

# Teletraffic requirements and system aspects for future mobile communications

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**Abstract**— The target of Next Generation Network (NGN) is to provide Quality of Service (QoS) assurance for demands emerged from different applications of nomadic users with any mobility pattern. The intention of this paper is to bring together the state-of-the-art knowledge in telecommunication networks design areas to improve the quality of NGN system design, and also to bind these different areas in order to understand and foresee specific issues. Proper system design and advanced optimized resource management schemes must be adopted to allow each user be connected to the preferred access network at any instant of time. Vertical optimization of the protocol stack as well as horizontal integration of different systems are the mandatory points. Moreover, the adoption of the IP protocol for mobile environment and extension of packet-based services to the air interface calls for innovative QoS approaches and advanced performance modelling efforts. These new challenges require the development of new methods of teletraffic theory and the special attention should be paid to traffic and wireless link modelling techniques.

## I. INTRODUCTION

The development of mobile communication systems shifts approximately in ten years cycles. Nowadays, with the commercial launch of third-generation (3G) networks, we have to face the question of what a fourth-generation (4G) scenario might or should be. Rather than linking 4G to something like 'yet more bandwidth', the trend is to see 4G as a new paradigm for wireless networks, mobile and fixed, where network and service characteristics of reconfigurability, interworking, adaptable services and interoperability are the order of the day. 4G systems should provide intelligent, adaptable and personalized services by encompassing all wireless systems from public to private, operator-driven to ad-hoc, broadband to personal area, 2G systems to 3G systems.

4G systems should be flexible enough to support all those services of today's fixed networks without any limitations, and to provide them in an Always Best Connected (ABC) access strategy [1], so that the users are granted with the most suitable connection for the given environment, satisfying as much as possible the QoS requirements of the service and the user at a price which is right for both. Such features should be realized through multi-access networks and should be transparent to the user.

However, one of the first major challenges is to address the QoS question in the end-to-end IP scenario. This is an inherent problem for many service types even in fixed networks. Wireless and mobility add their own QoS problems on top of this inherent IP flaw. This paper will focus on new ways through which 4G All-IP networks may provide QoS guarantees, thus requiring the definition of appropriate network architectures and QoS frameworks as well as traffic and mobility issues.

3G systems have created the basis for multimedia traffic with QoS support on the move. We expect that 3G systems architecture and related QoS provision approach should evolve to face the challenges of future systems. QoS is not assured for each particular traffic flow, but rather is guaranteed for the aggregated flow of a given class. This approach does not seem valid for future scenarios where plenty of applications and different user profiles will require a finer characterization of QoS levels. Additionally, call level performance indicators such as call blocking probability and handover failure rate, typical for 2G systems, should be integrated with packet level QoS metrics dealing with packet error, packet delay and so on. Finally, current 3G systems are characterized by lack of energy efficiency considerations, end-to-end seamless transport, reconfigurability and application scalability. Additionally, inherent characteristics of mobile users' like their mobility and traffic demands as well as typical features of mobile systems like unstable nature of the air interface have to be addressed before the required quality and transparency of user services will be achieved by mobile systems. These limitations have to be overcome in future 4G All-IP systems.

The reminder of the paper is organized as follows. In Section II we consider principles of system design for NGN networks. Section III is devoted to QoS assurance in 4G mobile networks. We also consider possible approaches for the end-to-end QoS provision. Teletraffic aspects of the air interface are considered in Section IV. The last section concludes this paper by highlighting the requirements imposed on future 4G systems.

## II. SYSTEM DESIGN FOR PERFORMANCE OPTIMIZATION AND NETWORK EFFICIENCY

As mobile wireless communications evolve from supporting circuit-switched, voice-centric systems to future 4G All-IP networks the reliable, and efficient support of heterogeneous multimedia services becomes significantly important [2]. In this scenario, system design becomes an important task, especially for what concerns the provision of effective solutions for the ubiquitous access to Internet and the QoS guarantee for different traffic classes. The system must be optimized to improve the performance perceived by users and the efficient use of network resources, which is an important prerogative for making revenue for operators and for allowing the realization of services at affordable costs.

