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GSM-UMTS Infrastructure Deployment Dilemma

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Abstract – Following a decade of explosive and phenomenal growth, Mobile Operators today are frustrated about the next deployment move of their network infrastructure. In this article, we examine the different mobile infrastructure generations and deployment scenarios, taking into account key factors such as: status of existing networks, market demands of anticipated services/capacity/coverage, applications/content readiness, O&M cost, terminal availability, cycles of technology, 3GPP standards maturity, vendors capability, regulatory impacts and, above all, the economic implications. We conclude with guidelines which should assist operators in better making their choice.

I Introduction

Along with the high pace of Mobile infrastructure growth of 2G systems, GSM operators around the world are at early stages of upgrading their networks with different forms of mobile data technology generations, namely: High Speed Circuit Switched Data (HSCSD: 2.25G), General Packet Radio Service (GPRS: 2.5G) and Enhanced Data rates for Global Evolution (EDGE: 2.75G). They are also reviewing architectures and deployment plans of third generation mobile 3G. UMTS (Universal Mobile Telecommunications System) is the dominant 3G system. UMTS is an evolution of GSM which represents more than 70% of all mobile users worldwide today. The network architecture of UMTS mobile system has been evolving, partly resembling its GSM origin (GERAN, UMTS Release 99), and rapidly driving towards its foreseen dream of NGN All-IP architecture (Rel-4, Rel-5, Rel-6), in order to enable multiplicity of multimedia services and other innovative bandwidth-hungry applications [1], [2], [3], [4]. While the migration steps and upgrades from GSM to 3G have been foreseen to evolve progressively from generation to the next over a 6 years time-frame (1997-2002), it is only in 2001 that their deployment altogether started to appear practical and make business sense. A number of deployment scenarios towards 3G are being proposed. They are conceived to suit every possible network environment [5], [6], [7]. Small-scale deployments and field trials are being conducted by several mobile operators.

The multiplicity of technology options and deployment scenarios, combined with the so many time sensitive factors stated below, make the choice of deployment of next generation infrastructure far from being clear, and is expected to continue as such for some time to come. In a competitive environment, however, it is clear that the choice of next mobile network infrastructure technology and architecture would make the difference between Mobile Operators success and failure [8].

The quest for Mobile Network Operators is how to utilize mature and standard technologies to build the most effective infrastructure in terms of low CAPEX/OPEX (Capital Expenditure /Operational Expenditure), efficiency, capacity, coverage and service, in order to provide for services that people need, like, afford and prepared to pay for, under regulatory and budget constraints.

In section II, we summarize the constituents of GSM generations, and highlight what it takes for transition to such generations and the services they offer. We then examine, in section III, the significance of the 3G UMTS emerging Releases, developed by 3GPP (3G Partnership Project), along with the environments and timeframes in which they are evolving. The mobile infrastructure deployment dilemma is then defined in section IV together with viable deployment scenarios considered by most operators.

We then provide guidelines which we believe will assist Mobile Operators in better making their choice, for avoiding a long wait that could lead to loss of opportunities, or rushing deployments and investment that may turn non-optimal.

II. GSM Generations Accumulation

A. Vanilla GSM Network: 2G

The GSM network can be divided into two subsystems, namely: Network Services Subsystem NSS (subsequently denoted: Core Network CN in UMTS terminology) and Base Station Subsystem BSS (Radio Access Network RAN).

Fig.1 shows the different entities of the GSM Network along with the interfaces between the entities, as described below:

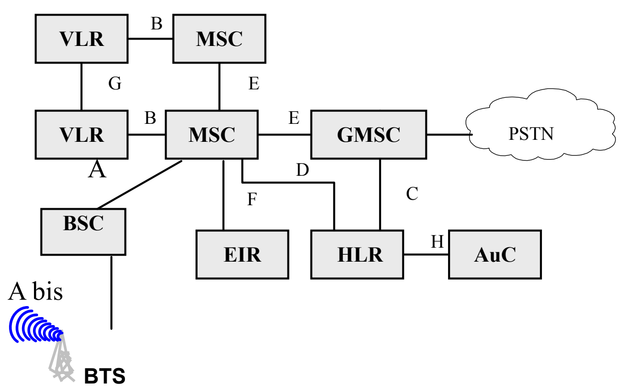

Fig.1 GSM Network Basic Architecture

MSC (Mobile Switching Center): performs all necessary functions in order to handle the circuit switched services to and from the mobile stations and the rest of telecom networks. In addition to its interfaces with the radio access networks, Fig.1 shows the interfaces to the fixed PSTN network (Gateway MSC), other MSCs, and various core network registers (HLR, EIR, AuC). The functions of an MSC include: coordination of call setup from all Mobile stations MS's, handover management, collecting the data for the billing center; signaling exchange between different interfaces; and echo canceller operation.

