# QoS-Oriented MAC Technology for Distributed All-MPLS/ATM Satellite Integrated Platform for 3G+/4G and WLAN Communications

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*Abstract* – **The future generation of satellite multimedia communications requires dynamical control of space bandwidth resource and stringent quality of service (QoS) guarantee. It is known, that the medium access control (MAC) protocols developments have a dominant effect on the ensuring ability of the QoS and other breakthrough wireless technologies 4G. This paper describes novel QoS-oriented long-delay multifunctional MAC (MFMAC) technology, which ensures a perspective basis for creating a cost-effective completely distributed (neural-like) all-MPLS/ATM-MFMAC architecture for satellite integrated multiservice platforms, core, and access networks. Proposed satellite platform's architecture will be allow an effective support and integration of mobile satellite and terrestrial cellular, personal, WLAN, and other wireless systems future generations 3G+/4G for such remote regions, as Russian North, Siberia, Greenland, Canada, Alaska, Central and South-East Asia, South America, etc. The proposed architecture develops another alternative of all-MPLS/ATM integration suitable for completely distributed traffic structures, which creates on the effective technique of ATM selecting, rather then ATM switching.**

*Keywords – MAC; soft QoS; dynamical control; distributed; all-MPLS/ATM; platform; mobile; satellite; 3G+/4G; S-UMTS, S-PSC.*

## INTRODUCTION

The future generation of global satellite multiservice communications 3G+/4G generations must provide the advanced multimedia services and e-applications for any mobile and geographical distributed user (personally), at any time (up to real time), at any place (globally), of any kind information (voice, data, video, image, command, positioning, etc.), of any desired quality of services (QoS), and of any traffic parameters (TP) in a low-cost and mass-market manner [1]. The 3G+/4G global environment will be built on a mix of terrestrial and space-based infrastructure and will be based on IP/ATM. These environment may include the personal level (S-PCS, T-PCS), the local and wide area level (PAN, WLAN, WWAN, and MBWAN), the cellular level (3G+/4G, UMTS, S-UMTS), and the global and regional all-IP/ATM backbone/core/platform level. This presents a number of challenges like networking-in-the-sky, effective medium access layers, QoS provisioning, integration of space and terrestrial networks, scaleable resource control on the network and the access levels. There are a number of novel ideas that provide the required capabilities: a new distributed MAC layer technology with integrated dynamic distributed QoS control [1, 2]. This technique will be combined with space-based MPLS to create a global mobile 4G fully distributed communications [3, 4]. The paper will be focused on such novel solutions.

## II. BACKGROUND

The today's satellite multimedia systems are based mainly on *centralized* architecture with very high traffic concentration, which structure is not adequate concerning traffics topology for rural and distant areas especially. Therefore the cost of these systems is unacceptable large for deployment of future mass personal communications, which includes many geographical distributed customers [2]. A number of known systems use a *static* technique QoS provisioning (*hard* QoS) [5], which is not suitable for future multimedia systems 4G.

What is the most promising telecommunication technology of future satellite multimedia 4G communications: IP or ATM? The author supposes that a combination of these two leading technologies will provide the most promising basis for the near future. The IP/ATM integration technologies have emerged as advanced concepts that are expected to provide broadband multi-service to the end users by making the best utilization of the advantages of IP (packet switching, adaptive routing, heterogeneous, flexibility, scalability, etc.) and of QoS-oriented-MAC-based ATM (soft QoS provisioning, dynamical traffic engineering and resource allocation, multimedia, high speed, guarantee, etc.) in a cost-efficient manner.

The multi-protocol label switching (MPLS) over asynchronous transfer mode (MPLS/ATM, for short) were proposed as very promising extensions to the existing IP/ATM technique [6]. MPLS/ATM is based mainly on routing, switching and also on further developing the IP capabilities. Switch-based MPLS/ATM's label distribution protocol (LDP) supports *hop-by-hop label routing* through the network [6] (see Fig. 1a). Switch-based LSRs used to date have been based

