoS control and management research can then be finally exploited in the 3/4G network area [80, 85, 87]. During all of the development of the 3/4G area, QoS issues have been present the whole time and have been standardized since 1999[7, 8, 9, 107].

## 5.11 Policy Monitoring

The key element of policy [based] system functionality is the ability to monitor and meter the efficiency of the enforcement of the policy system rules. This can be done indirectly by monitoring the system and its efficiency and by estimating the efficiency of the policy system by the obtained measurement results. This is the usual (legacy) way to tune the policies and it will take a longer time and more research to find answers to the questions: what rules should be executed in the system, as well as how this should be done. An alternative way is to monitor the policy system and policy usage as in [44, 83].

## 5.12 Policy Based Management in the future 3/4G network and system management systems

The [PVI] gives an overall picture and description of a framework for the future 3/4G network management, based upon use of PBM. The presented model is compliant with the TMF NGOSS, as it should be to, in order to gain official acceptance. It also follows all pertinent IETF PBM standardization and agreements, as required for true openness and 3rd party compatibility. It holds the standardized components, COPS protocol interface for policy distribution and negotiation, PDP for policy decisions, PEP for policy enforcement and the basic DiffServ and RSVP-PIB and some new 3G related PIBs, which may be defined by the relevant network vendors themselves for their own network element equipment.

The [PXI] discusses issues concerning the best policy rule language, it's requirements and possibilities. As the XML language has reached wide acceptance in all areas, as a means to transfer structured knowledge of any kind, XML would be a good choice and indeed a clear candidate for policy rule distribution. Without any extra standardization work, the XML language is already suitable and easily forms a basis for any common or tailored restricted area management language.

The possibilities of the applicability of XML are shown with examples in [PXI]. The [PXI] also contains an interpretation and mapping of the TMF NGOSS policy model entities into the real world functional entities used in real PBM systems.

## 5.13 Results

For the future well being of the next generation networks, PBM represents an opportunity to reach something that the current control and management systems have not been able to do. This opportunity is the possibility to control and manage in Real Time an entire new ¾G network and service system, which previously has been beyond reach of any current management system. There is still much to be done in the research, standardization and development areas, but the foundation of the future development structure is already laid down and the development of the new management system model and associated framework can already be started.

Publication [PVI] contains a Policy Based Management model for a future 3G services network, containing a model based on IETF, 3GPP and TMF defined standards and recommendations. The presented model will be used as basis for the development of a network management system for the next generation 3G-system.

The most important parts are the new policy information base definitions for new domains that are not yet defined by the IETF Policy Based management standardization and the integration model for the management system to use a common management language on all levels of the management system components.

The basic management model has three main layers. The highest layer is the user level containing user interface and Policy Management functionalities. In FIGURE 11 the main function the Policy Server is located in the Management Server.

The middle layer is the network management layer. It contains network management level policies.

### 5.13.1 Resource management architecture for 3G networks

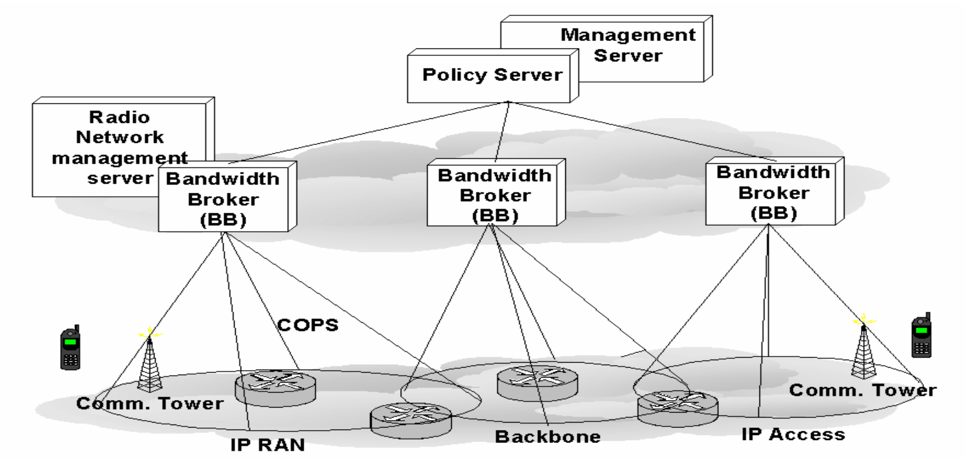


FIGURE 11 Resource management architecture

These policies can be domain specific as presented in FIGURE 11 containing 3G RAN, operator Backbone and other IP access domains. Rules for different domains can be considerably different from each other. This layer can also have semi-fast (1-5 seconds) control loop activity to tune the network domain performance.