HLR (home location register): provides support to entities of the Circuit Switching "domain" such as the MSC and GMSC, through the D and C interfaces, respectively. It enable subscriber access to the services. The HLR contains the permanent subscriber data which include: International Mobile Subscriber Identity (IMSI); MSISDN (the directory number of the MS); MS class information; possible roaming restrictions; and supplementary services parameters. HLR also contains temporary data like the current (VLR) address.

VLR (Visitor Location Register) controls mobile stations roaming in an MSC area. When an MS enters a new location area, it starts a registration procedure. The MSC in charge of that area notices this registration and transfers to the VLR the identity of the location area where the MS was situated. When a user registers with another network, the subscriber data is removed from the old VLR and copied to the new VLR. If this MS is not yet registered, the VLR and the HLR exchange information to allow the proper handling of calls involving the MS. The VLR contains the information needed to handle the calls set-up or received by the MSs registered in its data base. A VLR contains information from all active subscribers in its area, including MSs from other networks.

AuC (Authentication Centre): is an entity which stores data for each mobile subscriber to allow the IMSI to be authenticated and also to allow communication over the radio path between the mobile station and the network to be ciphered. The AuC transmits the needed data via the HLR to the VLR and MSC. The AuC is associated with an HLR and connected to it through the H-interface.

EIR (Equipment Identity Register): is the logical entity which is responsible for storing in the network the International Mobile Equipment Identities (IMEIs). The mobile equipment may be classified as "white listed", "grey listed" and "black listed".

The BSS is the system of base station equipments which is viewed by the MSC, through a single "A interface", as being the entity responsible for communicating with Mobile Stations in a certain area. A BSS may consist of one or more base stations. Where an "Abis-interface" is implemented, the BSS consists of one **Base Station Controller (BSC)** and one or more **Base Transceiver Station (BTS)**. A BSC is network entity with the functions for control of BTS's.

A BTS is a network entity which serves one cell. The channel spacing of BTS's is 200 kHz which uses Gaussian Mean Shift Key modulation and provides transmission rate of 270.833 kbps, which offers 8 time-division 16 kbps voice channels.

B. GSM Network with HSCSD: 2.25 G

The principle of HSCSD is twofold: first to facilitate less redundant error-correction overhead of the GSM Radio Link Control RLC that would result in increase of the data bit rate from 9.6 to 14.4 kbps, and second to allow the multiplexing or bundling 2, 3 or 4 of time slots into a higher bit streams. An effective form of bundling is realized in several networks in such a way that it would be dynamically performed based on the instantaneous traffic situation, thereby not adversely affecting the system capacity. Some networks charge extra for the additional time-slots and some don't charge more. HSCSD is implemented in more than 40 of the advanced GSM networks in more than 30 countries serving more than 100 million subscribers, where data rates in the area of 28.8 and 43.2 kbps are offered. The main applications of HSCSD are: E-Mail, fax, LAN Access, file transfer, surveillance, Videophone, and real-time video and audio streaming.

It is worthwhile noting that while the initial deployment of HSCSD started back in 1997, it was restricted to a single type of PC card. Only starting from mid 2001, however, several Mobile models became readily HSCSD capable. One of the latest Nokia models was announced to offer video streaming service through HSCSD.