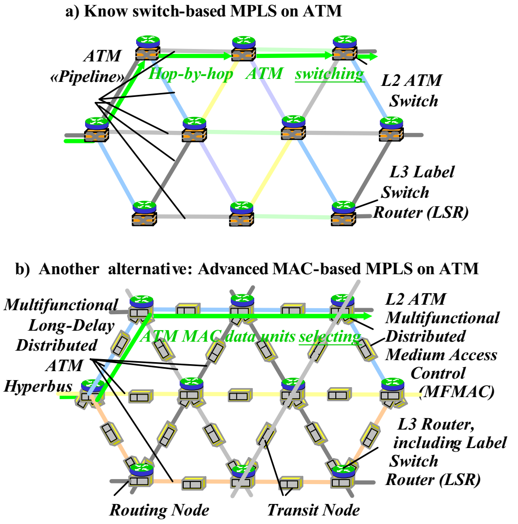


Figure 1. Two alternatives of the MPLS on ATM

on ATM switches. The ATM cell forwarding mechanism supports also *hop-by-hop ATM label switching* [6]. However switch-based mechanisms support effectively the multimedia satellite networks with very centralized architecture only, because the quantity of such "hops" is strictly limited, and their main components – big ATM switches and high rate "Pipeline" – need very high traffic concentration [2]. Unfortunately, its cost is unacceptably high for the satellite multimedia personal networks in context of remote users with geographical distributed traffics, and mass-market to supporting.

In [2] a novel integration alternative MPLS/ATM-MFMAC been proposed, which suitable for *completely distributed* all-MPLS/ATM satellite networks architecture and soft QoS provisioning (see Fig. 1b). This alternative bases on using an ATM *selecting* technique, rather then ATM *switching*. Indeed, the alternative solution combines an advanced long-delay broadband L2 ATM MFMAC technology [2] with completely distributed multifunctional L2 ATM Hyperbus architecture [7], and the L3 MPLS over ATM routing technique [6].

The advanced ATM MFMAC technology is based on RS-token broadcast reservation (TBR-RS) MAC protocol [8, 9]. This protocol uses the recurrent M-sequences (RS) MAC-addressing possibilities in order *"all-by-one"* mechanism to organize an adaptive high effective multiple access to long-delay space medium, soft DynQoS provision and distributed dynamical control of traffic and bandwidth resources, and other important MAC mechanisms [8]. The dimension of this MAC-address space can be equivalent of IP-address capacity of IPv6. The ATM Hyperbus builds a virtual bus connecting between all L2 nodes [7]. The topology of virtual bus can be represented by a passive optic tree, wireless or satellite [7] bus, cross-hexagonal (see Fig. 1b), ring-radial ("metro") topology, etc. The suggested MPLS/ATM structure can include little of L3 LSR/MFMAC *routing* nodes (RN) for buses or edge internetworking, and possible many hundreds of L2 ATM/MFMAC scalable *transit* nodes (TN) for ATM data cells *label selecting*. The advanced-MAC-based MPLS/ATM does not require hop-by-hop switching mechanisms. The label distribution protocol uses a *label selecting* mechanism by TN and *label routing* mechanism by RN for setup of selected path through the network. The ATM cell forwarding protocol uses also a non-hop-by-hop label selecting mechanism by transit and routing.

Thus, the starting-point for improvement of MPLS/ATM technology was a thesis about dominant effect of MAC layer modernization to ensuring of novel required abilities [8-10]. Unfortunately, many MAC protocols, which proposed for multimedia wireless and satellite, for example [5, 11], are based on published per 70-80-s' years classical free, reservation, and hybrid multi-access methods [12]. There was not great progress and new ideas in development of ATM MAC layer's technique focused at soft QoS and dynamical control provision, and also at creating of all-IP/ATM wireless environments, last years.

