A CRITICAL ANALYSIS OF MAP-BASED MOBILE TELEPHONY ARCHITECTURE EVOLUTION

Ştefan MÂNZA[1], Horia HUMĂILĂ[2]

Telefonia mobilă este domeniul cu cea mai rapidă dezvoltare din industria Telecomunicaţiilor, jucând un rol important în fenomenul de globalizare şi dezvoltare economică. Un rol particular în dezvoltarea Telefoniei Mobile este jucat de segmentul de comunicaţii de date pentru care este prevăzută o dublare a traficului în fiecare an în următorii cinci ani. Lucrarea de faţă prezintă cele mai importante aspecte din istoria dezvoltării arhitecturilor de telefonie mobilă de tip MAP de-a lungul timpului, începând cu versiunea analogică 1G şi terminând cu versiunea actuală Release 9, evidenţiind în special rolul din ce în ce mai important al comunicaţiilor de date în contextul general, precum şi ce avantaje/ dezavantaje sunt asociate cu fiecare nouă arhitectură.

Mobile telephony is the fastest developing field of the Telecommunications indystry playing a major role in the world globalization process and in the economic development. A particular role in the Mobile telephony development is played by its data communications part which is planned to double every year in the next five years. The present work presents the highlights of the MAP-based arhitecture development over the years starting with the 1G analogic transmission and ending with the present reference architecture: Release 9 , with a special focus on the increased role of the data mobility part within the generic mobility framework as well as underlining the advantages / disadvantages of each new architecture.

1. Introduction

This article proposes to describe the state of the art and the trends in the field of the Packet Switched Mobile Architecture as reflected in the more generic Mobile Telephony Architecture evolution.

Although initially it was indented as an low importance auxiliary service, the Packet Switched Mobile Architecture increased its relevance over the years within the Mobile Reference Architecture arriving to completely replace the Circuit Switched option and establish itself as the only option for the future-proof next generation Mobile Architecture. The architectural main focus is the European-originated MAP-based Mobile Telephony Architecture.

[1] Ph.D. student, Automatic Control and Computers Faculty, University POLITEHNICA of Bucharest, Romania, e-mail: stefan.manza@gmail.com

[2] Ph.D. student , Automatic Control and Computers Faculty, University POLITEHNICA of Bucharest, Romania

2. 1G

Although the Mobile Telephony concept was known and tested starting with the end of World War 2, the first real commercial attempt to implement a large scale mobile telephone system dates from 1979, when the Nippon Telegraph and Telecom (NTT) launched the service covering the Tokyo area.

NTT was followed by the 4 Scandinavian countries in 1981 when Nordic Mobile Telephone (NMT) system was launched in the Scandinavian region.

This represented the 1st generation of mobile phones, known as 1G architecture which was entirely based on unencrypted anagogic transmission of its radio side , therefore the term 1G strictly refers to analog cellular technologies that became available in the 1980s [1]

Advantages:

- *1G offered for the first time the possibility of mobile communications at a wide commercial scale*

Disadvantages:

- *The 1G communications were anagogic / unencrypted,*
- *The terminal-to-network signaling is performed inband*
- *No Data transfers were possible in the wide commercial version*

2. 2G (GSM)

Initially launched as a European initiative in 1982 by CEPT the Groupe Special Mobile (Special Mobile Group) was tasked to develop a standard for mobile telephony across Europe in the 900 MHz band. Five years later in 1987, the signature by thirteen countries of a Memorandum of Understanding to develop a pan-European common cellular telephony system in the 900 MHz band marked the official birth of GSM, set for service launch in 1991. [2]

By 1990, the first set of specifications GSM **Phase 1**, was frozen and published and the first 2G network was launched in 1991 in Finland by Radiolinja, the 2G network age was born.

The initial 2G architecture allowed for out-of-band signaling and addressing and was based on Circuit-Switched voice and data calls.