HSCSD, being mainly a software upgrade does not entail new network elements and so the GSM operator not only avoids having to redesign the network, but can also have fast implementation (in weeks) and enjoys the GSM large coverage. The deterring drawback of HSCSD is the inefficient switched circuit nature to offer data services

C. GSM Network with GPRS: 2.5G

GPRS is another lane in the road to higher and more efficient mobile data communications. It requires relatively minor additions to the GSM network, mainly: Serving GPRS Support Node SGSN, Gateway GPRS Support Node GGSN and Packet Control Unit PCU. Fig.2 depicts the basic GPRS architecture showing such additions, which are described below:

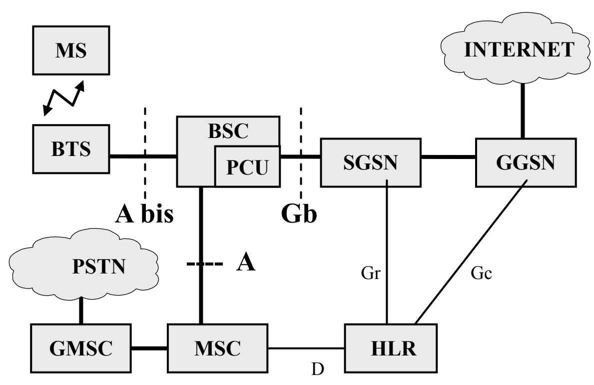

Fig.2 GPRS Basic Architecture

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The SGSN handles originating and terminating packet data transfer. It stores two types of subscriber data namely: subscription information (e.g. IMSI) and location information (e.g. VLR number, GGSN address of each GGSN for which an active Packet Data Protocol PDP context exists). The SGSN connects to the BSS via the Gb interface. It also has interfaces to many other core network entities.

The GGSN corresponds to the GMSC in the circuit-switched network. It is a gateway between the GSM/GPRS network and other external packet-switched networks such as "the Internet". The GGSN stores subscriber data received from the HLR and the SGSN. There are two types of subscriber data, similar to SGSN, needed to handle originating and terminating packet data transfer. The location information includes the SGSN address for the SGSN where the MS is registered. The connection among SGSN and GGSN nodes take place over tunnels that encapsulate IP packets in Protocol Data Units PDU's.

The PCU is mainly an upgrade of BSC to support all GPRS protocols for communication over the air interface. One important aspect of GPRS is that the SGSN is connected to BSS (PCU) through frame-rely.

GPRS achieves data efficiencies over GSM networks in three ways: the first two are somehow similar to HSCSD in that less redundant coding schemes are employed as shown in table-1, and multiple time slots are assigned. The third factor is due to the statistical multiplexing nature of the packet switching. While GPRS is intended to achieve rates up to 115 kbps, practical GPRS implementations offer data speeds around 30 - 50 kbps. There are several "multislot " classes that are expressed in terms of the number of time slots allowed in each of the up and down link directions.

Table.1
GPRS Channel Coding Schemes

Channel Coding Scheme	CS-1	CS-2	CS-3	CS-4
Code rate	1/2	~2/3	~3/4	1
Data rate kbit/s per slot	9.05	13.4	15.6	21.4
Maximum data speed with 8 time-slots	72.4 kb/s	107.2 kb/s	124.8 kb/s	171.2 kb/s

The move from GSM to GPRS, however, is not merely establishing a new network infrastructure which supports higher data rates and new mobile sets. The main driver of GPRS is to facilitate access to Internet and mobile related data applications. The next mobile service wave that is being enabled by GPRS is Multi Messaging Service MMS, which is expected to follow the success of Short Message Service SMS. In this perspective, GPRS is seen by many operators as a gateway to facilitate the anticipated 3G applications.

According to GSM Last December, there were 130 GPRS commercial network, 15 in testing phase and 37 networks under construction worldwide. There are now more than 100 Mobile models that support GPRS.

D. GSM Network with EDGE: 2.75G

EDGE is an enhancement of both HSCSD and GPRS denoted EHSCSD and EGPRS which is achieved primarily through the use of higher modulation schemes in the air interface. The modulation scheme is based on 8-PSK as shown in Fig3. It results in 3 times the bit rate of GMSK.

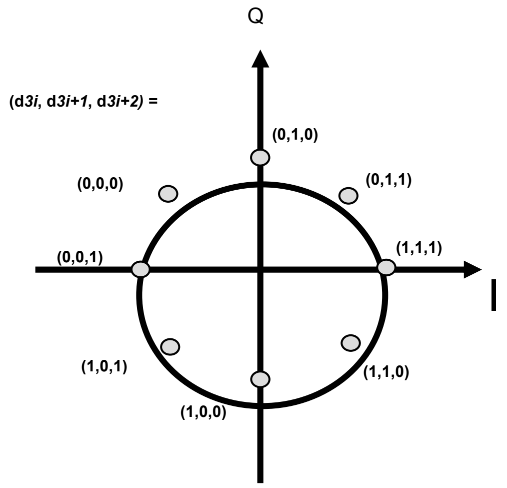

Fig. 3 8-PSK Modulation in EDGE

The data rates for packet mode achieved by EDGE are depicted in table-2. Higher rates are also achieved in the circuit mode (EHSCSD). It is conceived that a bit rate of 48 kbps per timeslot under normal conditions is achievable, which yield 384 kbps for 8 time slots. This should allow the offering of multimedia services comparable to 3G systems.