## III. Requirements to the QoS-Oriented MAC

Assume that at some time $t$ some quantity of $N_t$ satellite networks nodes $SN_i$ with $k^{th}$ data service classes, input multimedia traffics intensities $G_{ikt}$, output traffics intensities $S_{ikt}$, and total input intensity $G_t = \sum_{i,k} G_{ikt} \le C_{MAC}$, where $C_{MAC}$ is MAC efficiency, $C_{MAC} = \max_{\{G_t, t\}} \sum_{i,k} S_{ikt}(G_{ikt})$ are active. It is assumed that the *soft-QoS-oriented MAC* protocol must guarantee providing of following defined or optimal values $[X_{ikt}]$ of parameters $X_{ikt}$ for each $i^{th}$ nodes $SN_i$, each $k^{th}$ data service class, and for each little interval up to real time $t$: a) *dynamical controlled* (*soft*) *QoS parameters* – mean delay $[D_{ikt}]$, loss probability $[R_{ikt}]$, throughput $[S_{ikt}]$, possible, jitter $s_{[X]}$ and other; b) *soft traffic parameters* (DynTP) – peak $[P_{ikt}]$ and mean $[M_{ik}]$ rates, and possible other; c) *soft bandwidth recourses* $Y_{it}$ (DynBRA). The multimedia wireless traffics parameters above specified can be calculated using the numeric-analytical method of *intensities balance* [13].

The specific conditions of the satellite networks 3G+/4G (the long-delay space medium, the geographical distributed multimedia traffics, the soft QoS-oriented MAC, the completely distributed all-MPLS/ATM architecture, the mass market, and other) requires the MAC protocol abilities to overcoming of three principal problems: so-called *time barrier*, *dynamical barrier*, and *economic barrier* [2, 8].

The *time barrier* appears due to the effect of *degradation* of long-delay MAC efficiency when the round trip time increases (Fig. 2).

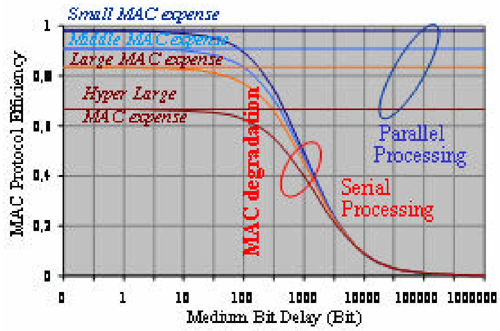


Figure 2. The time barrier illustration (for 1000 bit packet)

One can show [2, 8] that the MAC protocol efficiency depends on normalized medium's bandwidth resources expenses on multi-access control $v_o$, on normalized round trip time $v_p$, and also from method of the multi-access control instructions processing: $C_{MAC} = 1/(1 + av_0 + bv_p)$,where $a \ge 1$ – coefficient depends on MAC algorithm, $b$ – coefficient depends on method of the *MAC* instructions processing, $b$ = 1, if processing's method is *serial* (SIP), and $b$ = 0, if processing is *parallel* (PIP) or *parallel-conveyer* (CIP) [9].

The *dynamical barrier* problem has birth on such essential reason as dynamical instability of the well-known parallel processing reservation MAC schemes with the defined or fixed superframe formats (SFR) [5, 10-12], which GPRS includes also. The protocol efficiency of these methods is $C_{MAC}^{parallel} = 1/(1 + v_0 N / J)$, where $J$ is a fixed or adaptable number of the information (data) slots, and $N$ – is the number of the reservation (control) minislots in the superframe, and coefficient $a=N/J$. In [8] was shown, that as the intensity $G$ increases, the dependence of the delay time on the SFR's protocol efficiency becomes more and more critical with respect to the value of the control parameter $a=N/J$. And the graph of a delay time function has a $U$-like shape ([2], Fig. 3a), if we want to guarantee the limited loss probability. The operational field of the adaptation characteristics, where the delay time is minimal, decreases rapidly as the traffic intensity $G$ increases.

Therefore SFR's protocol supports the *real maximum throughput* $C_{MAC}^{real} = \max_{\{G,D\le[D]\}} S(G)$ only up to 0.30÷0.50 Erlang.

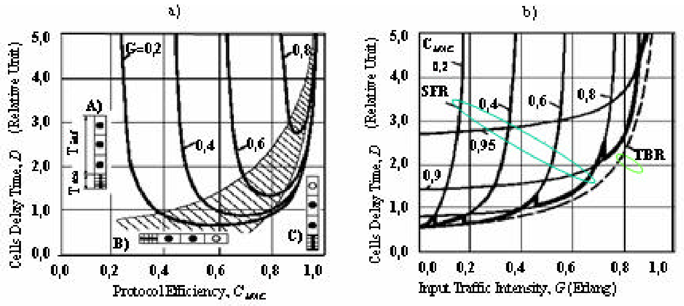


Figure 3. The dynamical barrier illustration

As it was shown above, *economic barrier* is due to unacceptable costs incurred by any well-known satellite centralized architecture, making a low-cost wireless broadband ATM mass-market implementation difficult.