The lowest layer is the network element level. This is the traditional management area, which is now combined to higher and smarter level control and management.

Publication [PXI] presents the common XML based language model to be used with 3G Policy Based Management. As XML is a widely exploited and accepted standard, it will be easily adopted as one of the PBM definition languages. [PXI] also presents the mapping model from the PBM to the TMF policy and event model, which are the key elements for the PBM functionality.

### 5.13.2 Policy Based Management architecture for 3G systems and networks

FIGURE 12 presents the architectural basis for the 3G network and system Policy Based Management model.

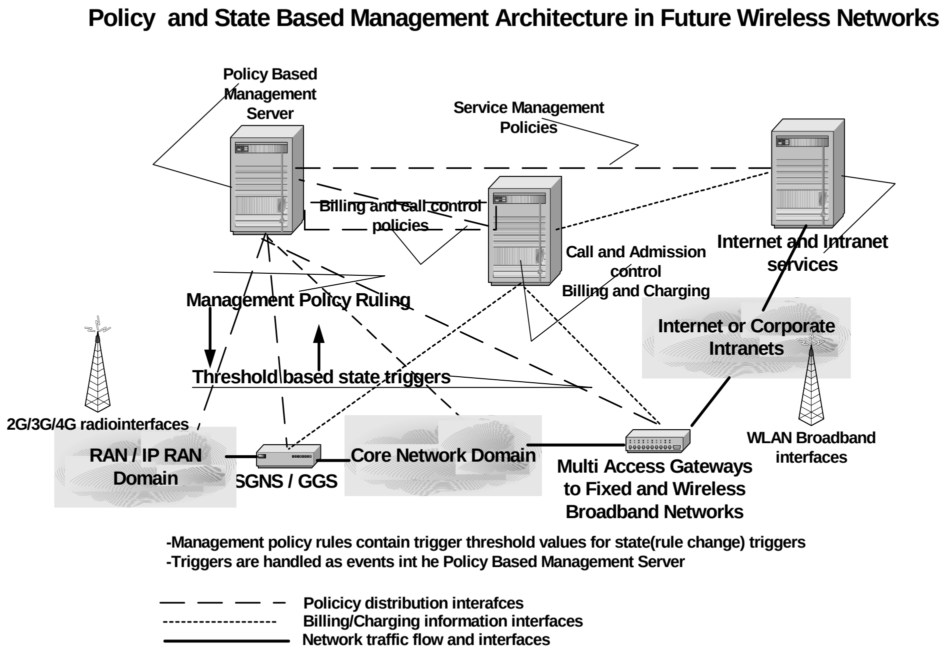


FIGURE 12 Policy Based Management Architecture in 3G Networks

It is based on the same principles and ideas as the former IP RAN model with some new and more mature views to the subject. It is also based on the latest IETF Policy related standardization and the future TMF NGOSS PBM management model.

To be able to serve and manage in the ultimate cases more than 100 000 Networks elements, in real time, a new and novel management innovations and inventions have to be presented. An example of a new control and management architecture as well as a completely new and state based control idea is presented as a part of the future research projects.

### 5.13.3 State based management model

FIGURE 13 depicts the relationships between different control functionalities and the threshold states of the control state machine. Here the load control is only an example and any other state based function can be used here.