Some of the other highlights of Phase 1 (with focus on data and supplemental services) were [2]:

- The Data calls over Switched Circuits were offering speeds of up to 9.6kbps allowing connection with an ISDN modem through PSTN.
- Allowed for Supplementary services pertaining to call barring and call forwarding such as barring of all incoming calls, barring of incoming calls when roaming outside the home network, call forwarding on no reply, call forwarding on mobile subscriber busy etc

- Support for facsimile (fax) communications (Group 3: the most widely used)

Phase 1 was followed in 1995 by **Phase 2** and some of the highlights related to Phase 2 (with focus on data and supplemental services) were [2]:

- Half-rate data services allowing a higher maximum number of data users.
- SMS enhancements such as SMS concatenation, replacement.
- Supplementary services such as enhancements to call barring and forwarding, calling line Identification presentation and restriction, multiparty calls, etc.
- Fax enhancements.

Starting with **Phase2+** the release naming was changed in order to reflect the year it was released on and thus the **Phase2+** was rebranded as **Release96** (or **R96**).From **R96** on, a new release will come out each year. The most notable **R96** improvements regarding data services were [2][3]:

- Data services at 14.4 kbit/s.
- CAMEL (Customized Applications for Mobile networks Enhanced Logic) Phase 1. CAMEL enables the definition of services on top of existing GSM services such as allowing using the same phone number when roaming outside one's home network. CAMEL Phase 1 offers call control related functionalities

Advantages *of 2G networks over its 1G predecessor were:*

- *phone conversations were digitally encrypted;*
- *2G systems were significantly more efficient on the spectrum allowing for far greater mobile phone penetration levels;*
- *2G expanded the data services for mobile, starting with SMS text messages*
- *Data speeds reached up to 14.4kbps*

Disadvantages *(compared with later systems)*

- *The data traffic was transmitted using circuit switched calls.*

3. 2.5G (GPRS)

Starting with **R97** the GSM architecture was adapted in order to allow for higher data speed rates and reduce the dependency on Circuit Switched calls in order to establish a data call by requesting radio resources only when there is data to send.

Although the Access Network was partly redesigned to support packet transmission and shared resource allocation schemes, the GSM architecture has undergone its biggest change on its core side as it was modified in order to allow 2 parallel types of calls:

- Circuit Switched Calls (CS)
- Packet Switched Calls (PS)

New core architecture elements appeared that would duplicate the equivalent CS functionality for the PS side.

Apart from the architectural changes, the most notable R97 improvement regarding the data services were[2][3]:

- Four coding schemes, CS-1 to CS-4 using GMSK (Gaussian Minimal Shift Keying) modulation, and link adaptation allow an efficient use of radio resources. (Based on specifications in Release 97, GPRS typically reached speeds of 40Kbps in the downlink and 14Kbps in the uplink by aggregating GSM time slots into one bearer)
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Advantages *of 2.5G networks over its 2G predecessor were:*

- *Dual-core architecture covering for both Packet Switch and Circuit Switched calls*
- *Data speeds reached up to 40kbps*

Disadvantages *(compared with later systems)*

- *Very high latency: over 700ms*
- *Data speed did not allow for a wide class of applications to be used (video, multimedia, even rich HTTP content)*

4. 2.75G (EDGE)

The need for higher data speeds resulted in an immediate ‘upgrade’ of the data rates provided by the newly introduces Packet Switched GSM data architecture, called Enhanced Data rates for Global Evolution or EDGE.

Through the introduction of the 8-PSK (8 Phase Shift Keying) modulation on the GSM air interface for both packet-switched data (EGPRS – Enhanced GPRS) and circuit-switched data (ECSD – Enhanced CSD), EDGE boosts peak and average data rates as well as network capacity. EGPRS provides data rates up to 59.2 kbit/s per time slot per direction (i.e. up to 473.6 kbit/s per 200kHz carrier).

Apart from EDGE data rates, **R98** added the following enhancements over its predecessor regarding data and supplemental services [2][3]:

- Location Services (LCS) in CS Domain: Definitio of mechanisms to support location technologies in GSM based on cell identity
- Lawfull Interception Architecture
- Modem and ISDN interworking for GPRS
- GSN Number Portability (MNP)
- Enhanced QoS Support in GPRS

- GPRS Mobile IP Interworking

***Advantages** of 2.75G networks over its predecessor were:*

- *Enhanced data speeds : up to 200kbps*
- *Reduced latency : bellow 200ms*
- *Increased mobility : through NMP and Mobile IP*
- *Increased security : through LI support*

***Disadvantages** (compared with later systems)*

- *Still a quite large latency that did not allow for proper interactive-class applications (e.g. video-conference, VoIP, gaming)*
- *Although QoS existed on RAN side, the service provided was not guaranteed. All packets passing through the RAN side got a best effort treatment form the network.*

5. 3G (UMTS) and 3GPP

The ITU (International Telecommunication Union), as a worldwide telecommunication standard body, played a key role in 3G definition.