In summary, the following abilities must be achieved during creation of soft QoS-oriented long-delay MAC protocols:

- high efficiency and throughput of access control to long-delay wireless and space mediums (the time barrier overcoming aspects);
- high controllability, differentiation, stability, and guarantee of dynamical control of DynQoS, DynTP, and DynBRA (soft QoS and the dynamical barrier overcoming aspects);
- scalability, multifunctional and universality abilities on basis of the common dynamically controlled and adaptive ATM MAC protocol through the entire network hierarchy – core, backbone, and access networks (all-MPLS/ATM-MFMAC aspects);
- low-cost, neural-like, completely distributed hyper-bus architecture supporting of the MAC-sublayers through all networks hierarchy (economic barrier overcoming aspects).

One can show the MAC protocols with adaptive frame time processes ensure a highest short-delay efficiency and maximum of real throughput [1, 3]. The same protocols with controlled access and parallel-conveyer MAC instruction processing (CIP) ensure the best time barrier overcoming abilities by long-delay mediums (long-delay efficiency) [3, 8]

We show that higher long-term soft QoS capabilities can ensure the controlled access protocols [9]. The hybrid access protocols SFR (for example - TBQF [5]) using the token generations' rate and token buffer size mechanisms are able also to soft control of the bandwidth resources, delay, and loss probabilities. However, this protocol's technique of parallel (PIP) request /reservation /assignment instruction processing supports effectively a soft QoS only by input traffic's stationary or slow (long-term) variation characteristics (see Fig. 3a). Otherwise, by short-term traffic intensity variation, the high values of bandwidth utilization can't be supported, and the catastrophically decreases the stability of the process superframe formats adaptation can occur, by long-delay space medium especially [2].

As shown in [2], the best dynamical soft-QoS capabilities can be represented on the asymptotic ideal dependence TBR (Fig. 3b). Such asymptotic ideal dependence ensures the MAC protocols with *adaptive frame* time access processes, *controlled (reservation)* access mechanisms, and *parallel-conveyer processing* of MAC instruction [8, 9]. One of them, such capabilities ensures the MAC protocol TBR-RS [2, 8]. This protocol provides the stabile automatically "on-the-fly" adaptation of the M-periodical hyperframe for variable traffic intensity [8]. At the same time, this protocol allows to realize a universal RS-token MAC tools *"all-by-one"* for dynamical (up to real time) soft control of QoS, traffic parameters, and bandwidth resources. This tools implements effective RS-token MAC mechanisms for the optimal planning of control policies, the bandwidth resource scheduler, traffic shaping, dropping discipline, and united system time, simultaneous [ 8].

One can show, that the best ability to overcome the economic barrier and the best compatibility to all-MPLS/ATM requirements can ensure the adaptive MAC protocols with distributed controlled access, adaptive frame time processes, parallel-conveyer instruction processing, and smallest multi-access expense (SME), including TBR-RS [1, 3].

## IV. QoS-Oriented Long-Delay MFMAC Technology

As noted above, the QoS-oriented MFMAC technology can be successfully realized on base developing of the RS-token broadcast reservation (TBR-RS) MAC protocol [2, 8]. This protocol uses the recurrent M-sequences (RS) MAC addressing opportunities in order to organize a RS-token tools *"all-by-one"* for high effective multiple access to long-delay space medium, soft DynQoS provision and distributed dynamical control of DynTP and DynBRA (Fig. 4).