4G system should be achieved as an evolution of 3G ones. Hence, it is important to consider basic aspects of the QoS mechanism implemented in 3G networks. 3G systems are based on the end-to-end classical layered QoS architecture, based on the Bearer Service concept (see Fig. 1). This is a flexible way of designating a kind of bit pipe at a certain network level (stratum concept), between given network entities, with certain QoS attributes and capacity. Each bearer service relies on the QoS-enabled services of lower layers [3], [4].

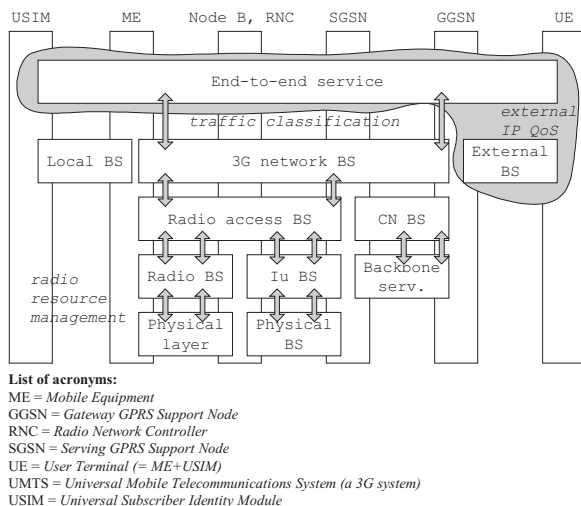


Fig. 1. Bearer Services (BSs) architecture at both different 3G interfaces and different layers for the packet-switched domain of the core network.

The QoS 'functions' in such architecture can be summarized as follows:

- End-to-end QoS management and support;
- Scheduling and dynamic resource allocation (air interface, RAN level);
- Transmission adaptivity and diversity to counteract the dynamics of the radio channel (air interface, RAN level);
- Connection Admission Control, CAC (air interface, RAN level).

Future 3G releases are oriented towards packet-switched traffics, IP and high-speed access. In particular, an innovative feature of 3G realization in UMTS - Release 5 is represented by IP-based Multimedia Services (IMS), with on an IP core

network (IPv6) and the handling of multimedia services using SIP signaling and the bearers offered by the packet-switched domain. However, 3G systems still leave some unsolved problems to 4G. Among others the substantial aspects are outlined below:

- Bandwidth restrictions limit the number of operators and constrain the data rate available per user;
- Energy consumption poses significant constraints in the design of terminals and calls for innovative concepts to be adopted for system design (especially, the air interface protocol stack);
- System dynamics is continuously changing in terms of traffic patterns and loads, user locations, network congestion, radio channel conditions;
- Lack of end-to-end seamless transport mechanism spanning different wireless and wired networks;
- Coexistence of heterogeneous services, needing different QoS levels;
- Lack of air interface reconfigurability for mobile terminals in order to allow the access to different wireless systems based on distinct technologies;
- Lack of scalability in applications and services depending on the access networks, etc.;
- Difficulties in roaming across distinct service networks (i.e., RANs).

According to the above 3G limitations, mostly related to RAN, the system aspects that need improvements in the migration from 3G to 4G can be outlined as follows:

- A new radio interface (physical layer, antenna system);
- Support of different RANs, e.g. through the Software Defined Radio technology;
- Vertical handover support between RANs;
- Interoperation of different networks with joint and optimized resource management: novel inter-system handover protocols and introduction of a resource broker for a centralized resource control with management of QoS on a session basis;
- Optimization of scheduling techniques for multimedia traffic under diverse constraints, QoS requirements and objectives;
- IPv6-based CN; IPv6-based macro mobility control for QoS support; use of IP micro-mobility protocols for an efficient management of intra-domain mobility;
- Novel design of the air interface protocol stack: (i) a cross-layer approach is needed to allow the exchange of information also between non-adjacent protocol layers; (ii) introduction of a middleware for the support of different access devices with heterogeneous characteristics.

Therefore, 4G system should be based on new optimization paradigms in accordance with two different and complementary approaches, as outlined below [5].

