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KEY ASPECTS AND RECOMMENDATIONS REGARDING THE MIGRATION OF THE MOBILE ARCHITECTURES TOWARDS 4G ALL-IP ENVIRONMENT

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Lucrarea prezintă cele mai importante aspecte din viitoarea arhitectură 4G LTE-Advanced, câteva din elementele care trebuie luate în considerare în planificarea migrării reţelelor actuale 3G către arhitectura 4G all-IP, precum şi care sunt principalele aplicaţii care vor genera creşterea de bandă mobilă necesară acestei migrări. Prin această cercetare se oferă o bază de pornire pentru orice operator de telefonie mobilă care caută o cale de a ajunge la viitoarea arhitectură de reţea 4G pe baza implementărilor curente şi totodată să elaboreze paşii de urmat sub forma unei „liste de puncte cheie ale proceselor de migrare", listă ce poate fi adaptată în funcţie de cerinţele specifice aplicaţiilor ce vor veni.

The present work presents the highlights of the next generation 4G architecture, some of the key elements that need to be taken into account when planning for a 3G to all-IP 4G network architecture migration as well as the main applications which will trigger the mobile bandwith demand which justifies this migration. The paper can be considered a starting base for any mobile operator as it helps both to properly plan the 4G future network architecture based on the architecture that they are using today as well as shaping the most likely migration process based on a pre-agreed "migration focus points list". This list can be modified accordingly and enhanced with more real-life example date that will help shaping the mobile network of the future architecture.

1. Introduction

This article proposes to describe the key elements brought by the next-generation LTE-Advanced architecture proposed by 3GPP **Release 10**.

As a natural part of the LTE-Advanced discussion, we have also briefly mentioned the key elements that a mobile provider needs to focus on when planning its migration from today's CS/PS 3G architectures towards the next-generation all-IP 4G architectures.

In its last part, the article enumerates which are the predicted applications driving the increase of mobile bandwidth demand justifying the migration towards higher capacity 4G architectures.

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2. The road towards 4G (IMT-Advanced and 3GPP LTE-Advanced)

The International Telecommunication Union (ITU) is the internationally recognized entity chartered to produce an official definition of the next generation of wireless technologies. Its Radio communication Sector (ITU-R) is establishing an agreed upon and globally accepted definition of 4G wireless systems that is inclusive of the current multi-dimensioned and diverse stakeholder universe.

In particular, ITU-R, working under a mandate to address systems beyond 3G, has progressed from delivering a vision of 4G in 2002 to establishing a name for 4G in 2005 (IMT-Advanced).

Starting in 2008 and throughout 2009, ITU-R held an open call for the "first invitation" of 4G (IMT-Advanced) candidates. Subsequent to the close of the submission period for the first invitation an assessment of those candidates' technologies and systems will be conducted under the established ITU-R process, guidelines and timeframes for this IMT-Advanced first invitation. The culmination of this open process will be a 4G, or IMT-Advanced family. Such a 4G family, in adherence to the principles defined for acceptance into this process, is globally recognized to be one that can grow to include all aspects of a marketplace that will arrive beyond 2010; thus complementing and building upon an expanding and maturing 3G business.[1]

3GPP technologies have been an essential and widely deployed part of the 3G technology family under the ITU-R IMT-2000 family since the onset of these recommendations released by the ITU-R. 3GPP has continued its role of enhancing its members of the IMT-2000 family through all released revisions of Recommendation ITU-R M.1457 and has continued this evolution of 3G through the incorporation of LTE technology in the ITU-R work.

3GPP continues with its working assumption that the 3GPP proposal for IMT-Advanced shall be based on E-UTRAN capabilities and the requirements for IMT-Advanced in ITU-R shall initially be not less than those contained in 3GPP [2].

The Target Requirements for IMT-Advanced framework (4G) are briefly listed bellow [3]:

- Based on an all-IP packet switched network.
- Peak data rates of up to approximately 100 Mbit/s for high mobility such as mobile access and up to approximately 1 Gbit/s for low mobility such as nomadic/local wireless access, according to the ITU requirements.
- Dynamically share and utilize the network resources to support more simultaneous users per cell.
- Scalable channel bandwidth, between 5 and 20 MHz, optionally up to 40 MHz.