ITU and the IMT-2000 Framework

The IMT-2000 framework (International Mobile Telecommunications 2000) was initially launched by the ITU (International Telecommunication Union), in order to define 3G system and evolution for heterogeneous 2G technologies This was felt the best way to define a common basis for performance, global access and seamless mobility requirements.

The IMT-2000 framework not only aims at defining international standards for 3G, but also cares about frequency spectrum issues, technical specifications for radio and network components, as well as regulatory aspects.[PTL08]

3GPP

As a result of IMT-2000’s call for candidate 3G radio access technologies, 3GPP (3rd Generation Partnership Project), was established in December 1998 as a collaboration project between ETSI (Europe), ARIB4 (Japan), TTC5 (Japan), ATIS6 (North America), TTA7 (South Korea) and CCSA8 (China) to develop a global third generation mobile phone system specification

Under the 3GPP guidance the **R99** came out and apart from the introduction of the UMTS (described in the section bellow), layed out the following key improvements [2][3][4]:

- Charging and Billing for GPRS – Advice of Charge / Hot Billing / Pre-Paid
- End to End UMTS QoS Management
- Circuit Switched Multimedia (Video) calls

UMTS (3G)

UMTS is based on a standard developed by the 3GPP, commercially launched in 2001 in Japan – under the name of FOMA (Freedom of Mobile Multimedia Access) – and 2003 in other countries. UMTS supports two variants: a FDD mode, being the most deployed, and a TDD mode, mainly supported for the Chinese market.

UMTS relies on the CDMA (Code Division Multiple Access) multiplexing scheme using a high chip rate direct spread sequence. In its first form,UMTS/FDD advantages were limited to increased data rates (up to 384 Kb/s per user on a single channel), the possibility of simultaneous packet and circuit applications, and improved roaming capabilities.

A theoretical maximum bit rate of 2 Mb/s over dedicated channels has been defined within the specification, but has never been deployed as such in commercial networks.

UMTS is often presented as the **3G** evolution of GSM networks. Although the UMTS radio interface is completely different from the GSM/EDGE one, a lot of architectural concepts and procedures have been inherited from GSM.

The UMTS/3G architecture brings major changes on the Radio side, where the BTS+BSC radio cell structure becomes NodeB +RNC however on the Core side it reuses the existing parallel CS and PS architecture introduced by the **2.5G** generation.

Starting with the year 2000, the Release numbering has changed under the 3GPP guidance and therefore the new Release specification linked with that year was initially named **Release 2000** and later became **Release 4**.

The most important improvements it brought over the earlier releases were [6]:

- Gb over IP: Definition of IP transport over the Gb interface between the BSC and the SGSN, as an alternative to frame relay
- Multimedia Messaging Support (MMS)
- SIGTRAN over SCTP definition as an alternative signaling transport protocol

***Advantages** of 3G networks over its predecessor were:*

- *Enhanced data speeds : up to 384kbps*

- *Reduced latency : bellow 150ms*
- *Enhanced QoS : including guaranteed bitrate , loss , jitter and latency*
- *Increased reliance for IP-based transport on the RAN , SS7 and Packet Core side*

Disadvantages *(compared with later systems)*

- *The data bandwidth although large, was not enough to provide acceptable service in high density urban sites*
- *No unified framework for signaling and billing related to various applications made possible by the increased bandwidth and reduced latency provided by 3G*

6. 3.5G (HSDPA)

Starting with **Release 5**, 3GPP introduced its Evolved 3G Radio Architecture (or 3.5G) which could reach sppeds up to 10MBps

High Speed Downlink Packet Access (HSDPA) is a feature based on a downlink shared channel, data only, that allows data rates of up to 10 Mbps. It is designed to support services that require instantaneous high rates in the downlink and lower rates uplink (also called "reverse link"). It also allows to decrease the level of retransmissions (at the Radio Link and hence higher layers), in turn allowing the reduction of delivery time. Examples of end-user services using HSDPA are Internet browsing and video on demand.