**Vertical Approach.** 4G system optimization calls for a vertical design of the air interface protocol stack. Such cross-layer approach requires interfaces between different platforms across the layers, which exchange control information beyond the standard ISO/OSI structure. Cross-layer interfaces can be within, between or beyond adjacent abstraction layers.

Although interfaces between adjacent layers are in general preferable, there can be the need for efficient and direct interaction between non-adjacent layers; in general, a layer should be aware of the other layers of the protocol stack. In fact, OSI layer 3 (e.g., IP) and above often need direct interfaces to OSI layer 2, e.g., for handover support. Another example concerns transmission parameters (e.g., transmission mode, channel coding and link layer retransmissions) that must be related to application characteristics (e.g., type of information, source coding, etc.), network characteristics, user preferences and context of use. Moreover, layers 2 should be aware of higher layer (i.e., 3 and 4) behaviors in order to take decisions on traffic management. In general, we can refer to the air interface protocol architecture shown in Fig. 2, with the proposed interactions among the different layers and with a middleware.

**Horizontal Approach.** In the 4G scenario, different wireless technologies will operate to allow the best access to the users, depending on their locations, mobility characteristics, applications, user profile, etc. This is in accordance with the ABC paradigm. Therefore it is necessary that the use of the resources in the different RANs be globally coordinated by means of a resource brokerage function. Such intelligence is centralized and allocates sessions to RANs or switches them from one to another, when some conditions are met.

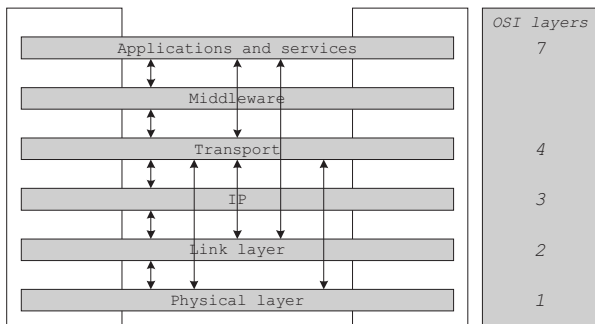


Fig. 2. Possible cross-layer interactions for the air interface in 4G All-IP systems.

### III. END-TO-END QoS OF 4G ALL-IP NETWORKS

A major weakness of current IP networks is that they do not provide QoS guarantees. Indeed, only the best effort service is supported, so that inadequate QoS levels may be obtained by real-time services. This problem will get even worse when multimedia services have to be extended to the air interface. Currently, the challenge is to add IP QoS in the reservation mechanisms of radio network technologies and to propose consistent end-to-end resource reservation model.

In the past, IETF proposed two QoS frameworks for IP networks. These are Integrated Services (IntServ, [6]) based on connection-oriented resource reservation principle, and Differentiated Services (DiffServ, [7]) based on service differentiation principle. IntServ, based on CAC procedures, can provide deterministic QoS guarantees and requires a signaling protocol in order to inform network elements about the necessary resource reservation. On the other hand, DiffServ employs a

different approach. In order to distinguish between packets with different QoS requirements DiffServ specification defines packets marking procedures. It provides probabilistic QoS guarantees to aggregated traffic flows and uses CAC algorithm, which is based on Service Level Agreements (SLAs) between subscribers and service providers or between two service providers.

Since interworking between 4G All-IP networks and the public Internet is expected, QoS provision should be based on the frameworks available for IP-based fixed networks. These are:

- Service differentiation;
- Connection-oriented resource reservation;
- Integration of service differentiation and connection-oriented resource reservation.

In following subsections we provide further discussions about these approaches.

#### A. Service differentiation

Due to high scalability, service differentiation can be nowadays seen as the most obvious approach for QoS provisioning in IP-based networks. IETF DiffServ working group has standardized two *Per Hop Behavior* (PHB) groups:

- *Assured Forwarding PHB* (AF PHB, [8]);
- *Expedited Forwarding PHB* (EF PHB, [9]).

AF PHB is designed for a range of applications, which require different QoS guarantees. There are four classes of PHB identification codes within the AF PHB group. Within each class there are three distinct DiffServ CodePoints (DSCP) with different packet drop precedence. EF PHB is targeted to applications, which require strict guarantees of end-to-end delay and should not suffer from packet losses.