- Peak link spectral efficiency of 15 bit/s/Hz in the downlink, and 6.75 bit/s/Hz in the uplink (meaning that 1 Gbit/s in the downlink should be possible over less than 67 MHz bandwidth)
- System spectral efficiency of up to 3 bit/s/Hz/cell in the downlink and 2.25 bit/s/Hz/cell for indoor usage
- Smooth handovers across heterogeneous networks.
- Ability to offer high quality of service for next generation multimedia support

Within its **Release 10**, 3GPP is planning to exceed the IMT-Advanced requirements mentioned above and propose a viable 4G alternative.

The proposed 3GPP **Release 10** 4G candidate is based on the already successful 3.9G LTE technology and is called LTE-Advanced [4].

The **Release 10** LTE-Advanced enhancements include[5]:

- Support for wider bandwidth (over 20Mhz)
- Uplink transmission scheme (support for MU-MIMO and multilayer antennas (MU-MIMO allows a terminal to transmit (or receive) signal to (or from) multiple users in the same band simultaneously))
- Downlink Transmission scheme (support for up to eight layers of antenna transmission and MU-MIMO)
- Coordinated Multiple Point Transmission and Reception (CoMP) (when a UE is in the cell-edge region, it may be able to receive signals from multiple cell sites and the UE's transmission may be received at multiple cell sites regardless of the system load)
- Relying (The concept of Relay Node (RN) has been introduced to enable traffic/signaling forwarding between eNB and UE to improve the coverage of high data rates, group mobility, cell edge coverage, and to extend coverage to heavily shadowed areas in the cell or areas beyond the cell range)

Other **Release 10** proposed enhancements are [5]:

- Heterogeneous Networks (deployments where low power nodes are placed throughout a macro eNB cell layout. These low power nodes include micro, pico, RRH, relay and femto nodes)
- Machine-to-Machine communications (establishing requirements for 3GPP network system improvements that support Machine-Type Communications (MTC))
- Fixed Mobile Convergence Enhancement : interworking between 3GPP and Broadband Forum architectures (most likely over the S9 interface)
- Single Radio Voice Call continuity: 3GPP is investigating techniques for supporting seamless service continuity for subsequent hand-back to 4G/HSPA of IMS voice sessions initiated in 4G/HSPA and previously

handed over to 2G/3G CS access. Additionally, it is investigating feasibility of enabling handovers of the voice calls directly initiated in 2G/3G CS with minimum impact to CS core network and access nodes.

The 3GPP **Release 10** is expected to be completed in the first quarter of 2011.

Advantages *of LTE-Advanced networks over its predecessor are:*

- *Enhanced data speeds: up to 3.3Gbps downstream (8x8 MIMO with 100MHz per channel) and 1.6Gbps upstream (4x4 MIMO with 100Mhz per channel)*
- *Up to 45% signal gain at cell edge and 15% signal gain on a call overall average by using relaying technology.*
- *Single Radio Voice Call continuity allowing for a robust usage of VoIP in LTE-Advanced and end-to-end interworking with 2G/3G CS-based voice access.*

Disadvantages

- *The large cell offered network speed will require a massive upgrade and expansion of the transport and core network capacity which greatly increases the complexity and costs or LTE-Advanced implementation*

3. Architecture Migration towards EPC/LTE/LTE-Advanced

When looking into the future, the main question for network operators and vendors is when and why **4G** wireless networks will be needed. Looking back only a few years, voice telephony was the first application that was ‘mobilized’. The Short Message Service (SMS) followed some years later (starting with the introduction of **2G**) as the first mass market mobile data application.