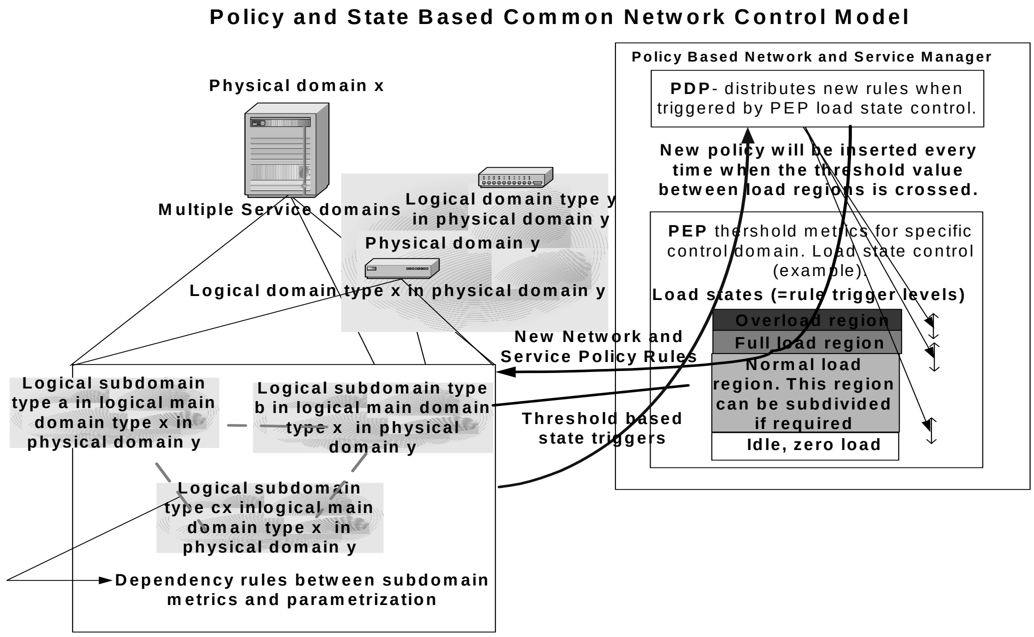


FIGURE 13 Policy and State Based Common Network and Service Control Model example

In the example in FIGURE 13 any state transition can trigger a new policy request, from PEP to PDP (or LPDP if applicable) and a new Control Policy for the network or service will be loaded into the PEP. In some cases for policy change, a certain state pattern and a state change (or multiple state changes) are needed.

State based management model for 3G systems and networks is the second patented innovation included into the thesis.

### 5.13.4 Summary

PBM control and management research goals have been to develop and define a solid and robust model for future 3G and 4G control and management. The reason for needing a new control and management model is that the current models and tools are simply inadequate and ineffective and their performance is simply to low for future Real-Time control and management challenges.

# 6 3/4G, WLAN AND COMPLEMENTARY ACCESS INTERWORKING

The next step in the 3/4G connectivity evolution will be complementary access. This means that all existing network access technologies are connected together and in wireless environment the seamless handover between different wireless technologies is supported as a default. All 3G services will be available through different access methods and the properties of the services are adjusted according to the used network terminal or equipment capabilities.

The re-configurability of networks, terminals, network inter-working, application adaptability and business models etc. will raise major new challenges. The early stages of this trend may be seen in present commercial activity to create wireless network inter-working involving 2.5G and 3G cellular systems, 802.11 wireless LANs (WLANs) [65], 802.15 Wireless Personal Area Networks, (WPAN)[66], and 802.16 Wireless Metropolitan Area Networks, WMAN [67], to deliver services over a type of always-on (or always-connected) wireless network access connection service, at attractive location-dependent price/performance ratios [68, 69].

At the time of writing this thesis, the standardized maximum speed for the 3/4G cellular networks is 2Mb/s and the fastest xDSL connection can reach up to 8Mb/s. It would of course be very nice to be able to connect both of these medias with 1:1 speed to each other, however the speed for 3G/WCDMA connections are mostly limited to 384 kb/s or at maximum 512kb/s for User Equipment (UE) due to technical restrictions. Adding WLAN 802.11 with speeds up to 54 Mb/s to this scenario, means that we will face a very difficult - and yet unsolved-Inter-working and QoS problem.

The future speed of 3G networks is expected to increase towards a maximum of 8-16Mb/s in the future. This will be achieved by enhanced UMTS technology High Speed Downlink Packet Access HDSPA and 64-QAM modulation [21].

IEEE 802.11 Task Group-E is working on 802.11e standard proposal that is targeted to the WLAN area whilst the IETF RAP working group is looking at the Internet side of the problem and finally the 3GPP TSG working group S2 is looking for a solution to the 3/4G side of the problem. IEEE 802.11e is still in a draft state, but the expectations of getting it ready during the next two years, are high.

Some similar research projects on 3G WLAN Inter-working have been executed as [101, 102, 103, 104, 105, 106], but the official Inter-working model Rel. 6 from 3GPP will be frozen by the end of year 2004.

## 6.1 DiffServ and IntServ

DiffServ and IntServ are the 2 main QoS management models for IP networks. DiffServ[119] uses traffic aggregates that are controlled by routers using DiffServ Code Point in IP (DSCP) packet header. DiffServ's advantage is that it does not need nor use any signal along the routed path.

IntServ[120] uses resource reservation signaling that is sent through the path that the traffic packet is routed. Every time a new connection is established this resource reservation signal has to be sent and the reservation must be kept up by additional refreshing signals, and because of the signaling traffic IntServ has been seen as poorly scalable in large networks. However in the future 3G and 4G network flow based resource reservation will become dominant and IntServ will be one of the main choices when choosing the future QoS management method.