Table.2
EGPRS Modulation & Coding Schemes

MCS	Slot Capacity (kbps)	Modulation	Channel Capacity (kbps)
MCS-1	8.8	GMSK	70.4
MCS-2	11.2	GMSK	89.6
MCS-3	14.8	GMSK	118.4
MCS-4	17.6	GMSK	140.8
MCS-5	22.4	8PSK	179.2
MCS-6	29.6	8PSK	236.8
MCS-7	44.8	8PSK	358.4
MCS-8	54.4	8PSK	435.2
MCS-9	59.2	8PSK	473.6

From the technology point of view EDGE looks very

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attractive, and it requires minimal changes in a GPRS core network. Although it requires new BTS's with 8-PSK modulation capability, most of BTS's installed after year 2000 by sound Mobile vendors are expected to be EDGE compatible. It is expected that many new EDGE mobile models will be introduced in 2003, and in 2004 all new GSM/GPRS devices to support EDGE. The main problem is that today, only 10 Mobile Operators, mainly in America, endorsed EDGE, with more than 20 in field trials. [9]. Such "wait and see" situation of operators would lead EDGE to loose the economy of scale factor, and consequently loose in competition with other approaches. In line with the optimistic expectations of 3G systems at the onset of this century, most operators made their plans to go directly from GPRS to 3G CDMA systems.

III. Groundbreaking Emerging UMTS Releases

A. UMTS: Release '99

The fundamental difference between GPRS and UMTS R99 is the introduction of UTRAN (UMTS Terrestrial Radio Access Network) which is based on Wideband Code Division Multiple Access (W-CDMA) in the radio access part. Similar to GSM/GPRS, UMTS is logically divided into Radio Access Network (UTRAN) and Core Network, connected through Iu interfaces as shown in Fig.4

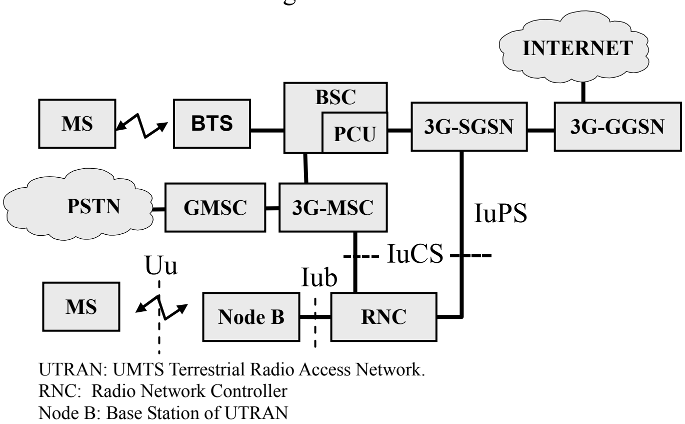

Fig.4 UMTS R99 Basic Architecture

UTRAN consists of one or more Radio Network Subsystems (RNS's). The entities which constitute the RNS are RNCs (Radio Network Controllers) and Node B's. RNC controls one or more Node Bs. It may be connected via the Iu interface to an MSC (IuCS) and/or to an SGSN (IuPS). An RNC is comparable to a BSC in GSM.

Node B is the UMTS equivalent of a base station transceiver. Functions that are performed by a Node B include: Uplink inner-loop power control; reporting of uplink interference measurements, downlink power information, soft handover execution; error detection; rate matching; power weighting and combining of physical channels; modulation and spreading/demodulation and despreading of physical channels; frequency and time synchronization; radio measurements and RF processing.

