GSM – Capacity Enhancements, New Features, and Evolution to 3G

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ABSTRACT

Globally, there has been rapid growth in cellular, with GSM being the dominant standard worldwide. As the market grows, the GSM standard has been continually enhanced via new techniques that increase the capacity, as well as the standardization of new features that introduce enhanced functionality and services. With these on-going changes, GSM is positioned well to serve the needs of the different markets in a very cost-effective way. With a clear evolution path to 3G, GSM’s future is ensured. The goal of this paper is to summarize the key techniques that increase the capacity of GSM systems and the new features that have been introduced into the GSM specifications in the recent releases of the standard. New applications of GSM/GPRS will be mentioned.

1. INTRODUCTION

In December 2002, there were approximately 775M GSM subscribers worldwide with 543 operators in 191 countries [1]. The rapid growth of GSM, since its commercial introduction in 1991, has exceeded all expectations. Even in the midst of the significant economic crunch within the global telecom industry, the GSM market continues to grow steadily. Today GSM is specified for operation in 5 frequency bands (400, 800, 900, 1800, and 1900 MHz) with a potential for spectrum allocations up to 110 MHz depending upon the region. Even with the spectrum allocation available in each region, it is expected that many GSM operators will experience capacity issues. Hence, there is an urgent, on-going need to develop and implement techniques that will increase the capacity of GSM/GPRS networks in order to satisfy:

- Increasing number of subscribers,
- Increase in user traffic (voice, SMS, data applications).

This paper will describe a few of the key capacity enhancing methods [2,3] and their potential benefits to operators in terms of capacity.

Since 2000, the standardization of GSM has been combined with the UMTS standardization of Wideband CDMA (WCDMA) under the Third Generation Partnership Project (3GPP) [4], with each annual release of the standard covering GSM+UMTS. The main goal is to realize the vision that UMTS will provide a common core network (merger of GERAN (GSM/EDGE Radio Access Network) and UTRAN (UMTS RAN)) with multiple radio access methods, including GSM/EDGE and WCDMA. The main advantage from the GSM perspective is that the new features and capabilities introduced into the 3G network will be available to GSM users. The key dates in the evolution of GSM are:

- 1997 – Introduction of GPRS
- 1999 – Introduction of EDGE
- 2000 – Merger of GERAN and UTRAN
- 2002 – Release 6 of GSM+UMTS spec

In this paper, we provide a brief discussion of the new features [2,3] introduced as part of the different annual updates of the specifications.

2. GSM CAPACITY ENHANCEMENTS

The main techniques for enhancing the capacity of GSM networks are [2]:

- Adaptive Multirate (AMR) vocoder [2]
- Tighter frequency-reuse [2,5,6]
- Smart Antenna Methods [7,14]
- Interference suppression techniques [10,17]

2.1. AMR Vocoder

This new speech codec [2] (based on Algebraic CELP) was introduced in the GSM...
standard in 1999. It is also the mandatory speech codec for WCDMA. Currently, GSM has three speech codecs – full rate (FR), enhanced full rate (EFR), and AMR, with AMR providing significant quality improvements over the other two. Both FR and EFR are fixed rate codecs, while AMR can operate over a wide range of rates given below (for the narrowband (NB) and wideband (WB) modes):

<table>
<thead>
<tr>
<th>Mode</th>
<th>Rates (Kbps)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NB</td>
<td>12.2, 10.2, 7.95, 7.4, 6.7, 5.9, 5.15, 4.75</td>
</tr>
<tr>
<td>WB</td>
<td>23.85, 23.05, 19.85, 18.25, 15.85, 14.25, 12.65, 8.85, 6.60</td>
</tr>
</tbody>
</table>

The main features of AMR are:

- Wide range of source and channel coding options.
- Operate in full rate and half rate channels.
- Uses in-band signaling to change modes (Network-master, and mobile-slave).
- Can use different rates – uplink, downlink.
- VAD and DTX to reduce interference and improve battery life of MS.

The wideband mode samples audio at a rate of 16 KHz and is suitable for speech and music.

The AMR codec optimizes the performance of the speech coder by adapting to the channel quality, with the adaptation being done autonomously (w/o user interaction). The expected benefit from widespread use of AMR in the network is that the capacity can have 2X increase. Hence AMR provides high quality as well as robustness, while enhancing capacity.

### 2.2. Enhanced Frequency Re-use Techniques

One of the factors that has the most impact on cell capacity is frequency reuse [2,5,6]. Traditionally, GSM networks have deployed 4/12 reuse (4 sector/12 cell) or 3/9 reuse with frequency hopping. New methods that enable tighter frequency reuse are

- **Re-use partitioning** [2]
- **Fractional loading** [6]

In **re-use partitioning**, the effective reuse is decreased by dividing the available frequencies into layers, each with different reuse –

- **Overlay layer** employing loose frequency reuse to ensure full coverage within cell and reliable reception (such as needed for BCCH)
- **Underlay layer** providing tighter reuse and hence increased capacity.

Traffic management is employed to maximize the use of frequencies in the underlay layer. Frequency hopping is essential to obtain good performance in the underlay layers.