## 6.2 3G WLAN Interworking Model

All the main functionality needed for 3G WLAN (Rel 6.0) Inter-working has been defined in [10,11, 12, 13, 14, 55]. The general model is presented in FIGURE 14 [55]. The basic idea is that the WLAN UE uses the same identification and subscriber information as the 3G UE and subscribers. This enables the WLAN subscribers to use same or similar services as the 3G subscribers and the knowledge of the user services is then located in one centralized place for simplicity.

Interface Ww is a basic 802.11x [37] radio interface with (or currently without) MAC 802.11e QoS capabilities. The Wu interface is located between the WLAN UE and the Packet Data Gateway (PDG) and it presents a tunnel transporting traffic between WLAN UE and PDG. The Wn interface is located between Wireless Access Gateway (WAG) and the PDG in the Home Public Land Mobile Network (HPLMN). The Wa interface is connected to WLAN networks and it is used for EAP authentication between the WLAN AP and the 3G AAA systems. The Wa interface may require a protocol conversion capability to 3G AAA protocol. The Wg interface is an AAA interface between the 3G AAA server and the WAG. The Wp interface is between the WAG and the PDG and provides WLAN 3GPP IP access. The Wi interface provides IP access to public (or private) data networks. Other interfaces, Dw, Wx, D'/Gr' Wf and Wo provide connections to the corresponding 3G services, SLF, Home Subscriber Server (HSS), Home Location Register (HLR), Charging Gateway (CG).

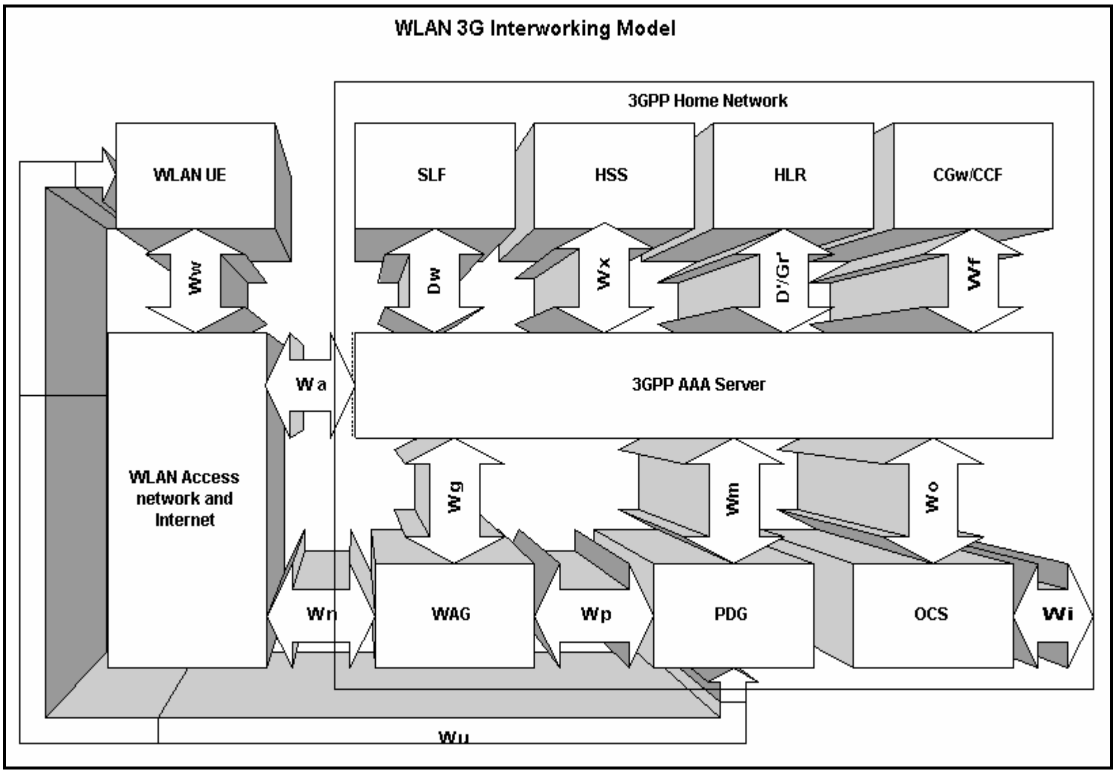


FIGURE 14 WLAN 3G Interworking reference model and interfaces

## 6.3 3G Complementary Access

3G Complementary accesses can be understood in the 3G contexts as any additional access technology that provides inter-working capabilities with 3G technologies. These technologies are WLAN, Bluetooth 802.15.1[70], WiMax 802.16[67], Ultra Wide Band (UWB) 802.15.4[67] or any other future wireless technology. Also fixed networks can act as complementary access networks towards 3G. Typically home connections or even WLAN core connections are sometimes done with various ATM based xDSL techniques and if these system have connections to the 3G infrastructure and service functionality, they can be considered to be 3G complementary access connections. In the future, complementary access will be a fundamental basis for the tele- and data network, entirety, and 4G systems.