Rel-5 HSDPA results from a **Rel-4** study that considered a number of techniques in order to provide instantaneous high speed data in the downlink. Some considerations taken into account in the evaluation of the different techniques were[7]:

- to focus on the streaming, interactive and background services.
- to prioritise urban environments and then indoor deployments
- to enable compatibility with advanced antenna and receiver techniques.
- to take into account User Equipment processing time and memory requirements.
- to minimize changes on existing techniques and architectures.

As of 2009, the most common devices are using HSDPA 3.6 Mbit/s or HSDPA 7.2 Mbit/s both variants being defined in **Release 5**

7. IMS

Apart from the HSDPA definition, **Release 5** has also introduced the concept of IMS (IP Multimedia core network Subsystem)

The objective of IMS is to efficiently support applications involving multiple media components as video, audio, and tools like shared online whiteboards, with the possibility to add and drop component(s) during the session. These applications are called IP Multimedia applications (or "services").

The efficient support of these applications is based on the principle that the network is able to dissociate different flows within the multimedia session. These flows are typically used to carry the data resulting from the different media components of the application, and so have different Quality of Service characteristics. As the network knows these characteristics, a more efficiently handling of the resources is possible. It also enables to dissociate the session negotiation from the bearers establishment. [7].

Other notable **Rel-5** enhancements are [2][7]:

- IP Transport in UTRAN (the possibility to use IP at the transport layer in the Iub, Iur, Iu-Ps and Iu-Cs interfaces, as an alternative to ATM)

Advantages *of HSDPA networks over its predecessor were:*

- *Enhanced data speeds : up to 10Mbps downstream*
- *Reduced latency : bellow 100ms*
- *Centralized Application signaling and billing through IMS*

Disadvantages *(compared with later systems)*

- *Limited upstream speed did not allow for services requiring massive subscriber-initiated IP traffic*

HSUPA

As described above, **Release 5** allowed the possibility to implement considerably higher download speeds than the original 3G UMTS allowed. As a natural evolution, the next release (**Release 6**) introduced Radio improvements that allowed for higher Upload speeds as well.

High Speed Uplink Packet Access (HSUPA) is justified as the use of IP based services becomes more important and there is an increasing demand to improve the coverage and throughput as well as reduce the delay of the uplink. Applications that could benefit from an enhanced uplink may include services like video-clips, multimedia, e-mail, telematics, gaming, video-streaming etc.

Allthough the name HSUPA was created by Nokia (the official 3GPP name for 'HSUPA' is the name Enhanced Uplink (EUL)) it became ‘de facto’ naming for wide public.

The following items were part of the overall design effort to make higher Uplink transmission rates possible in **Release 6** [8]:

- Node B controlled scheduling of uplink transmission timeslots granted to each UE
- Hybrid ARQ (Automatic Repear reQuest): Rapid retransmissions of erroneously received data packets between UE and Node B,
- Shorter TTI (Transmission Time Interval): Possibility of introducing a 2 ms TTI.

The main aim of HSUPA is to increase the uplink data transfer speed in the UMTS environment and it offers data speeds of up to 5.8 Mbps in the uplink. HSUPA achieves its high performance through more efficient uplink scheduling in the base station and faster retransmission control.

The combination of the HSUPA and HSDPA capabilities results in HSPA : High Speed Packet Access which will be used to define the Evolved 3G Data speed capabilities starting with **Release 6**

Other important **Release 6** improvements over its predecessors were focused mainly towards providing additional services over the high-speed data architecture [8]:

- Multimedia Broadcast and Multicast
- WLAN – UMTS interworking within 3GPP framework
- Presence Capability (PRESNC) : the ability to provide real-time "presence information" about a user, i.e. his/her capability to answer a call
- Speech Recognition and Speech Enabled Service (SRSES)
- 3GPP enablers for Services like Push to Talk over Cellular (PoC) .
- Voice over IMS : Voice Calls over IP make use of Conversational Packet Switched Multimedia Services that can be performed through IMS in an efficient and integrated way.