By today’s standards comparably simple mobile phones were required for the service and little bandwidth. In a way, the SMS service was a forerunner of other data services like mobile e-mail, mobile Web browsing, mobile blogging, and push-to-talk, mobile instant messaging and many others. Such applications became feasible with the introduction of packet-based wireless networks (in **2.5G**) that could carry IP data packets and increasingly powerful mobile devices. [6]

The continuous increase in mobile bandwidth demand as well as the very fast increase of Mobile Data users worldwide , creates a very good business case for migrating the current **3.5G/3.75G** networks towards the **3.9/4G** LTE/LTE-advanced Architectures which will offer a much lower cost per provided bandwidth and bandwidth expansion compared to the current technologies.

In their attempt to arrive to the EPC/LTE/LTE-advanced network architectures, the mobile network operators should focus (among other things) on the following very important migration points, as presented in the sections bellow.

3.1. Mobile Access and Transport

3.1.1 Frequency ReFarming

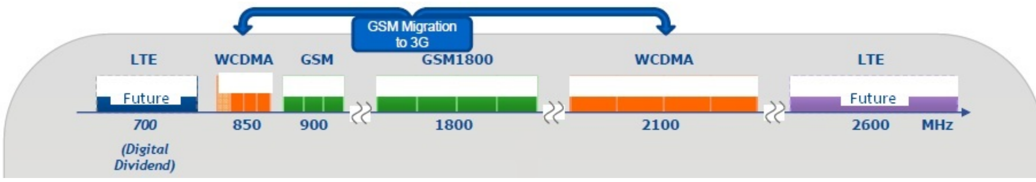

Fig. 1. Frequency usage and refarming example

Either motivated by the lack of frequency spectrum of by the prohibitive license fees for additional spectrum, frequency refarming is sometimes the only a mobile operator has in hands in order to make ‘space’ for the new EPC/LTE/LTE-Advanced technology into its already overcrowded spectrum.

Frequency Refarming has been made possible by the advances in the current 2G/3G technology implementations on both Terminal and Radio Cell side which allows for a relative ‘easy’ change of frequency used in order to implement a specific technology. By migrating and co-locating the older 2G/3G technologies in the same spectrum space, the operator can re-use the ‘freed’ spectrum in order to test and implement the new EPC/ LTE/LTE-Advanced technology at a much lower cost and without being ‘bound’ to new frequency auctions that would free up additional spectrum from the regulatory side.

In most of the countries, frequency refarming is also used as a temporary workaround to ‘free’ up spectrum for LTE while waiting for the ‘digital dividend’ spectrum release: the spectrum between 200Mhz and 1Gbps that is currently used by the analogical TV transmission systems.

3.1.2 All-IP Transport Architecture

The current GSM and UMTS networks are mostly based on SDH as the convergence technology using 2Mbps transport connections dedicated to either 2G or 3G mobile RAN traffic. In Europe, a high percentage of this SDH offering is based on Microwave technology (in most cases self-owned). The primary issue with the SDH based architecture is the non-scalability of this solution We have seen the impact of high data traffic volumes over the last 12-18 months with the HSDPA evolution and the future eHSPA and LTE RAN requirements will further highlight the scaling issues here.

It is clear that convergence at a packet layer enables a more flexible and scalable approach and achieves the desired single network requirement. The statistical multiplexing gains can significantly reduce the aggregate bandwidth demands that are especially important for the economics of HSDPA, HSPA and LTE/LTE-Advanced deployment.

In the LTE/LTE-advanced case, the underlying IP transport is mandatory to extend up to the enodeBs due to their all-IP architectural setup requirements

When discussing the network migration strategy towards an all-IP setup, the following scenarios can be foreseen:

- Migrate all GSM (TDM) and UMTS (ATM) traffic onto a packet-based infrastructure without any change to the radio equipment using technologies like TDMoMPLS / ATMoMPLS.
- GSM and UMTS traffic remains on the existing SDH based transport and all new traffic (HSDPA/HSUPA, HSPA and LTE) will be placed onto a newly built MPLS IP-based transport infrastructure (as their cells have the capability of connecting using native IP to the mobile core)
- Upgrade all GSM Base stations/UMTS NodeBs and controllers to support native IP and migrate onto an unified packet infrastructure for the future use of HSDPA/HSUPA, HSPA and LTE. [7]