Complementary access is quite a new research area and it has become important quite late on, because of the 3G-network development and implementation. There are preliminary and common research results available publicly [97] including results on management [98], but the most important results are still in the hands of tele- and datacom vendors, due to the fact that the complementary 3G access technologies are also the key to the future 4G technologies.

## 6.4 QoS in complementary access networks

At the moment the most important QoS question in the complementary access area is the WLAN Inter-working QoS including it's control and management. The most promising direction that is somehow visible at the moment is IEEE 802.11e WLAN QoS, which provides DiffServ or IEEE 802.11o/q type aggregate QoS classes to the air interface. The more challenging flow based QoS and its management has been yet proposed from any direction neither the research nor the tele- or network equipment vendor side. The advantage of the 802.11e technology lies in the similarity of the functionality and it's mappability to the DiffServ or 802.11p/q priority queue models that can be easily applied in the future systems and equipments.

For the flow based QoS control, the future of WLAN radio interface remains to be seen. A solution to this problem will be possible through the new wireless radio techniques, which enable larger bandwidth and more simultaneous capacity for multiple users to be controlled and managed. Until these techniques and mechanisms have emerged, the main QoS control functionality will be a combined DiffServ, 802.11p/q and WLAN 802.11e QoS cross mapping in the WLAN AP and air interface. Because of the increasing importance of the complementary access in operators integrated network infrastructures, complementary access is therefore widely under investigation.

## 6.5 Results

Publications [PVII, PVIII, PXII and PXIV] are concentrating to give a clearer picture what happens and what are the consequences when creating an End-To-End QoS environment in a complementary access case [PX], where the core QoS is handled in the RAN part with the pre-configured legacy ATM links between WBTSs, RNCs and SGSN and the Core network links using either DiffServ or RSVP, and the WLAN radio interface using the future WLAN QoS standard 802.11e.

These scenarios are important since the radio interface in certain multi AP circumstances represents a hub like functionality, where all QoS vanishes under equally competing wireless CDMA stations. This intensive competition will surely lower or even prevent any real time speech or video connection, disturbing markedly also any Interactive type connections. I have believed that with a correctly configured 802.11e environment a fully satisfactory 3GPP traffic/QoS class based traffic is possible and that it will enable the ¾G network evolution up to the current WLAN connected workstations and the handsets coming later. The results in papers [PVII, PVIII, PIX and PXIV] have shown that a considerable improvement can be achieved by the combination of the current QoS techniques in the complementary access and WLAN case.

Publication [PX] concentrates also to define alternative complementary access QoS management models, which can be applied in the future datacom as well as 3G-network management. Each alternative solution has been explained and evaluated. The status of the 802.11e standard is still open, but the majority of vendors are already working on developing 802.11e compatible equipment for the market, in preparation for when the standard is approved.

### 6.5.1 General Issues

With the evolution of QoS-capable 3G wireless networks, the wireless community has been increasingly looking for a framework that can provide effective network-independent end-to-end QoS control. One big problem arises with these kind of diverse networks: namely the dissimilarity of traffic characteristics and QoS management methods in access and core networks. The problem with WLAN networks is the high error rate probability. IEEE 802.11e standard has been applied trying to correct the situation by enabling the use of a maximum of eight separate priority queues for prioritizing higher priority traffic compared to other traffic. QoS supported WLAN uses the *Enhanced Distributed Co-ordination Function* (EDCF), which is the basis for the *Hybrid Co-ordination Function* (HCF).

RSVP has been used in domains, where there is no direct radio interface. In the RAN case we have assumed that the radio interface between BTS and UE in RAN will be handled similarly to WLAN but with different methods defined by 3GPP standardization. As RAN is based on ATM, the basic assumption has been that the RAN is correctly dimensioned to carry all traffic coming from and going to UE direction, so by default RAN QoS is out of scope of the scenarios considered in this article.