Advantages *of HSUPA networks over its predecessor were:*

- *Enhanced data speeds in the upstream: up to 5.8Mbps upstream*
- *Non UMTS systems allowed within 3GPP architecture (WLAN)*

Disadvantages *(compared with later systems)*

- *No final standardized methodology for policy control and charging within the network, specially related to specific QoS requested by each application.*

8. 3.75G Evolved HSPA (HSPA+)

Release 7 brought another evolution in the Data Transfer speed over Radio, called Evolved HSPA or HSPA+.

HSPA+ provides HSPA data rates up to 84 Megabits per second (Mbit/s) on the downlink and 22 Mbit/s on the uplink through the use of a multiple-antenna technique known as MIMO (for "multiple-input and multiple-output") and higher order modulation (64QAM). MIMO on CDMA based systems acts like virtual sectors to give extra capacity closer to the mast. The 84 Mbit/s and 22 Mbit/s represent theoretical peak sector speeds. The actual speed for a user will be lower. At cell edge and even at half the distance to the cell edge there may only be slight increase compared with 14.4 Mbit/s HSDPA unless a wider channel than 5 MHz is used.

Other **Release 7** enhancements include [9]:

- IMS support of conferencing (IMSconf)
- Global Navigation Satellite System in UTRAN (GNSS)
- Evolution of Policy Control and Charging (PCC), additionally a single reference point between the PCRF and the PCEF was introduced: the Gx reference point
- Voice Call continuity between CS and IMS
- One Tunnel (Direct Tunnel) solution for Optimization of packet Data traffic (OPTUNEL)
- Diameter on the GGSN Gi interface (DIAMGi) : a replacement for the Radius protocol in order to provide Authentication, Authorization and Accounting (AAA) services

***Advantages** of HSPA+ networks over its predecessor were:*

- *Enhanced data speeds: up to 84Mbps downstream and 22Mbps upstream using MIMO*
- *Reduced latency : under 50ms*
- *Standardized Policy Control and Charging for QoS establishment*

***Disadvantages** (compared with later systems)*

- *The absence of an all-IP architecture covering both RAN and Core.*

9. 3.9G (EPC and LTE)

EPS (Evolved Packet System) introduced in 3GPP **Release 8**, represents the very latest evolution of the UMTS standard and proposes a significant improvement step, with a brand new radio interface and an evolved architecture for both the Access and the Core Network parts.

EPS, whose radio access is called Evolved UMTS Terrestrial Radio Access Network (E-UTRAN) or LTE (Long Term Evolution), is expected to substantially improve end-user throughputs, sector capacity and reduce user plane latency, bringing significantly improved user experience with full mobility. With the emergence of Internet Protocol (IP) as the protocol of choice for carrying all types of traffic, EPS is designed to provide support for IP-based traffic with end-to-end Quality of service (QoS). Voice traffic will be supported mainly as Voice over IP (VoIP) enabling better integration with other multimedia services.

The two major disruptions brought by EPS are [10]:

- Improved radio performances
    - Spectrum efficiency
    - Throughput increase up to 100Mb/s downlink and 50Mb/s uplink
    - Reduced time for state changes
    - Reduced user plane latency: to a target LTE maximum end-to-end delay of 5ms (competing with fixed line networks).
    - Scalable bandwidth : capable of operating with 1.25/2.5/5/10/20 MHz bandwidths in uplink or downlink,
- IP packet-only system – resulting in a unified and simplified architecture.

As presented above, LTE has been set aggressive performance requirements that rely on physical layer technologies, such as, Orthogonal Frequency Division Multiplexing (OFDM) and Multiple-Input Multiple-Output (MIMO) systems, Smart Antennas to achieve these targets.

In the new EPS architecture, the **Release 7** SGSN becomes MME(Mobility Management Entity) which only handles the signaling part of the traffic flow.

The UMTS NodeB becomes Enhanced Node B and has the capability to forward the user data over IP encapsulation natively.

The **Release 7** GGSN is ‘split’ into 2 logical entities under EPS:

- Servings Gateway (local mobility anchor for the eNodeB initiated tunnels)
- PDN Gateway (User IP allocation , DPI functionality, charging and PCEF functionality)

The PCRF element becomes a ‘central’ entity in the EPS as a central decision point for all the Policy and Charging decisions of the Mobile Packet Core.