The all-IP reference transport architecture is presented below:

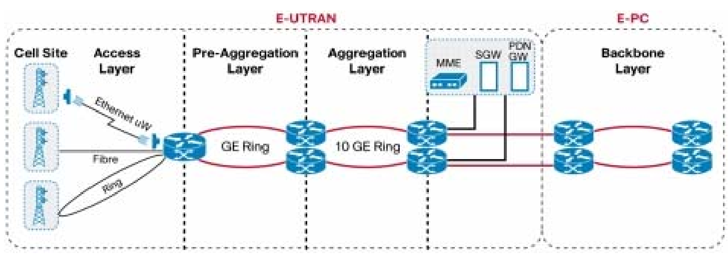

Fig. 2. All-IP any access transport architecture reference

3.2 . Mobile Core

3.2.1 IPv6 Migration

Due to the lack of remaining 'free' IPv4 public address pools within IANA administration on one hand and the incredible speed growth that Mobile Internet is experiencing, the migration towards an IPv6 infrastructure is a key element in the readiness for 'all-IP' EPC core that any operator should consider.

When looking at the potential way to address the network IPv6 migration the following items must be considered:

- Migration of the Transport and IP Infrastructure Network -> this is typically less of a concern as it does not normally use public IPs and is not accessible from outside the provider network.
- Migration of the Subscriber IP and Subscriber –related Eco-system (DNS , DHCP , etc) -> this is the main focus and challenge

The migration strategies are summarized in the table below:

Table 1

Mobile Core IPv6 subscriber migration strategies

Options	**Design Assumptions**	**Challenges**
All-IPv4	Large scale NAT44 at the network edge or at Mobile GW level. It is the easiest to achieve short term solution.	Legal Intercept / Billing and Logging synchronization challenges PAT port exhaustion issues if the Internal vs External IP pool ration is too high
All-IPv6	Will need statefull NAT64 to connect to the IPv4 Applications and users. It is the desired long-term solution	Conditioned by the number of applications supporting IPv6 Roaming in/out potential compatibility issues Requires upgrade of existing Mobile Core elements to support IPv6 user IP handling
IPv4v6 or IPv4+IPv6 dual-stack	Can use Release 9 ‘on-demand’ IPv4v6 or Release 8 and earlier separate IPv4 and IPv6 PDPs IPv4 or IPv6 usage by the UE is based on DNS IPv6 or IPv4 address being returned. It is the optimal way to insure a gradual transition from an all-IPv4 to an all-IPv6 network	IPv4v6 requires Release 9 compatible Mobile Core If pre-Release 9 mobile core is used or interworked with in Roaming, 1 PDPv4 and 1 PDPv6 could be active in the same time consuming more network resources

The connectivity in a dual-stack Mobile Core environment is presented below:

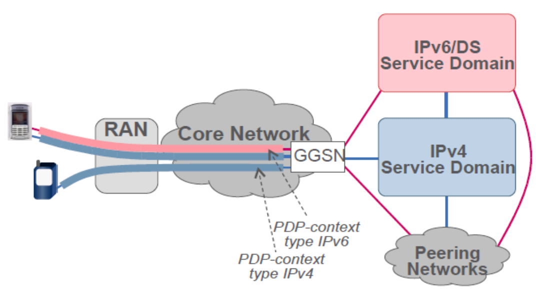

Fig. 3. IPv6 dual-stack Mobile Core

3.2.2 Non-3GPP access to the Mobile core and Fixed Mobile conversion (FMC)

The EPC is not limited to supporting 3GPP IP Access Networks as non-3GPP wireless and wireline access networks are supported as well.

As the EPC is an all-IP network, it is highly indicated to bring under its umbrella all the existing separate Mobile Provider IP networks that until now could not share the same policy umbrella and core architecture. This is the reason for which a vendor that is planning to migrate towards an all-IP EPC core should properly investigate and plan for the integration of its existing non-3GPP wireline and wireless networks under the 3GPP EPC umbrella.