### 6.5.2 Mapping QoS attributes to cross domain interfaces

3GPP has defined four traffic (QoS) classes and three subclasses (Interactive THP, Traffic Handling Priority) that can have their own QoS attributes [3]. All traffic in the 3G network will be handled according to the operator and service's requirements for each of these traffic classes. The main QoS method to be used at the core network is supposed to be DiffServ [1]. In addition to that, 3GPP has defined RSVP as an additional UE originated QoS method in 3GPP Rel6 between UE-SGSN (UE Serving GPRS Support Node) and GGSN (Gateway GPRS Support Node). RSVP can be used in the situations, where scalability problems will not arise (e.g. small networks). 3G traffic classes are: *Conversational* class (for voice and real-time multimedia messaging), *Streaming* class (for streaming applications like Video On Demand (VOD) etc), *Interactive* class (interactive applications like eCommerce, WEB-browsing, etc.) and *Background* class (for background applications such as e-mail and FTP). QoS values for each traffic classes are defined in [2]. In DiffServ domain four priority queues can be implemented for each of the 3G traffic classes. The three THPs (Traffic Handling Priority) are also available for *Interactive* class to further sub-classify class traffic by inserting it to three separate queues. 3G to DiffServ mapping process can be policy based controlled and the mapping can be indicated at the IP level by the DSCP (DiffServ Code Point) inserted to the TOS field by DS classifier/marker mechanism, or by the actual application that generates the control plane traffic.

The nature of RSVP functionality differs significantly from DiffServ. RSVP uses end-to-end signaling enabling a single UE to reserve end-to-end transport capacity from the network or RSVP can be used by Bandwidth Broker and COPS-PR (Common Open Policy Server Policy Provisioning) protocol to set appropriate traffic filters to routing nodes, to achieve similar capacity reservation than by UE signaling.

### 6.5.3 Simulations

The goal for the simulations is to study how much the throughput of the traffic decreases with various error rates, while changing the traffic mix and average packet sizes of the individual traffic class.

We used network simulator version 2 (ns-2) with IEEE 802.11 EDCF functionality implemented by Ni Qiang et al. in the Planete Project-INRIA [118]. To emulate the process of packet transmission errors, we extended the simulator by implementing a two-state Markov model to the air interface.

We used network simulator ns-2 with IEEE 802.11 EDCF functionality implemented by Ni Qiang et al. of the Planete Project-INRIA [118]. To emulate the process of packet transmission errors we extended the simulator by implementing a two-state Markov model in the air interface. MMPP is a doubly stochastic process where the intensity of a Poisson process is defined by the state of a Markov chain (see Fig. 15). The transition matrix $Q$ of the modulating Markov chain is defined by

$$Q = \begin{bmatrix} -\omega_1 & \omega_1 \\ \omega_2 & -\omega_2 \end{bmatrix} \quad (53)$$

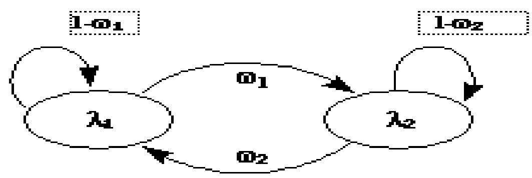


Fig. 15 State machine for a 2-state MMPP

In our error scenario, the channel switches between a "good state" and a "bad state", G and B respectively: Packets are transmitted correctly when the channel is in state G, and errors occur when the channel is in state B. When the channel is in state G, it can either remain in this state, with probability $\omega_1$ or make the transition to state B, with probability 1-$\omega_1$. Likewise, if the channel is in state B, it remains in this state with probability $\omega_2$ and changes state with probability 1-$\omega_2$.

### 6.5.4 Optimal packet size

The best packet size combination was found from the simulation results by calculating an emphasized factor for all packet size combinations. The factor was calculated by using the formula (53)

$$S_i = D_i + T_i , \qquad (53)$$

where

$$D_i = \sum_{j=1}^{4} 100 * \delta_j * d_j^i \qquad (54)$$

and

$$T_i = \sum_{j=1}^{4} 100 * \tau_j * b_j^i . \qquad (55)$$

$D_i$ is a total delay factor and $T_i$ is a total throughput factor calculated from the results of all classes. $\delta_j$ is the weight coefficient of the delay of class *j* and $d_j^i$ is the factor calculated to the delay of class *j* at the iteration *i*. $\tau_j$ is the weight coefficient of the throughput of class *j* and $b_j^i$ is the factor calculated to the throughput of class *j* at the iteration *i*. The delay factor $d_j^i$ is a factor between 0 and 1. It was calculated with formula (56)

