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Comparison of second-generation (GSM) and third-generation (UMTS) cellular telephone networks

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Abstract

The rapid evolution of mobile telephony technologies has led to the development of several generations of cellular networks, each bringing significant improvements in terms of throughput, quality of service and functionalities. This article presents a comparative study between second-generation networks (GSM) and third-generation networks (UMTS). The analysis focuses on functional architectures, multiple access techniques, modulations, throughput, interfaces, logical channels and services offered. The results show that UMTS, although it reuses part of the GSM infrastructure, brings major improvements particularly in terms of throughput (up to 2 Mbit/s), multimedia capacity and mobility management. However, UMTS does not completely replace GSM but complements it, allowing a progressive transition to the third generation.

Keywords: GSM; UMTS; 2G; 3G; Mobile Telephony; Comparison; W-CDMA; TDMA; FDMA

1. Introduction

The evolution of mobile telephony networks has experienced remarkable progress since the appearance of the first analog systems of the first generation (1G) to current digital networks. Each successive generation has brought significant improvements in terms of capacity, quality of service, throughput and functionalities offered to subscribers.

The second generation (2G), represented mainly by the GSM standard (Global System for Mobile Communications), marked a major technological breakthrough by introducing digital technology into mobile networks. It not only improved voice quality, but also introduced new services such as short messages (SMS) and international roaming. The third generation (3G), embodied by the UMTS standard (Universal Mobile Telecommunications System), brought mobile broadband, paving the way for multimedia services, videoconferencing and high-speed Internet access.

The problem of this study focuses on the comparison between these two generations of networks. More specifically, it aims to answer the following questions:

- What advantages does the third generation offer over the second?
- What are the main architectural and technical differences between GSM and UMTS?
- Why is UMTS considered a major evolution compared to GSM?

The objective of this work is to present a detailed comparative analysis of GSM and UMTS networks, highlighting their similarities, their differences and the improvements brought by the third generation. The research hypothesis is that

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the fundamental difference between these two generations lies in their functional architectures and their multiple access techniques, which directly influence their performances and the services they can offer.

2. Material and methods

To carry out this comparative study, we adopted a methodological approach based on documentary research and technical analysis.

2.1. Documentary research

We consulted specialized books in telecommunications and mobile networks, as well as university courses taught at ISTA/Kinshasa. We also used webographic resources to complete our information.

2.2. Technical analysis

We carried out a comparative analysis of the fundamental technical parameters of the two standards, including:

- Functional architectures;
- Multiple access techniques (FDMA, TDMA, CDMA, W-CDMA);
- Modulations used (GMSK for GSM, QPSK for UMTS);
- Throughputs and capacities;
- Interfaces and protocols;
- Logical and physical channels;
- Services offered to subscribers.

2.3. Comparative synthesis

The information collected was synthesized in the form of comparative tables to facilitate the visualization of differences and similarities between the two generations.

3. Results and discussion

3.1. Architecture of GSM and UMTS networks

3.1.1. GSM network architecture

The GSM network is structured into three main subsystems:

- **The Base Station Subsystem (BSS)**: composed of Base Transceiver Stations (BTS) and Base Station Controllers (BSC). It manages radio resources and ensures transmission on the radio interface.
- **The Network Subsystem (NSS)**: composed of Mobile Switching Centers (MSC), databases (HLR, VLR, AuC, EIR) which manage calls, mobility and subscriber authentication.
- **The Operation and Maintenance Subsystem (OSS)**: ensures supervision, fault management and network configuration.

3.1.2. UMTS network architecture

The UMTS network presents a similar architecture to GSM at the core network level (CN), but introduces a new access network called UTRAN (UMTS Terrestrial Radio Access Network). UTRAN is composed of:

- **Node B**: equivalent to BTS in GSM, they ensure radio reception and transmission functions.
- **Radio Network Controllers (RNC)**: equivalent to BSC, they manage radio resources and control the Node B.

Major difference: Unlike GSM which uses a centralized architecture with BSCs, UMTS introduces a more distributed architecture with RNCs that can communicate with each other via the Iur interface, allowing better mobility management (soft handover).

3.2. Multiple access techniques

Table 1 Comparison of multiple access techniques

Criterion	GSM (2G)	UMTS (3G)
Access technique	FDMA + TDMA	W-CDMA (DS-CDMA)
Frequency band	890-915 MHz (UL), 935-960 MHz (DL)	1900-2025 MHz, 2110-2200 MHz
Channel width	200 kHz	5 MHz
Users per channel	8 (TDMA)	Several hundred (CDMA)
Duplexing	FDD	FDD/TDD

GSM uses a combination of frequency division multiplexing (FDMA) and time division multiplexing (TDMA), which limits the number of simultaneous users per cell. UMTS uses W-CDMA (Wideband Code Division Multiple Access), which allows multiple users to share the same frequency simultaneously using distinct spreading codes.

3.3. Throughputs and capacities

Table 2 Comparison of throughputs and capacities

Criterion	GSM (2G)	UMTS (3G)
Voice throughput	13 kbit/s	12.2 kbit/s
Max data throughput	9.6 kbit/s (GSM), 171 kbit/s (GPRS), 384 kbit/s (EDGE)	384 kbit/s (mobile), 2 Mbit/s (fixed)
Quality of service	Basic	Improved, with service classes

UMTS offers significantly higher throughputs than GSM, enabling multimedia services and smooth Internet browsing.