One of the major advantages of the service differentiation approach is the unification of service classes within a certain domain. The availability of SLAs between domains allows to implement service differentiation on a networks basis. Due to a limited number of service classes, the mapping between user application requirements and network services can be easily implemented.

#### B. Connection oriented resource reservation

Considering the connection-oriented resource reservation approach for QoS provisioning we have to note that all network elements in this architecture have to be aware of a certain connection establishment protocol and should maintain per-flow state for each connection. Since the number of users within the coverage area of a cell is statistically limited, we can expect that a connection-oriented resource reservation can be successfully implemented at the RAN scale.

Implementation of connection-oriented resource reservation within the RAN can allow to achieve a deep granularity of network services. Indeed, in this case the set of possible services is not limited to a predefined number of classes, but can be extended to fit specific requirements of a wide range of applications. Since the parameters of resource reservation at each node along the path of a connection establishment

request can be arbitrary defined in accordance with application requirements, the source can request an arbitrary amount of forwarding resources.

We have to note that such approach requires an implementation of resource reservation protocol user's terminals, which results in additional software requirements.

### C. Integrated approach

One of the promising approaches to maintain end-to-end QoS guarantees is to incorporate connection-oriented resource reservation within the RAN and service differentiation within both the 4G-All-IP CN and the Internet routers. Indeed, the service differentiation framework operates on traffic aggregates and no per-flow state has to be maintained in the core routers, while the connection-oriented resource reservation approach, when used with a specific connection establishment protocol, can provide deterministic QoS guarantees to applications. Based on the abovementioned properties, we can state that the integration of both approaches is a promising research direction, since it provides the best possible advantages to user applications:

- Deep granularity of user QoS requirements;
- Deterministic QoS guarantees within the RAN;
- High scalability of network routers within the CN;
- Seamless interoperation between 4G All-IP networks and the public Internet.

However, there are several drawbacks of the integrated approach:

- Implementation of a connection establishment protocol in both mobile terminals and RAN routers;
- QoS mapping procedures between RAN and CN of the 4G All-IP system.

A simple configuration of the proposed integrated approach is shown in Fig. 3 where RAN and CN consist of a number of IP-capable routers. In particular, there are four types of IP routers:

- *Local Routers (LR)*;
- *Edge Routers (ER)*;
- *Core Routers (CR)*;
- *Border Routers (BR)*.

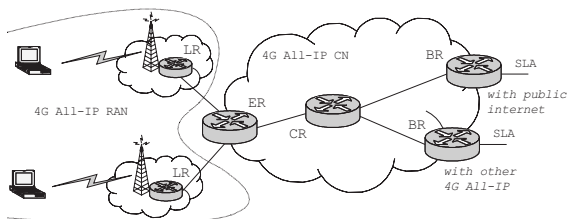


Fig. 3. Foreseen architecture for future QoS-enabled 4G All-IP networks.

IP QoS mechanisms have been specified having wired networks in mind. Whereas, IntServ and DiffServ have already received a considerable attention from researchers, only few studies on supporting a wireless IntServ or DiffServ have been published.

In fixed networks packet losses are primarily due to buffers overflow within the routers, while the error rate of the transmission medium is small (less than  $10E-9$ ). Therefore, packet losses caused by errors at the physical layer can be neglected. On the contrary, dealing with 4G All-IP networks, we have to take into account those packet losses, caused by bit errors at wireless transmission medium. Therefore, the main 'weak point' in end-to-end QoS architecture is the air interface between mobile terminal and first fixed point. To maintain the best possible QoS at the air interface novel methods of Forward Error Correction (FEC), Automatic Repeat Request (ARQ) and hybrid techniques should be developed and properly parameterized. Therefore, extension of QoS frameworks to the air interface introduces problems that should be solved before required QoS of user services will be achieved. These new challenges require development of new methods of teletraffic theory.