The core network portion of UMTS R '99 appears the same as the GSM/GPRS core network. Its capabilities are a superset of the phase 2+ Release '99 GSM core network capabilities. The main difference is that the UMTS entities shall support the higher bir rate bearer services generated by UTRAN (e.g. 64Kb/s for circuit switched data service and 2 Mb/s for packet switched data service). The same core network entities may serve both the UTRAN and GSM/GPRS radio access networks, as shown in Fig.4. The entities of UMTS core network can be preceded by 3G to denote core entities of UMTS R '99 or higher releases (e.g. 3G-MSC, 3G-VLR, 3G-SGSN, 3G-GGSN, ..etc.). The current few deployed UMTS networks and other trial networks are R99.

B. GERAN: "2.9" G

GERAN (GSM-EDGE Radio Access Network) is a 3GPP continued enhancement of EDGE in order for GSM networks to complement and align with future WCDMA deployments. GERAN started with Rel-4, and is continuing with Rel-5&6. In addition to the improvements to the IuPS, IuCS, A and Gb interfaces, for interoperability of BSS with 3G nodes, it includes other 3G aspects such as enhancements to streaming, location services (LCS), Real Time services (e.g.VOIP), and even the support of IP Multimedia Subsystem(IMS) [10], [11].

C. UMTS: Releases 4&5&6

The main network architectural changes of the UMTS Rel-4&5&6 from Rel-99 are summarized below.

Radio Network Controllers RNC's are allowed to have direct logical connections between each other in order to fully control radio resources among themselves without the need to go through the CN. The UTRAN is layered into a Radio Network Layer and a Transport Network Layer.

In line with the NGN architectural model, MSC's are allowed to be implemented in two different entities, namely: the MSC Server and CS-MGW (Circuit Switched Media Gateway). An MSC server and a CS-MGW make up the full functionality of an MSC. The current NGN SIP protocols are being adapted to achieve signaling and control requirements.

Fig.5 depicts the UMTS Network architecture in the form of the layered NGN architecture model of Transport, Control and Services. The Transport Layer may be built on any combination of IP Routers and ATM Switches platform, with a trend towards All-IP. The Transport Layer will also include the SGSN's, GGSN's, which could be part of Routers. The Transport Layer also includes different forms of MGW's. connecting to the Radio Access Network and PSTN/ISDN.

The Control Layer includes Signaling Gateways for converting signaling control information exchanged between different networks. It also includes Servers, Registers and the new IP Multimedia Subsystem being introduced in R5.

IM (IP Multimedia): involves functionality of the following CN entities [12] :

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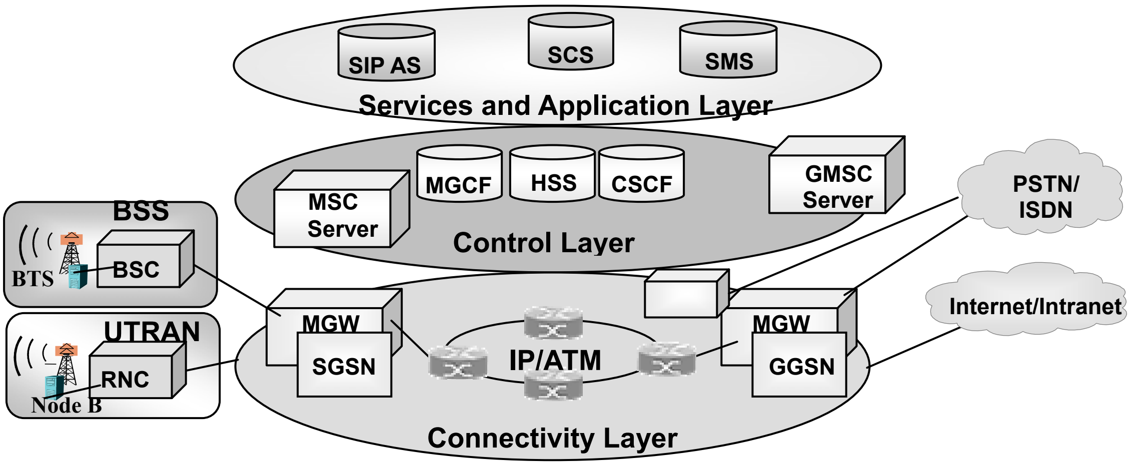

Fig.5 UMTS Rel-4, 5 & 6

CSCF (Call State Control Function) handles functionality of ICGW (Incoming Call Gateway), CCF (Call Control Function), SPD (Serving Profile Database) and AH (Address Handling). **MGCF** (Media Gateway Control Function) controls parts of the call state that pertain to connection control for media channels in an IM-MGW. **IM-MGW** (IP Multimedia – Media Gateway) terminate bearer channels from a switched circuit network and media streams from a packet network (e.g., RTP streams in an IP network). MFR (Multimedia Resource Function) performs multiparty and multi media conferencing functions. **MRF** would have the same functions of an MCU in an H.323 network.