$$d_j^i = \frac{d_j^{\max} - d_i}{d_j^{\max} - d_j^{\min}} , \qquad (56)$$

where $d_i$ is the measured delay at iteration *i*, $d_j^{\max}$ is the maximum limit of delay of class *j* and $d_j^{\min}$ is the minimum limit of delay of class *j*. The factor of all delays above the maximum limit is 0 and the factor of all delays below the minimum limit is 1. The throughput factor $b_j^i$ is also a factor between 0 and 1. It was calculated with formula (57)

$$b_j^i = \frac{b_i - b_j^{\min}}{b_j^{\max} - b_j^{\min}} , \qquad (57)$$

where $b_i$ is the measured throughput at iteration *i*, $b_j^{\max}$ is the maximum limit of throughput of class *j* and $b_j^{\min}$ is the minimum limit of throughput of class *j*. The factor of all throughputs above the maximum limit is 1 and the factor of all throughputs below the minimum limit is 0.

If there was no maximum and/or minimum limit defined for the delay or the throughput, the lowest result was the minimum limit and the highest result was the maximum limit. Coefficients $\delta_j$ and $\tau_j$ define how much weight are given to the delay and the throughput of a class *j* when calculating the total delay and the throughput factors.

With low error rates the weights on high priority class traffic characteristics are low, because when error rate is 0% or 20%, the delays and the throughputs of high priority classes are very satisfactory - with all packet sizes. Thus, with these error scenarios low priority classes' traffic characteristics can be emphasized, especially throughput, because delay is not an important issue with best effort traffic classes.

As the error rate increases, high priority traffic class traffic becomes more important, and their weights are raised. When the radio channel packet error rate is as high as 40%, best effort traffic class traffic characteristics are given no weight. In addition, the delays of Conversational and Streaming classes are so low that the emphasis is more on classes' throughputs. When the error rate is 60%, the highest priority traffic class gets all the weights.

An interesting issue arises from the results with the fact that the highest priority traffic class will get more bandwidth when the packet size and the channel error rate are increasing. With the proposed 3G traffic classification specifications this can lead to the situation that the highest class uses all the capacity under certain network conditions. Our simulation results proved this issue clearly. Based on that it is important to find out the limits where packet size and channel error rate can change. If we think for example the situation where we have small size high priority packets (voice traffic) under heavily loaded network i.e. channel error rate is high, we will lose also those small size high priority packets. In 0% and 20% error scenario, the best results are achieved when the highest-class packet size is about 1500 bytes, but if the error is very high (we tested with 60%), smaller packet size gives the best results.

### 6.5.5 IntServ versus DiffServ

Research results show that the throughput in DiffServ case is slightly better than in RSVP case. That is expected due to the resource reservation nature of RSVP. In DiffServ case all traffic classes can have unlimited number of flows compared to RSVP's bandwidth limiting functionality and access control.
The difference between these techniques is almost negligible due to the fact that both RSVP and DiffServ achieve the maximum capacity of the network. This is due to the amount of traffic in the network: the flows are sending traffic so intensively that there is always a demand of the bandwidth for best effort traffic and hence the network is quite overloaded all the time.

### 6.5.6 Summary

When starting the WLAN 3G interworking research the goal was to define a model to connect 3G QoS and WLAN 802.11e QoS under the same management model and ideas and study what the effects and benefits are compared to non-QoS cases. The reason for selecting just 802.11e for WLAN is the fact that no other QoS model has been presented so the choice was obvious.

# 7 SUMMARY

This work concentrates on defining models and scenarios for various 3G pricing and complementary access scenarios and simulating them. The main contributions of this thesis are the applicable management models for Policy Based Management, QoS and pricing in 3G and the complementary access areas.

This research and related simulation results have been used in various related documents in telecom QoS, pricing and network management development areas, by both the research community and the company that employs the author of this thesis. Also two patent applications (one US and one domestic) have been submitted concerning the research work related to the thesis.

The introduced concepts and presented models are new and based on the innovations of the author but were done in co-operation with the research teams from various universities and inside the Nokia Corporation.

The 3G pricing studies have taken a fresh view to the subscriber acceptance matter in 3G and services, which are very difficult to study because of the long time frames involved and the huge amount of material needed for the research. In the QoS and complementary access areas, the early start in 1999 was shown to be the right choice for the second research area, as they have become highly important for both the 3G and overall network and service management development. The ideas and models presented in this thesis are applicable and coming into the 3G market in due time, as part of the 3G evolution. The main contributions of the work are the pricing model for the 3/4G service networks where all QoS and subscriber constrains have been taken to account and handled in a proper way, while the optimization of the revenue of operators have been assured. In the Inter-working area, the most important network and service integration model with the 3G-WLAN and fixed networks have been defined and studied with simulations. In the PBM area a new management model for the whole 3/4G service networks has been defined and in addition new and needed Policy Information Bases (PIB) have been included. The language basis needed for PBM definitions have been introduced and the management model mapping to the TMF recommendations has been done. This work forms a solid basis for the future 3/4G management system design and implementation.