## IV. TELETRAFFIC ASPECTS OF 4G NETWORKS

The analysis of packet level QoS at the air interface is a very challenging and complicated task due to a number of factors. Wireless links have highly time-varying behaviors due to shadowing, multipath fading and other effects. Secondly, the nomadic behavior of users introduces another uncertainty. It can cause a handover procedure between different coverage areas. Hence, a new path in the fixed part of the RAN and possibly in the CN has to be established. This new path may have different delay, loss and bandwidth characteristics. The movement of the user may also influence its activity, which, in turn, influences call and packet level characteristics of the generated traffic. We also have to take into account teletraffic specific issues like usage of several simultaneous applications with *Variable Bit Rate (VBR)* traffic nature. Components that influence QoS at the air interface can be represented by the interaction of mobility, teletraffic characteristics and wireless medium, as shown in Fig. 4.

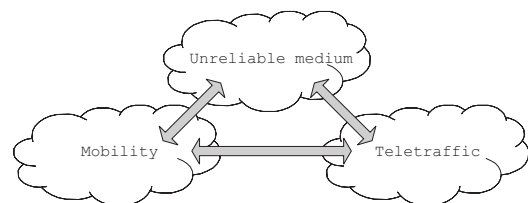


Fig. 4. Components that influence QoS at the air interface.

A 'mechanism' responsible for QoS support in 4G All-IP networks should predict the future state of the network based on both user mobility and its traffic parameters. Such mechanism has to incorporate a CAC algorithm, which denies or allows the admission of new calls on the basis of the network state.

Monitoring of real network can be done using specific measurements tools. In those cases when implementation of a network does not exist adequate traffic models emulating user behavior should be adopted for planning and optimization purposes. Therefore, it is crucial to develop traffic models of

various types of sources, which are assumed to be used in 4G networks.

### A. Traffic modelling

Due to the circuit-switched technology utilized by 2G systems, the user of a mobile system is granted with a constant bit rate channel during the cell dwell time (time for which a particular user stays in a certain cell). When a free channel is not available, the user is forced to leave the system. Handover calls between cells are served almost similarly: the handover call to a new cell is assigned one of the free channels during the cell dwell time. If all channels in the new cell are busy, the handover call is terminated. Therefore, the QoS provided to users by 2G mobile systems is typically limited to call level parameters like new call blocking, handover call blocking etc. Correspondingly, traffic models designed for 2G systems are primarily concerned with capturing call level parameters of traffic sources.

In 4G All-IP networks all calls including voice ones will be IP based. Therefore, dealing with 4G All-IP networks in addition to call level QoS parameters we have to consider IP level QoS characteristics like packet loss, packet delays, delay jitter etc. Thus, traffic models that take into account both call and packet level behavior are of paramount importance in 4G All-IP networks.

Due to the fact that users of 4G All-IP mobile networks will not occupy constant bandwidth during the whole duration of a call, these systems should benefit from statistical multiplexing at the network layer. In this case, a small fraction of users that employ bandwidth-greedy applications may produce a bottleneck at the wireless link. Therefore, the focus of user teletraffic modelling should be extended to include traffic models of various applications at both call and packet levels.

An example of correspondence between call and packet level traffic demands for voice application is shown in Fig. 5, where black rectangles denote talkspurt phases and gray ones denote call active phases. One can note that there is a strict correspondence between calling activity of the user and its packet traffic, i.e. when the call is off, no packets are generated; while the call is on, packets are generated according to a suitable model.

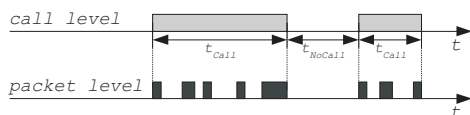


Fig. 5. Correspondence between call and packet levels traffic demands for voice application.

A survey of research papers [10], [11], [12], [13] has shown that traffic models designed for 2G systems do not take into account mobility behavior of single users. Most of them assume a stationary behavior of large populations of users and try to capture call level parameters by distributions like exponential one or its mixtures. Those models, while were shown to be fair predictors of stationary characteristics, are not concerned with per-user granularity, and therefore,

are not appropriate for traffic modelling purposes in 4G All-IP networks, where the mobility behavior can significantly affect call level parameters, and as a result, packet level characteristics.