**Fractional loading gain** is achieved if the reuse is reduced to 1/3 and when the frequencies are not fully loaded. Frequency hopping is essential for the interference averaging effect. Further, currently the basestations (BSs) in a GSM network are not synchronized. If BS synchronization is done along with MAIO planning (where MAIO – mobile allocation index offset, the parameter that determines the start of the hopping pattern), the interference effects can be further reduced.

In summary, achieving tighter reuse is a key approach to increasing capacity in GSM networks. The robustness of the AMR codec and the ability to tighten frequency reuse enable GSM networks to achieve significant capacity enhancements.

### 2.3. Smart Antenna Techniques

Smart antennas for cellular is an active area of R&D globally, particularly 3G systems [7]. Significant gains can be achieved through the use of antenna arrays (spatial processing) with either fixed or steerable beams [14]:

- Increased antenna gain through narrow beams (4-8 beams per sector) resulting in coverage/range improvements,
- Reduction of interference through spatial filtering providing C/I improvement.

The use of adaptive beams involves added complexity in terms of calibration and phase coherence. The estimation of the direction of arrival (DOA) of a mobile is critical and must be tracked throughout the call. In field trials, it has been observed that with smart antennas, GSM reuse can be significantly tightened. Smart antennas works well with other GSM enhancements such as frequency hopping and power control. The benefits of smart antennas can be observed even if only a few sites (~5%) have deployed them [7]. Recently, transmit diversity schemes (delay diversity, space-time coding) have also been evaluated for GSM [15,16], but have not been standardized.

### 2.4. Interference Suppression Techniques

Interference suppression for GSM/GPRS at the basestation can be done using antenna diversity and beam forming. On the MS side,
new methods have been developed that exploit the inherent redundancy between the I (in-phase) and Q (quadrature) signals for GMSK modulation [10]. These methods are very effective in the presence of a dominant co-channel interference, which is a likely scenario in a heavily-loaded system.

2.5. Performance Summary

<table>
<thead>
<tr>
<th>Method</th>
<th>Potential Capacity Increase</th>
</tr>
</thead>
<tbody>
<tr>
<td>AMR with FH and PC</td>
<td>Up to 2X</td>
</tr>
<tr>
<td>Tighter frequency reuse with FH</td>
<td>Up to 2X</td>
</tr>
<tr>
<td>Smart antennas</td>
<td>1.5X-2X</td>
</tr>
<tr>
<td>PHY algorithm enhancements</td>
<td>2X-4X</td>
</tr>
<tr>
<td>(diversity, interference suppression)</td>
<td></td>
</tr>
<tr>
<td>DTX</td>
<td>30%</td>
</tr>
</tbody>
</table>

Other methods include BTS synchronisation, and MAIO planning. From this table, it can be readily seen that there is strong potential for increasing capacity of GSM/GPRS networks.

3. NEW FEATURES OF GSM

3.1. GSM Evolution to 3G

As shown in Fig. 1, GSM systems are currently in Gen 2.5 (with the introduction of GPRS and Phase 2+ features), and have two paths to 3G:

- WCDMA – with new spectrum in UMTS band (1885-2025 MHz, 2110-2200 MHz)
- EDGE - in existing GSM bands