## 7.1 Future studies

Future studies and research are concentrating on the operability and management of the operator networks and services in the 4G areas. Whilst the wireless networks are growing towards complementary multi-access networks, the multiplicity and role of services is becoming more and more important. For this reason more and more efforts have to be taken to develop a new and more precise service monitoring and management systems, which is the next challenge for the wireless and wired equipment vendors. Also the standardization plays a very important role to unify and enable multi-vendor environments that optimize the performance, CAPEX and OPEX from the operator's point of view.

# FINNISH SUMMARY

Tutkimus käsittää kolme asiakokonaisuutta, jotka kuvaavat monipääsy-palveluverkkoihin liittyviä ongelma- ja tutkimusosa-alueita.

**Palvelun laadun (QoS) suhde laskutukseen**

Ensimmäinen osa käsittelee 3/4G- ja WLAN-verkkojen palvelun laadun laskutusta, säätöä ja hallintaa sekä esittää laskutus- ja säätömalleja analyysien ja simulointien avulla. Palvelun laadun ja laskutuksen suhdetta on jo aikaisemmin tutkittu laajasti, ja tutkimuksen tulokset ovat helposti sovellettavissa langattomiin 3/4G- ja WLAN-verkkoihin. Edellä olevaan liittyen on myös tutkittu tilaajan hyväksymissuhdetta palvelun hinnoitteluun. Tästä on esitetty verkkopalvelujen hinnoittelun hankintamalli operaattoreiden tarpeisiin ja tarkasteltu mallin käyttöä verkon kuormituksen säädössä. Tutkimuksessa on myös esitetty dynaaminen malli verkkopalvelujen hinnoittelun optimoinnista tilaajan kaistanleveyden, viiveen ja pakettihukan suhteen.

**Verkkojen politiikkapohjainen hallinta (Policy Based Management)**

Tietoliikenteen lisääntyessä data- ja televerkoissa ja verkkojen teknologioiden ja rakenteiden monimutkaistuessa sekä siirryttäessä piirikytkentäisestä 2G-teknologiasta pakettipohjaisiin 2.5/3/4G -verkkoihin tullaan tilanteeseen, jossa verkkojen hallinta muodostuu mahdottomaksi käsitteiden ja niiden kombinaatioiden määrän kasvaessa. Tähän ratkaisuksi on kehitetty hierarkkinen politiikkapohjainen säätömalli, joka mahdollistaa yksinkertaisen verkkojen ominaisuuksien säädön ylimmältä, verkko-operaattorin hallintakäsitetasolta ja poistaa tarpeen tuntea tarkasti eri verkkoelementtien säätökäsitteistöä. Esimerkkinä hallintapolitiikan kuvauskielestä on esitelty XML-kieleen pohjautuva radioverkon säätökieli RAML (Radio Access Management Language).

**3/4G- ja WLAN-verkkojen palvelun laadun integroitu hallinta**

Tutkimuksen päätavoite on ollut tutkia monipalveluverkkojen problematiikkaa. Työn päätulos on 3/4G- ja WLAN-verkkojen palvelun laadun integroitu säätö ja toiminta. Työssä on esitetty hallintamalli ja tehty simulointitutkimus eri palvelun laadun hallintamenetelmien vaikutuksesta käyttäjän saaman kaistan leveyden, viiveen ja pakettihävikin suhteen käyttäen WLAN-radiorajapinnassa QoS-standardia 802.1e.

**Yhteenveto**

Tutkimus esittää useita vastauksia kysymyksiin, jotka nousevat esiin 3/4G-verkkojen palvelun laatuun liittyvään säätöön ja hallintaan sekä laskutukseen. Tärkeimpinä ovat tilaajan hyväksymissuhde palvelujen hinnoitteluun, palvelun laadun säätö verkkoon pääsyn (Call Admission Control) avulla, 3/4G- ja WLAN-verkkojen palvelun laadun säädön yhteen liittäminen sekä yhteistoimintamallin määrittely, politiikkapohjainen säätö ja hallinta (Policy Based Control and Management).

Joidenkin tutkimuksessa esitettyjen tulosten suhteen pitää kuitenkin pitää mielessä, että kaikilla tutkimuksen osa-alueilla tutkimustyöt jatkuvat tämän julkaisun teon jälkeen.

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