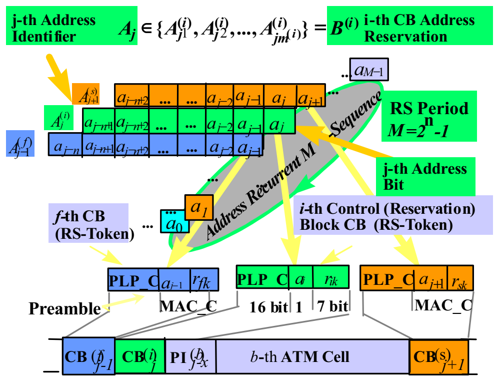


Figure 4. RS-token "all-by-one" MAC control mechanism

The *M*-subsequences $A_j = a_{j-(m-1)}, a_{j-(m-2)}, \dots, a_j$ serve as RS-identifiers of the MAC addresses and other protocol subjects, including the labels. Some number $m_{it}$ of "personal" identifiers

$$\{A_{jit}\} = \{A_{ji1}, \dots A_{ji2}, \dots, A_{jim_{it}}\} = B_{it} \qquad (1)$$

for passing of requests $r_{ik}$ in proportion to the required bandwidth resource value $[Y_{it}]$ is dynamically assigned to each $i^{th}$ station on a decentralized basis by Shannon-Fano method [2, 7]. Each *j*-th RS-token MAC address can be identified 1-bit unique RS-address bit $a_j$ using. The dynamical bandwidth assignments mechanism is based on this MAC addresses RS-token intensity (RS-token number at second) soft regulation in proportion to required resource. The bandwidth dynamical assignments policy can be defined on base theoretical-game task [2, 6]. One can show that protocol's realized efficiency can be near by potential capacity (2). To support the required $k^{th}$ service classes and queuing discipline mechanism of *priority segments* $[(j-l_{kt}),j)$, $M \geq l_{Kt} \geq ... \geq l_{kt} \geq ... \geq l_{2t} \geq l_{1t} = 0$, is used.

## V. The QoS, Bandwidth Resources, and Traffic Dynamical Control Tasks and Principles

The suggested method gives an opportunity to ensure a *proportional dynamic control* of the bandwidth resources since the value $Y_{it}$ of $i^{th}$ bandwidth resources in proportion to number $m_{it}$ of $i^{th}$ "personal" identifiers (1). The dynamic bandwidth utilization guaranteed up to 0.75÷0.85.

The dynamic control strategy can be constructed on a centralized as well as on a decentralized game basis. An example of a *centralized control strategy* is

*The task of weighted average delay minimization* [8]. Assume that are given the traffic intensities $G_{ikt}$ and the dependencies $X_{ikt}(\mathbf{Y}_t, \mathbf{L}_t)$ of the indices $X = D, P, M, R$ on the vectors $\mathbf{Y}_t = (Y_{1t},...,Y_{it},...,Y_{Nt})$ of the values of the reserved resources and the priority segments parameters $\mathbf{L}_t = (l_{1t},...,l_{kt},...,l_{Kt})$. For a given interval $t' < t < t''$ such legitimate values of the vectors $\mathbf{Y}_t$ and $\mathbf{L}_t$ must be found that minimize the weighted with certain weights $h_{ikt}$ delay time:

$$\sum_{i=1}^{N}\sum_{k=1}^{K} h_{ikt} D_{ikt}(\mathbf{Y}_t, \mathbf{L}_t) \rightarrow \min \tag{2}$$

with constraints of the form:

$D_{ikt}(\mathbf{Y}_t, \mathbf{L}_t) \leq [D_{ikt}]$, $R_{ikt}(\mathbf{Y}_t, \mathbf{L}_t) \leq R_{ikt}$, $P_{ikt}(\mathbf{Y_t}, \mathbf{L_t}) \geq [P_{ikt}]$, $M_{ikt}(\mathbf{Y}_t, \mathbf{L}_t) \geq [M_{ikt}]$, $i = 1,...,N_t, k = 1,...,K_t$.

In the *decentralized strategy* the control actions, the reserved resources $Y_{it}$, are generated on game basis by the users and are implemented by the network administrator with the help of a dynamic RS addressing mechanism.

*The resources reservation game task* [8]. Assume that are given some measure of the $k^{th}$ class information cost per unit time $H[G_k, \mathbf{W}_k(Y)]$ as a function of its traffic intensity $G_k$ and the vector of its delivery quality indices $\mathbf{W}_k(Y) = (D_k(Y), R_k(Y), P_k(Y), M_k(Y))$, and also the tariffs per unit time for the resources $T_Y$ and traffic $T_{Gk}$. Assume further that the $i^{th}$ users can keep track of the statistical estimates (averages) of the traffic intensity $\overline{G_{ikt}}$ and service quality $\overline{\mathbf{W_{ikt}}(Y_{it})}$ with a given band resource value $Y_{it}$.