3.4. Modulation

Table 3 Comparison of modulation techniques

Criterion	GSM (2G)	UMTS (3G)
Modulation	GMSK (Gaussian Minimum Shift Keying)	QPSK (Quadrature Phase Shift Keying)
Spectral efficiency	Moderate	High

The GMSK modulation used in GSM is a constant frequency modulation that offers good robustness but limited spectral efficiency. UMTS uses QPSK modulation, which allows transmitting two bits per symbol, offering a better throughput for the same bandwidth.

3.5. Interfaces and protocols

Table 4 Comparison of interfaces and protocols

Interface	GSM	UMTS
Radio interface	Um	Uu
Between BTS/BSC and RNC	A-bis (BTS-BSC), A (BSC-MSC)	Iub (Node B-RNC), Iu (RNC-CN)
Between RNC	Not applicable	Iur
Signaling protocol	SS7	SS7, IP

UMTS introduces new interfaces (Iub, Iur, Iu) that allow greater flexibility and better mobility management.

3.6. Logical channels

3.6.1. GSM

- Dedicated channels: TCH (traffic), SACCH, FACCH
- Common channels: BCCH, PCH, AGCH, SDCCH

3.6.2. UMTS

- Dedicated channels: DCH
- Common channels: BCH, FACH, PCH, RACH, CPCH, DSCH

UMTS has a greater variety of channels to adapt to different types of services and throughputs.

3.7. Security

Table 5 Comparison of security features

Criterion	GSM (2G)	UMTS (3G)
Authentication	Unidirectional (network checks mobile)	Bidirectional (mutual)
Encryption	A5 (weak)	KASUMI (more robust)
Identity protection	TMSI	TMSI + better protection

UMTS offers enhanced security compared to GSM, with mutual authentication and a more robust encryption algorithm.

3.8. Services offered

Table 6 Comparison of services offered

Service	GSM (2G)	UMTS (3G)
Voice	Yes	Yes (better quality)
SMS	Yes	Yes (improved)
MMS	Limited	Yes
Internet	Via GPRS/EDGE (slow)	High speed
Videophony	No	Yes
Multimedia	No	Yes
Video streaming	No	Yes

UMTS offers a much wider range of services than GSM, with superior quality.

4. Discussion

The comparative analysis carried out allows us to identify several major lessons.

4.1. Significant technological evolution

UMTS represents a major evolution compared to GSM, not only in terms of throughput but also in terms of architecture. The transition from TDMA/FDMA to W-CDMA allows more efficient use of the radio spectrum and better resource management.

4.2. Complementarity rather than substitution

Contrary to what one might think, UMTS does not completely replace GSM. In reality, the architecture of the core network (CN) of UMTS largely reuses that of GSM. Elements such as HLR, VLR, AuC and EIR are common to both systems.

Moreover, UMTS is designed to be interoperable with GSM, allowing subscribers to switch from one network to another transparently.

4.3. Impact of access technique on capacity

The W-CDMA technique used by UMTS allows significantly higher capacity than GSM. While GSM limits the number of users per cell to about 8 per channel, UMTS can accommodate several hundred simultaneously in the same cell.

4.4. Enhanced security

UMTS significantly improves security compared to GSM. Mutual authentication (the network checks the mobile and the mobile checks the network) and the use of the KASUMI algorithm (more robust than the A5 algorithm of GSM) strengthen the protection of communications.

4.5. New service perspectives

The high throughput offered by UMTS opens the way to new services: videophony, video streaming, music and video downloading, online games, etc. These services were impossible or of very poor quality with GSM.

4.6. Limitations of the study

This study has certain limitations. Economic aspects (deployment cost, terminal prices, tariffs for subscribers) have not been addressed, nor have regulatory aspects and real performances under operational conditions.

5. Conclusion

This comparative study between second-generation (GSM) and third-generation (UMTS) cellular telephone networks has highlighted the main technical and functional differences between these two technologies.

UMTS, as a third-generation network, brings notable improvements compared to GSM:

- **In terms of throughput**: from a few kbit/s to several Mbit/s;
- **In terms of services**: extension from voice and SMS services to multimedia, videophony and high-speed Internet;
- **In terms of capacity**: significant increase in the number of simultaneous users per cell thanks to W-CDMA;
- **In terms of security**: reinforcement of authentication and encryption;
- **In terms of mobility management**: introduction of soft handover for smoother transitions.

However, UMTS does not completely replace GSM. It complements it by reusing part of its infrastructure (core network) and ensuring interoperability between the two systems. This coexistence allows a progressive transition to the third generation.

Technological evolution does not stop there. Fourth-generation (LTE) and fifth-generation (5G) networks have already emerged, bringing even higher throughputs, reduced latency and new applications (IoT, autonomous vehicles, augmented reality). This dynamic of continuous innovation demonstrates that the field of mobile telecommunications is in perpetual evolution, responding to the growing needs of users in terms of connectivity and services.

Compliance with ethical standards

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Disclosure of conflict of interest

No conflict of interest to be disclosed.

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