**Mobility and traffic demands.** To illustrate the influence of user mobility behavior on its traffic demands let us define two classes of user mobility behavior with following two states:

- Fixed;
- Nomadic.

Assume that when the mobile user is in the fixed state it uses network services with probability  $p^F$ , and with probability  $(1 - p^F)$  stays idle. Similarly, when the mobile user is on move it accesses service with probability  $p^N$ , and does not use the network with complementary probability  $(1 - p^N)$ . Indices  $F$  and  $N$  stand for fixed and nomadic states, respectively. In what follows we explain why it is essential to assume that call level traffic demands depend on the mobility of the user, which leads to the case  $p^F \neq p^N$ .

To date voice service has been a dominating application in conventional 2G systems. Due to physiological tests the aural impression of information does not require too much attention (up to 20%), and therefore, a moving user is aware of the situation around even when moving (driving, walking, etc.). Therefore, to date one could assume  $p^F = p^N$ .

The situation changes with the introduction of multimedia services. Indeed, the visual information gives us more than 80% percent of overall information. Moreover, the combination of aural and visual information dominates with overall percentage up to 97%, and therefore, significantly affects our attention. When the aural information is presented in conjunction with other media it is fair to assume that moving users will not use such services frequently, since they require too much attention to concentrate on perceived information. It leads to the case  $p^F \neq p^N$  and dependence between mobility and traffic demands is evident. Since the calling activity of the user influences its traffic demands, such dependence may affect the QoS provided to the user.

Additionally, in some countries there are restrictions imposed on the usage of mobile phones when driving. It also leads to the case  $p^F \neq p^N$  even for monomedia voice application.

Both  $p^F$  and  $p^N$  implicitly define user traffic demands at the call level, and therefore, traffic demands at the packet level. Such dependence cannot be generally represented by functional relationship, but has probabilistic nature. Moreover, we cannot assume that parameters  $p^F$  and  $p^N$  are stationary. Indeed, based on the experience obtained from telephone networks, we can state that they change over several timescales depending on the time of the day, day of the week etc. However, given a certain timescale of interest we can expect a stationary behavior of  $p^F$  and  $p^N$ .

**Mobility models.** There are a number of mobility models presented in literature. The main purpose of those models is to predict the movement of users within a certain area. Most available models are related to and came from solutions of paging problems in 2G networks. Due to their nature, such models have a simplified representation of teletraffic part while

the mobility part receives main attention and often modelled by complex stochastic process.

**Teletraffic models.** As far as there are a number of applications in current IP networks, all of them should be supported by 4G All-IP networks. It is known that each application can be described by its own traffic characteristics. These characteristics should be measured from real traffic traces and then used to parameterize a model.

It is recognized from traffic modelling in fixed network that most applications have to be characterized using different traffic models. In those cases when general traffic model is used, we have to parameterize it differently depending on the traffic characteristics of certain application. The trend must be to use a general models like Markovian Arrival Process (MAP) or Batch MAP (BMAP) in order to represent the teletraffic part in 4G All-IP networks.

**Integrated models.** Based on abovementioned considerations, there is an increasing the need to develop new integrated traffic models incorporating both mobility and teletraffic parts. These models have to be further applied to investigate the QoS level provided for each application using analytic or simulation techniques.

To date only few studies are available, which simultaneously consider user's mobility behavior and its traffic demands. In particular, we can consider the work presented by Antunes *et al.* [14]; on the basis of general assumptions regarding teletraffic and mobility of the user, they propose to use a combination of two MAPs one of which describes user's mobility while the other specifies the teletraffic characteristics of applications. Despite obvious advantages, their model is quite complex, and therefore, its application in performance evaluation of 4G All-IP networks is limited.

In [15], the authors developed an integrated cross-layer traffic model for 4G All-IP networks. Basically, it consists of two different parts: mobility model and teletraffic model. The mobility behavior of the user is captured by a Markov chain with a finite state space, while the teletraffic characteristics at the call level are represented by a Markov chain with two states. Both models are integrated, so that the whole model can be seen as a doubly stochastic process while does not lead outside one-dimensional Markov chain framework. This is due to the special integration of both parts, which makes a teletraffic part a function of the mobility one of the composite model. They also show how to extend the proposed model to capture packet level characteristics of *Constant Bit Rate* (CBR) and *VBR* traffic types. While analytical tractability is retained, the main application area is simulation studies.