HSS (Home Subscriber Server) is the main data base replacing HLR. In addition to the HLR functionality such as the MAP related interfaces with GSM/GPRS entities, the HSS will support control functions of the IP Multimedia Subsystem such as the CSCF needed to enable subscriber access to the IM CN subsystem services.

R5&6 are not expected to be deployed before 2005. Another element of importance is the inclusion of the WLAN interworking with UMTS as part of R6.

IV. Deployment Scenarios & the Dilemma

With the above GSM generations in hand and UMTS releases on the tree and, taking into account key factors such as: status of existing networks, market demands of anticipated services/capacity/coverage, O&M cost, terminal availability, applications/content development, cycles of technology, 3GPP standards maturity, vendors capability, regulatory impacts and the economic implications, mobile operators worldwide are facing difficulties in deciding on the road to go. The viable next move considered by most GSM operators are as follows (Fig.6):

1. Immediately deploy GPRS, then wait for maturity of the "right" UMTS release, and get the network prepared for NGN. You are deploying, however, legacy system and may wait so long with inadequate services or rush an inadequate NGN infrastructure. The main advantage is that you gain a lead time in terms of creation of content and application providers and demonstrate the market readiness for services such as MMS.
2. Same as option-1, but implement HSCSD because it provides large coverage at low cost and can yield multimedia services.
3. Same as option-1, but in fear of competition, start right away deployment of UMTS R99. However, you will be growing a technologically intermediate infrastructure.
4. Stay with GSM until UMTS Rel-5 and until your NGN become mature. You may however loose your customers.
5. Deploy EDGE. You may however join just few other operators, which would lead to terminals' difficulties.

It is clear that, while the above options are being adopted by operators for some reasons or others, they all suffer from major drawbacks. The problem could further be magnified when other technologies such as WLAN, at least at hot spots, starts to compete with the long awaited Rel-5 &6.

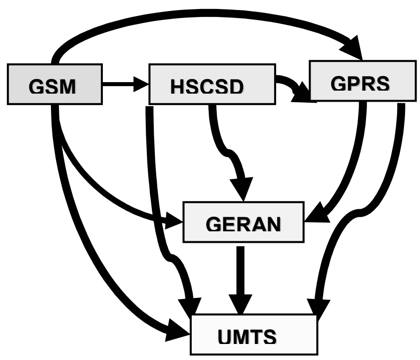

Fig.6 Mobile Deployment Choices

In view of such a dark picture, we believe that option 5 [1] is the best move, when seen in the following manner:

1. Deploy EDGE or upgrade GPRS to EDGE. This will more apply to networks with EDGE upgradeable BTS's. Then keep track with the GERAN upgrades. This is required in order to renew the existing huge GSM infrastructure and bring it to a level comparable and interoperable with the coming UMTS networks.
2. Nokia and Ericsson already announced that there will be EDGE terminals available by the end of 2003, old GPRS terminals will still continue to work under EDGE.

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3. Recently, this option started to gain interest by a growing number of operators, which need to optimize the use of existing systems, reduce their CAPX/OPEX, and avoid the high license fees of 3G spectrum.
4. It provides a peaceful waiting time for NGN and higher 3G Releases to mature, such waiting time may further relaxed when considering the WLAN complement in hot spots of high speed data applications..
5. Some studies showed that implementing UMTS islands in GERAN seas and GSM oceans would lead to considerable savings (up to 50%) [8], [13].
6. The applications that can be offered in the EDGE or GERAN environment is very close to those to be offered by UMTS.
7. GERAN standardization is part of the all-IP NGN architecture networks of the future R5 and R6 releases..

VI. Summary & Conclusions

We have examined the multiplicity of GSM generations in hand as well as the 3G UMTS Releases on the tree. We highlighted the dilemma facing mobile operators in making their choice for the path to take. We then recommended an approach which has the strongest technical arguments, and if agreed to by many other operators, it will definitely be the choice for every one to go at different scales.

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