Apart from the single core architecture there are features provided by the EPC that may be useful for these non-3GPP wireline and wireless access network. These features are listed below:

- Mobility
- Policy
- Authentication & Authorization
- Accounting
- Lawful Intercept
- Secure Access

For the trusted non-3GPP access the authentication depends on the support of the non-3GPP element connecting to the EPC.

For the non-trusted non-3PGG access UE connects to the EPC via the ePDG element by use of IKEv2/IPSec and authentication (over IKEv2) is done with EAP-AKA or EAP-SIM

The summary non-3GPP access to the EPC architecture is presented bellow.

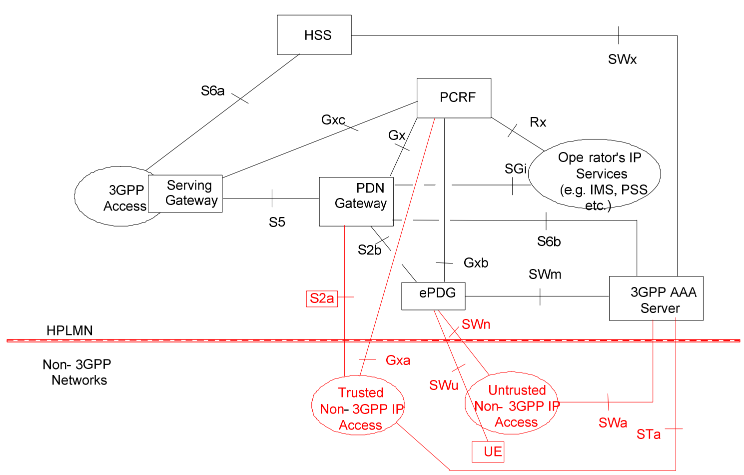

Fig. 4. Non-3GPP access into the mobile core [8]

3.2.3 Gx and Gy implementation

It is critically important for a network preparing to migrate towards next generation EPC to have both its Prepaid/Postpaid and Policy and Charging Control functionality already implemented , unified and standards based.

Prepaid /Postpaid:

The traditional Intelligent Network provides real-time charging & rating capabilities only to prepaid subscribers. The traditional billing system is always offline based on CDR file processing. It handles non real-time charging requirements, and its charging execution process is not directly involved in service application control. The Next Generation Online Charging System (OCS) is oriented to all subscriber types and service types, offers unified online charging and online control capabilities and can be used as a unified charging engine for all network services, making it a core basis for convergent billing in the network.

Due to its flexibility it can be used for offering both offline and online charging superseding the Gz interface, as well as complete charging flexibility, being able to report and react on:

- Various key GTP parameters (Ex : MSISDN, SGSN IP, MCC MNC, RAT, Charging Characteristics)
- Various dynamic network state transitions : SGSN change, RAT change, QoS Change

The 3GPP is describing the Online Charging System as implemented over the **Gy reference point** in 3GPP TS 32.299. The Gy is based on Diameter [9] as transport protocol and greatly reuses the principles laid down by the Diameter Credit Control Application [10] specifications, adapting them to the 3GPP use, parameters and terminology.

Policy and Charging Control:

According to 3GPP TS 29.212, the The Gx reference point is located between the Policy and Charging Rules Function (PCRF) and the Policy and Charging Enforcement Function (PCEF). The Gx reference point is used for provisioning and removal of Policy and Charging Control (PCC) rules from the PCRF to the PCEF and the transmission of traffic plane events from the PCEF to the PCRF. The **Gx reference point** can be used for charging control, policy control or both by applying AVPs relevant to the application.

As in the Gy reference point, the **Gx reference point** is based on Diameter (RFC3588) as transport protocol.

Policy and Charging Rules Function (PCRF) is the node designated in real-time to determine policy rules in a multimedia network. As a policy tool, the PCRF plays a central role in next-generation networks. Unlike earlier policy engines that were added on to an existing network to enforce policy, the PCRF is a software component that operates at the network core and efficiently accesses subscriber databases and other specialized functions, such as a charging systems, in a scalable, reliable, and centralized manner.