Some $i^{th}$, $i \in \{1,2,...,N_t\}$, user must reserve for a given interval $t' < t < t''$ such a legitimate bandwidth resource value $Y_{it}$ that maximizes his «gain»:

$$\sum_{k=1}^{K}\{H[\overline{G_{ikt}}, \overline{\mathbf{W_{ikt}}(Y_{it})} - T_{Gk}\overline{G_{ikt}}]\} - T_Y Y_{it} \rightarrow \max. \tag{3}$$

The users try to maximize their «gain» (3) by reserving resources $Y_{it}$ and varying traffic intensities $G_{ikt}$ (making «bets» $Y_{it}$ and $G_{ikt}$*).* Such procedures are simulated by non-cooperative dynamic *N*-person games.

By changing the tariffs for resources $T_Y$ and traffic $T_{Gk}$ the network administrator can in his turn engage in playing with the users to maximize his own «gain»:

$$\sum_{i=1}^{N_t}\sum_{k=1}^{K} T_{Gk}\overline{G_{ikt}} + \sum_{i=1}^{N_t} T_Y Y_{it} \rightarrow \max. \tag{4}$$

The conditions (3) and (4) ensure self-regulation of the input traffics $G_{ikt}$, required parameters of the traffic and service quality $[\mathbf{W}_{ikt}] = ([D_{ikt}],[R_{ikt}],[P_{ikt}],[M_{ikt}])$ and band resources $Y_{it}$ for each $k^{th}$ class of information, each $i^{th}$ user and on each time interval [*t′, t″* ). The tasks (2)-(4) can create an analytical base for bandwidth brokers (BB).

## VI. The All-MPLS/ATM-MFMAC-Based Architecture

The future global wireless environment 3G+/4G will be create on the principles of integration and global internetworking of wireless (WLAN), mobile 3G+/4G, and satellite systems [14]. The conceptual look of the completely distributed (neural-like) all-MPLS/ATM-MFMAC architecture of future global satellite multimedia networks is explained in Fig. 5. The proposed architecture is based on described above another alternative MPLS over ATM integration, and advanced soft-QoS-oriented multifunctional MAC technology. Their structure is created on so-called distributed *Virtual Spacemedium ATM Hyperbuses* [7] and uses the common universal dynamically adapted MFMAC protocol [2] through the entire networks hierarchy – core, backbone, and access networks. The orbital groups GEO, MEO, or LEO/HEO of satellite broadband digital retranslator ensure the global coverage.

The retranslator forms a multi-access *up* channel and broadcast *down* channels. The virtual hyperbusses L2 for various wireless and satellite MPLS/ATM systems, which differ according classes of the topology scales (W-MAN, W-WAN, S-UMTS, S-PSC), function hierarchy, technical characteristics, and kinds of medium, can be configured using up to 3 logically homogeneous basis components: 1) universal adaptive medium interface with medium type cartridge – L1-UAMI, 2) universal adaptive multifunctional distributed ATM medium access controller – L2-MFMAC, and 3)– the hyperbus's bandwidth broker server (HBBS) of the distributed dynamical control of QoS, traffic parameters (TP), and bandwidth resource assignment (BRA). Moreover, same hyperbus can implement simultaneously (in parallel) a function of access network, and function of core network or/and backbone, i.e. multifunctional.

It is perhaps appropriate to explain the other abbreviations used in Fig. 5: L3_LSR – label switch router; L3_LER – label edge router; RN – routing node; TN – transit (selecting) node; HBMN – hyperbus managing node; SCM-L3 – Spacemedium core/platform manager (L3 QoS managing); CNM 3G+– Core network manager of 3G+ ; CNM 4G – Core network manager of 4G; AAA – authentication, authorization, and accounting server; MBWAN – Mobile broadband wireless access network; S-SPCSN – Serving satellite PCS support node; T-SPCSN – Serving terrestrial PCS support node; SMWSN – Serving MBWAN support node; BB – Bandwidth broker; LBB – Local bandwidth broker; MWT – Mobile wireless terminal 3G; MBT – Mobile broadband terminal 4G; S-MBT – Satellite MBT terminal 4G; MPT – Mobile broadband PCS terminal 4G; S-MPT – Satellite PSC terminal 4G; broadband PAP – access point; BAP – broadband access point.