**Fig1: GSM Evolution**

```
        GSM Phase2
           ↑  "Existing spectrum"
        GSM→        EDGE→
        "New spectrum"
      IS-54  ANSI-136  WCDMA
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It is expected that handsets will be dual-mode (GSM-WCDMA) and that GSM will provide the wide-area coverage in areas where 3G coverage is not available.

3.2. EDGE Main Features

Enhanced Data Rates for Global Evolution (EDGE) arose out of the need to improve GSM capacity, specially for the new packet radio services introduced by GPRS. EDGE introduced two new improvements to the GSM standard – the Enhanced Circuit Switched Data (ECSD) mode and the Enhanced GPRS (EGPRS) mode for packet services. With EDGE, the following features were added to the specification:

- Modulation options: 8PSK and GMSK
- Nine modulation and coding (MCS) modes (MCS1-4 for GMSK, MCS5-9 for 8PSK)
- Data rates up to 384 Kbps (48 Kbps per slot)
- Link adaptation (between different MCS) for maximizing throughput
- Introduction of Type II Hybrid ARQ known as Incremental Redundancy (IR) to acknowledged mode operation provides up to 2 dB improvement in throughput
- Streamlined design of the RLC/MAC layer, separating channel coding for the control plane from the data plane.

Significant improvement in spectral efficiency over GSM

Ability to mix GPRS and EGPRS users in the system

Dual Transfer Mode (DTM) for simultaneous voice and data connectivity

Enhancements to QoS to harmonize user experience with UMTS

The EDGE standard has gone through one major revision in Rel ‘99. In addition, the GERAN is being systematically integrated into the 3G code network as a core Radio Access Technology (RAT), and Releases R4, R5 and
R6 of the GSM/EDGE specification address the harmonization of GSM with UMTS.

3.3. Quality of Service (QoS)

QoS is characterized by the following parameters – availability, throughput, packet loss, latency and jitter. QoS is critical for interactive real-time applications and streaming applications. A QoS profile is defined by a combination of attributes and is negotiated at the time of PDP context activation. A fundamental difference in the way QoS is handled between UMTS and GPRS is that UMTS treats QoS provisioning in a hierarchical manner – starting from end-to-end provisioning at the non-access stratum, and going down to choice of radio bearers with limits or guarantees on throughput, delay etc at the access stratum; whereas GPRS uses a direct mapping of services to limits or guarantees on throughput, precedence delay and error rates. In addition, UMTS treats the circuit and packet domains as mere interfaces that allow initiation of radio bearers with various properties, while GSM and GPRS are really separate networks that use the same logical organization at the physical layer. This aspect of the design does not change for EDGE; instead QoS provisioning is offered only for the packet domain.

<table>
<thead>
<tr>
<th>SDU size: 128 octets</th>
<th>SDU size: 1024 octets</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Mean Transfer Delay (sec)</td>
</tr>
<tr>
<td>Delay Class</td>
<td></td>
</tr>
<tr>
<td>1. (Predictive)</td>
<td>&lt; 0.5</td>
</tr>
<tr>
<td>2. (Predictive)</td>
<td>&lt; 5</td>
</tr>
<tr>
<td>3. (Predictive)</td>
<td>&lt; 50</td>
</tr>
<tr>
<td>4. (Best Effort)</td>
<td>Unspecified</td>
</tr>
</tbody>
</table>

Table 1. Delay is one example of a parameter in the GPRS QoS profile (from [11]).

In EGPRS, two fundamental changes were made to QoS provisioning allowing the first step to harmonization with UMTS [11,12,13]:

- Mapping of GPRS QoS to provisioning of background and interactive service classes
- Addressing of similar QoS through the establishment of a Packet Flow Context and a Packet Flow Identifier.

As part of the harmonization with UMTS, releases R4, R5 and R6 will provide conversational and streaming traffic classes via the UMTS core network. In addition, enhancements to the Gb interface between the SGSN and the BSC will also make it possible for traditional GSM/EDGE networks (See Figure 2) to provide streaming services.

3.4. GERAN and UTRAN Integration into 3G

UMTS has introduced significant network improvement over GSM – such as the separation of the application domain from service provisioning and the radio access technology. The driving motivation behind releases R4, R5 and R6 is that a common service-oriented architecture that will be independent of the access technology in terms of user-experience.

Thus, the GERAN has been made an integral part of UMTS network through definition of the same interface to the core network as the UTRAN. Moreover, QoS provisioning has been harmonized as mentioned above.

One significant addition to the standard for these releases is the addition of conversational IP multimedia services handled by the core network using a SIP-based call control mechanism. Another significant addition is harmonization of Authentication, Authorization and IP header compression with IETF standards with IETF.

3.5. 3G Applications

The 3G network using GSM/EDGE will provide significant benefits due to the flexibility of the service architecture. It is expected that multimedia services such as multimedia messaging (MMS), chat and internet telephony will play a dominant role in future services. Terminals will allow access to many applications based on video transmission – both still images and moving pictures, while applications such as downloadable music and online gaming will be introduced as well. The 3G service architecture will also allow increased usage and productivity in the enterprise environment.

3.6. GPRS-WLAN Integration

WLANs are economical and well-suited for limited coverage areas in dense deployment (hot-spot). Also, the advent of broadband services in the wired network has the effect of increasing customer expectation of wireless services. It is therefore convenient for cellular and WLAN operators to integrate the capacity
advantage of WLAN systems with the wide reach of GSM by coupling such networks together in their operational deployment [8,9].

WLAN systems such as 802.11 a.g and HiperLAN achieve data rates above 50 Mbps. The disadvantages of WLANs are the limited coverage and lack of roaming, both of which are the strengths of the cellular system. In addition, cellular has authentication and billing mechanisms. Recognizing the significant benefits of combining the strengths of GPRS and WLAN, the standardization activity has commenced [8]. The proposed integration has different levels of interworking – including seamless service continuity (WLAN→GPRS handoff) for packet applications, common authentication, and WLAN access to cellular circuit-switched services. This integration combines the strengths of WLANs and GPRS very effectively. This enhancement enables GSM to be well-positioned for evolution to 3G and beyond.

4. CONCLUSIONS

In this paper, we provide an up-to-date overview of the latest developments in GSM/GPRS – capacity enhancements, new features and continued evolution to 3G and beyond. The rapid growth in GSM subscribers necessitates the need for capacity enhancements in existing networks. The methods described in this paper have the potential to provide 2X-4X increase in capacity. The introduction of EDGE, and the combining of GERAN and UTRAN have provided the basis for many new features and applications. As the capabilities of the 3G core network grows, GSM users can access the benefits. Finally, the recent work on GPRS-WLAN integration is mentioned as a significant step in enhancing the GSM networks and enabling them to well-positioned to meet the future needs in wireless data.

5. REFERENCES

[1] GSM Association; www.gsmworld.com
[4] 3GPP: www.3gpp.org