The PCRF PCC Rule decisions may be based on one or more of the following:

- Information obtained from the AF (Application Function) via the Rx reference point, e.g. the session, media and subscriber related information.
- Information obtained from the PCEF via the Gx reference point, e.g. IP-CAN bearer attributes, request type and subscriber related information.
- Information obtained from the SPR via the Sp reference point, e.g. subscriber and service related data.
- Own PCRF pre-configured information

The PCEF (Policy and Charging Enforcement Function) is the functional element that encompasses policy enforcement and flow based charging functionalities. This functional entity is located at the Gateway (e.g. eGGSN in the GPRS case, and PDG in the WLAN case). It provides control over the user plane traffic handling at the Gateway and its QoS, and provides service data flow detection and counting as well as online and offline charging interactions.

Both Gx and Gy reference points architecture showing the connectivity towards the subscriber gateway is presented below:

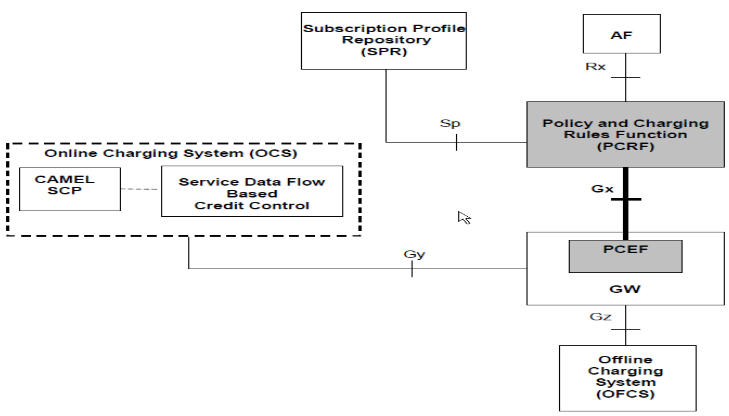

Fig. 5. Gx and Gy reference point [11]

3.3. Applications

3.3.1 Standardization of application access interface towards Mobile Network Core

As the largest driver for demand for more mobile bandwidth which ultimately justifies the migration towards all-IP EPC/LTE/LTE-Advanced architectures are the applications, it is imperatively important for the networks preparing to migrate towards the next all-IP level to insure the right platform allowing for the applications to be developed.
A crucially important facility that mobile applications need is a standardized way of accessing subscriber specific information and communication services when communicating with multiple mobile network providers.
Such set of ‘standardized mobile network provider communication tool’ is proposed by GSM Association OneAPI (Open Network Enablers API). It is a set of API specifications that can be implemented by network operators to allow access to network capabilities such as SMS, MMS, location, payments and more.
The GSMA OneAPI is an initiative to define a commonly supported API to allow mobile (and other network) operators to expose useful network information and capabilities to a Web application developers. It aims to reduce the effort and time needed to create applications and content that is portable across mobile operators.
The OneAPI Pilot running in Canada provides a single gateway for Web application developers to be able to use the OneAPI with all 3 of the major Canadian Operators in a commercial pilot.
The Version 1.0 OneAPI SOAP-based APIs offer the following standardized access towards specific information and communication services:

- SMS Web Service API
- MMS Web Service API
- Location Web Service API
- Payment Web Service API

The Version 1.0 OneAPI interworking with the various customer made-applications is presented below:

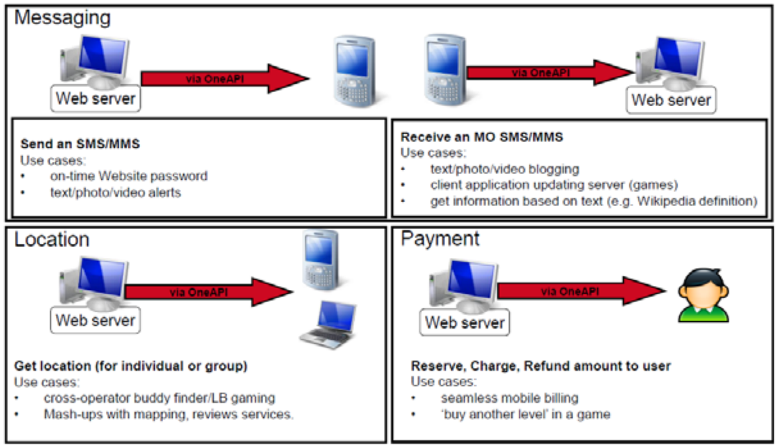

Fig. 6. OneAPI Version 1.0 overview (after [12])

Based on the success of its 1.0 Version implementation, the OneAPI API is planned to be further extended in order to add the following functionality:

OneAPI Version 2.0 – End 2010

- Data Connection Profile
- Device Capabilities
- Call Control (Voice)

OneAPI Version 3.0 - 2011

- SMS triggering via UDH and other triggering/provisioning technologies such as USSD
- QOS to ensure a good quality, jitter-free video stream between a Web server and handset

4. Application Trends driving the need for EPC/LTE/LTE-Advanced

As previously discussed, the mobile application development is the main driver behind the increased need for mobile bandwidth that justifies the EPC/LTE/LTE-Advanced migration.

The application trends are already visible and will increase the data bandwidth requirements in the future [13]:

- Rising use – due to falling prices, more people will use mobile applications that require network access.
- As we can see in the graph bellow belonging to a real Mobile Service Provider, the Packet Data usage over the last years has increased with a factor of 18 compared with a Voice increase multiplication factor of 2.

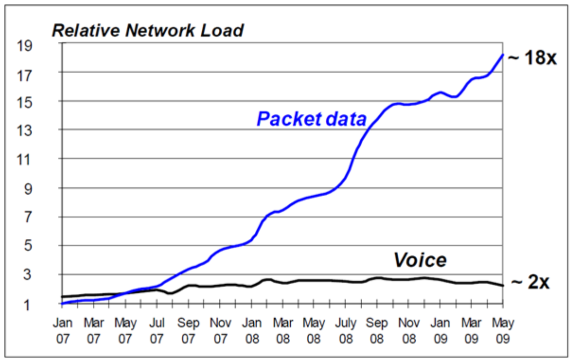

Fig. 7: UMTS-HSPA Voice and Data Traffic[14]

- Multimedia and other Mobile applications content – while first attempts at mobilizing the Web resulted in mostly text-based Web pages, graphical content is now the norm rather than the exception.
  Gartner, Inc. identified the top 10 consumer mobile applications for 2012 based on their impact on consumers and industry players, considering revenue, loyalty, business model, consumer value and estimated market penetration in their report in a November 2009 [15]
  - Money Transfer.
  - Location-Based Services
  - Mobile Browsing.
  - Mobile Health Monitoring.
  - Mobile Payment.
  - Near Field Communications Services.
  - Mobile Advertising.
  - Mobile Instant Messaging.
  - Mobile Music.
  - Voice over IP
- Fixed-line Internet replacement – while the number of voice minutes is increasing, revenue is declining in both fixed line and the wireless networks due to falling prices. In many countries, wireless operators are thus trying to keep or increase the average revenue per user by offering Internet access for PCs, notebooks and mobile devices over their UMTS/HSDPA or CDMA networks. Thus, they have started to compete directly with DSL and cable operators. Again, this requires an order of magnitude of additional bandwidth on the air interface.

Being a strong supporter of the fast Mobile Data Networks growth, Pyramid Research expects LTE networks to grow more quickly than prior 3G networks, reaching 100 million subscribers in just four years from initial 2010 deployments. [16]

Another study based on Cisco's Visual Networking Index (VNI) predicts that Mobile video will be responsible for the majority of mobile data traffic growth between 2009 and 2014. As the picture bellow shows, overall mobile data traffic is expected to grow to 3.5 exabytes per month by 2014, and over 2.4 of those are due to mobile video traffic.