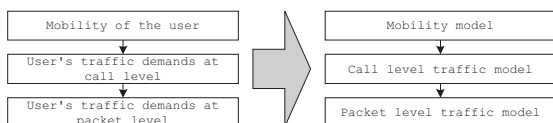


Fig. 6. Integrated traffic modelling of 4G All-IP mobile network user.

### B. Models of the air interface

An important property of wireless links is that their performance is affected by atmospheric conditions and other

factors such as multipath fading. Provisioning of QoS is therefore difficult due to high and correlated *Bit Error Rate* (BER). To overcome these problems, a radio link protocol with a suitable error control mechanism has to be used. Such protocol eliminates the influence of BER using error correction techniques like FEC, ARQ or their combination. However, the choice of error concealment strategy and its parameters depend on both wireless link characteristics and the nature of the traffic source.

There are a number of wireless link models proposed in literature. The most convenient way is to assume that the bit errors occur with constant probability for every bit in the sequence. However, it was shown by Gilbert that bit errors are correlated rather than independent, and therefore, such simple models are not good predictors of bit errors.

It was Gilbert who proposed to use a Markov chain to describe bit error correlations. His model requires two states of a discrete-time Markov chain one of which is error-free ( $p_0 = 0$ ) while another is associated with bit error probability  $p_1 > 0$ . Later, this model has been extended by Elliot who allowed the error free state of the Gilbert model to have bit error probability greater than zero ( $p_0 > 0$ ). Such model is more flexible in terms of its application area. However, this model still has only two states of Markov chain and, therefore, the range of bit error correlations is limited. The next extension came from Fritchman, who allowed an arbitrary number of error-free states of the Markov chain and the range of bit error correlations has been significantly expanded. The last extension was made in middle 90<sup>th</sup> when Fang proposed to use a versatile Markov based model by allowing an arbitrary number of error states.

All abovementioned models were extensively used for performance evaluation of data-link layer protocols. However, those studies were based on steady-state behavior of Markov chains modelling bit errors. Such analysis gives us only basic ideas regarding the performance of error control protocols. In general, time varying nature of wireless links depends on user mobility, and therefore, cannot be considered independently. Therefore, in order to evaluate the QoS expectations experienced by applications running over air interface the wireless link model should depend on the mobility behavior of the user, or should be integrated with traffic model.

## V. CONCLUSIONS

The evolution of mobile communications from current 3G to future NGN (practically, 4G) will require a novel design of the system architecture in order to integrate different access technologies with a globally optimized approach and by means of the unifying IP network protocol. Suitable techniques need to be defined in order both to coordinate the resources in different RANs (horizontal ABC approach) and to redesign the air interface protocol architecture, allowing cross-layer interactions among protocols at different levels (vertical approach), a mandatory task is to improve the network efficiency and to increase the degree of satisfaction of users (QoS expectations).

We have identified that the major 'weak point' in end-to-end QoS provisioning is the air interface between mobile

terminals and the access entity. New teletraffic methods must be developed to adequately predict QoS expectations that a particular application may experience at various levels of wireless link congestion. A special attention should be paid to traffic and wireless link modelling issues.

Traffic models, developed for wired networks cannot be effectively used in wireless environment since both mobility of users and unreliability of transmission medium have to be taken into account. Those models, developed for 2G networks have a simplified structure of teletraffic part. Therefore, an adequate model for the 4G All-IP environment should explicitly take into account both mobility of users and teletraffic characteristics of various applications at per-user granularity.

Wireless link models available up to date are primarily concerned with stationary characteristics of the wireless link behavior. However, mobility of the user, an inherent property of mobile networks, restricts the application of such models. To facilitate performance evaluation of QoS at the air interface the wireless link models should either incorporate the mobility behavior of the user, or integrate the traffic model.

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