Although EPS is an all-IP domain, in **Release 8** the Voice calls are not mandatory to be placed over the IMS system and alternatives for Circuit Switched based calls have been foreseen.

Other **Release 8** important enhancements include [12]:

- Self Organizing Networks – SON
- Circuit Switched Call Fallback in EPS
- System enhancements for the use of IMS services in local breakout
- Dual-carrier (or dual-cell) HSDPA operation
- Support for Home NodeB / Home eNodeB (FemtoCell)

The **Release 9** main focus is to improve the EPS/LTE specifications and features introduced in **Release 8** as well as to 'port' existing UMTS based features over the EPS/LTE

The most important **Release 9** features worth mentioning are [13]:

- Non-contiguous dual-cell HSDPA/HSUPA: dual-band operation,
- MIMO + DC-HSDPA : combining the dual-carrier HSDPA operation with MIMO
- IMS EMERGENCY OVER EPS (emergency services over IMS and EPS)
- Location Services over EPS
- MBMS services support over LTE

Release 9 was completed by 3GPP and currently is the latest completed major 3GPP Release, at the date of writing this article there is ongoing works towards the completion of 3GPP **Release 10**.

Advantages *of LTE networks over its predecessor were:*

- *Enhanced data speeds: up to 173Mbps downstream and 58Mbps upstream (2x2 MIMO)*
- *Reduced latency : under 5ms*
- *An IP-only end-to-end architecture*

Disadvantages

- *The absence of a standardized VoIP-only reliable system to replace the legacy CS-based calls*
- *The absence of a standardized roaming framework*

10. Synthetic results of the analysis

Among the last 20 years the mobile wireless technology has greatly evolved, in order to keep up with the increasing customer demands, has diversified its service offerings, and has always incorporated the latest cutting edge technologies in order to retains its status of "the most evolved telecommunications industry branch".

Below is a table summarizing the main, network speed/latency, features and Data services brought by each of the major mobile network architecture:

Tabel 1

Mobile Architectures comparison

Mobile Archit..	Data Speed Up/Down	Data latency	QoS	MI MO	IMS	PCRF	Data Core	Typical Data Service
1G	No	none	No	No	No	No	None	Voice call
2G	14.4Kbps	<700ms	BE	No	No	No	CS	Fax
2.5G	40Kbps	<700ms	BE	No	No	No	PS	WAP/HTTP
2.75G	200Kbps	<200ms	BE	No	No	No	PS	Streaming
3G	384Kbps	<150ms	Guaranteed	No	No	No	PS	VoIP
3.5G	5.6/10Mbps	<100ms	Guaranteed	No	Yes	No	PS	Home Broadband
3.75G	22/84Mbps	<50ms	Guaranteed	Yes	Yes	Yes	PS	Company Broadband
3.9G	58/173Mbps	<5ms	Guaranteed per Service	Yes	Yes	Yes	All-IP	Telepresence

Although the mobile wireless technology has evolved tremendously over the last 20 years, its core infrastructure still remained ‘anchored’ within relying on the ‘traditional’ circuit switched transport and architecture. With the imminent introduction of the 4th generation network, the mobile operators across the world are facing the tremendous task of migrating their existing networks towards a completely new transport and core architecture based entirely on IP.

11. Conclusions

Even if at the beginning the main purpose of Mobile Telephony was to safely deliver a circuit switched call over the air interface, in the light of IP technology penetration into the mobile world and increased demand for service and application diversity, the focus has shifted over the years towards delivering multiple IMS-controlled applications (including Voice Calls), each with its appropriate QoS and charging characteristics over a unitary packet switched environment.

The paper has identified the main drivers behind the need for mobile network increased data transport in the years to come which is supposedly the main reason for mobile operators to migrate towards all-IP EPS/LTE/LTE-Advanced architectures:

- Rising use – due to falling prices, more people will use mobile applications that require network access
- Multimedia and other Mobile applications content – while graphical content is now the norm rather than the exception

- Voice over IP – the fixed line world is rapidly moving towards VoIP
- Fixed-line Internet replacement.

A future work intends to capture the challenges, opportunities and drivers towards migrating the current networks into an all-IP environment and to offer in the same time some innovative migration ideas and comparative analysis between different migration options.

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