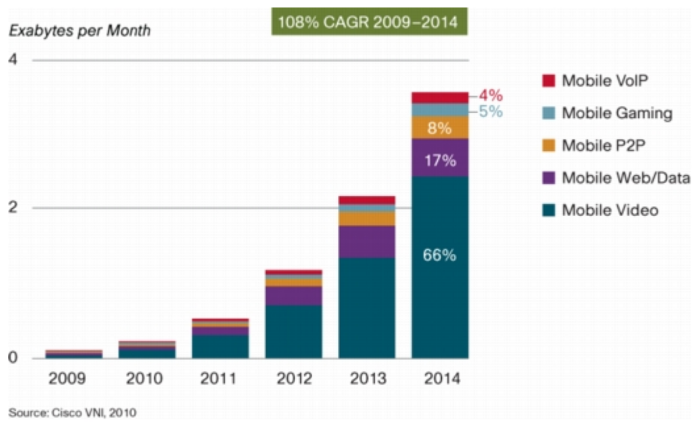

Fig. 8: Global Mobile IP Traffic Will Grow at a CAGR of 108 Percent from 2009-2014

According to Cisco, the advent of laptops and high-end handsets onto mobile networks is a key driver of traffic, since these devices offer the consumer content and applications not supported by the previous generation of mobile devices. Chief among these new sources of traffic is video, but other applications such as P2P are already making an impact. Despite the relatively small number of laptops with mobile broadband aircards today, P2P traffic from those devices already accounts for 20 percent of all mobile data traffic globally. As shown in the figure bellow, a single laptop can generate as much traffic as 1300 basic-feature phones, and a smartphone creates as much traffic as 10 basic-feature phones. iPhones, in particular, can generate as much traffic as 30 basic feature phones.[17]

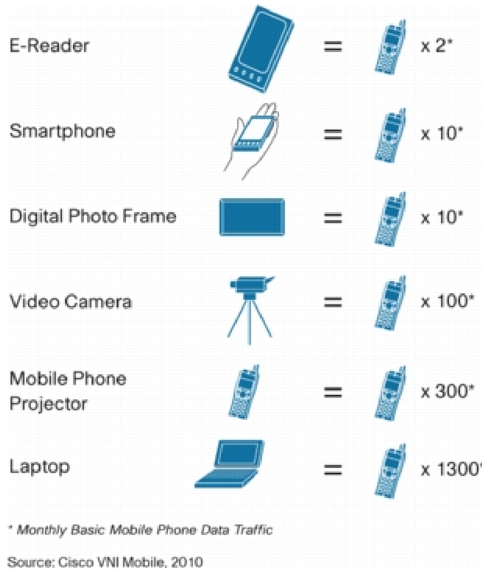

Fig. 9 High-End Handsets and Laptops Can Multiply Traffic

5. Conclusions: Trends to Watch

The present work can be considered a starting base for any mobile operator as it helps both to properly plan the 4G future network architecture based on the architecture that they are using today as well as shaping the most likely migration process based on a pre-agreed "migration focus points list". Cisco's approach to forecasting IP traffic is conservative, and there are certain emerging trends that have the potential to increase the traffic outlook significantly. The most rapid upswings in traffic occur when consumer media consumption migrates from offline to online or broadcast to unicast.

• **Applications that might migrate from offline to online**: The key application to watch in this category is gaming.

• **Behavior that might migrate from broadcast to unicast**: Live TV, network DVR, TV Anywhere. The majority of video minutes still reside on the broadcast network. Should a significant number of these minutes migrate to a unicast platform, the traffic increase could be dramatic. Trials conducted by all major mobile operators have converged on the opinion that around 40 – 60% of users would like to watch mobile TV, provided it is appropriately priced and has consistent quality. News, sports, weather, location-based services, traffic information, business newswires (e.g., stock prices), and cartoons featured high in the surveys as the programs most likely to be watched [18] and they are all prone to be transmitted over unicast.

• **New consumer behavior**: 3DTV. The most likely scenario for home 3DTV is that it will take three to five years to gain momentum.[19]

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