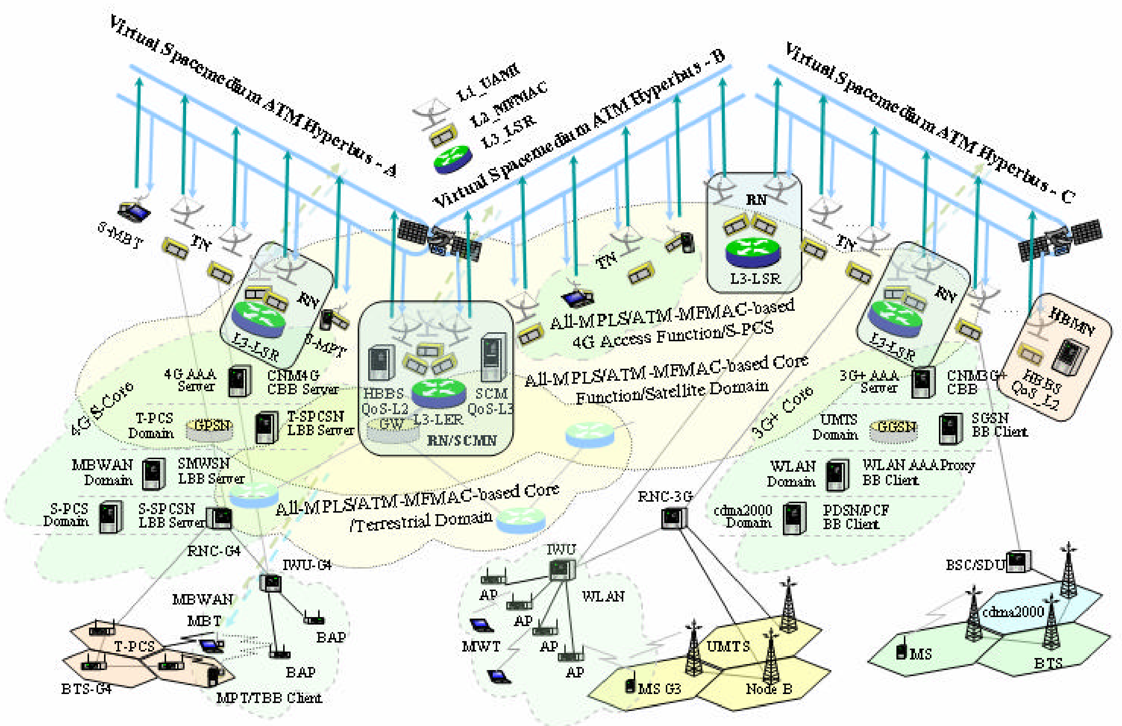


Figure 5. Conceptual model of the integrate satellite all-MPLS/ATM-MFMAC architecture

The main advantages of the MFMAC-based MPLS/ATM integration technology: a) Through path dynamic control and guaranteed QoS provisioning; b) Through path bandwidth on dynamic demand; c) Multifunctional, universal, and adaptation capabilities; d) All-MPLS/ATM completely distributed architecture; e) Minimum value of expensive data units switching – maximum value of inexpensive data units selecting, f) Minimum of cells delay – maximum of reliability; g) Low cost, simplicity, support of multimedia service mass-market.

## VI. Conclusions

The development's strategy of the mobile and satellite systems bases on evolution from voice-oriented channel switching technique of 2G to multimedia-oriented soft-QoS-aware packet switching technologies and all-IP/ATM architecture of global wireless environments 3G beyond and 4G. This strategy allows the investments to save. Unfortunately, the technological restrictions and "rudiments" of outdated generations will be a "charge" per this evolution, which will be following as the deterrent of the technical features, efficiency and economy of the future generation networks, inevitably. Indeed, it is an appropriate time to look beyond 3G and search for the breakthrough steps. The future satellite integrated platforms and communications 3G+/4g are very suitable for these breakthrough steps, since their world market is not burdened with a large investment, and the 2G generation (Iridium, Globalstar, etc.) has a didactic history.

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