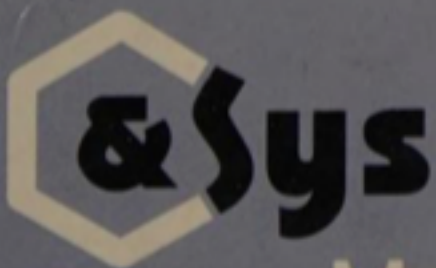
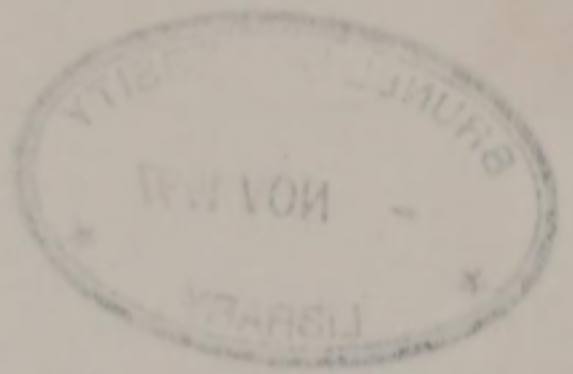

GSM[®]

The **GSM** **S**ystem for **M**obile Communications



Michel MOULY
Marie-Bernadette PAUTET



The GSM System for Mobile Communications

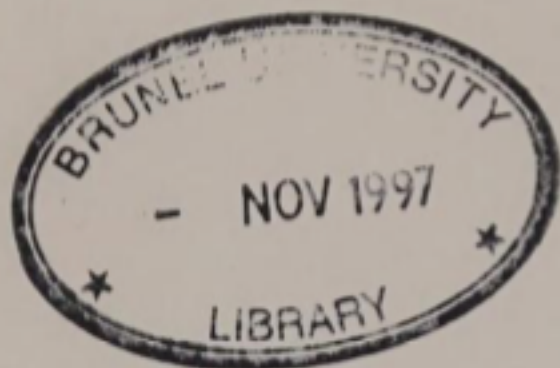
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The GSM System for Mobile Communications

A comprehensive overview of the
European Digital Cellular Systems

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not to a pre-defined portion of the resource, and we will prefer to refer to fast associated signalling as a mode of use of the channel. The FACCH gives an example of the conceptual difficulties: to which channel does the stealing flag belong?

We understand that diverging in terminology from the *Specifications* (or for that matter from the established usage in some field, as our using emission where most often transmission is used) will cause some difficulties. On the other hand, we hope that the new terms help the reading of this book, and that the balance is beneficial for the overall understanding of the GSM concepts.

4.2. THE MULTIPLE ACCESS SCHEME

Many techniques have been devised to create channels out of a communication medium, in order to use them as separate links. Using the standard terminology, the radio interface of GSM uses a combination of Frequency Division Multiple Access (FDMA) and Time Division Multiple Access (TDMA), with a pinch of Frequency Hopping for flavour. But the resulting mixture is something different than just the juxtaposition of the ingredients.

A basic concept of the GSM transmission on the radio path is that the unit of transmission is a series of about a hundred modulated bits, and is called a **burst**. Bursts have a finite duration, and occupy a finite part of the radio spectrum¹. They are sent in time and frequency windows, that we will call **slots**. Precisely, the central frequencies of the slots are positioned every 200 kHz within the system frequency band (FDMA aspect), and they recur in time every 0.577 ms—or more exactly, every 15/26 ms (TDMA aspect). All slot time limits are simultaneous in a given cell. A time interval corresponding to simultaneous slots will be referred to as a time slot, and its duration will be used as a time unit, designated **BP** (Burst Period).

¹ In practice, there are specification and implementation tolerances, and some energy is sent outside the finite spectrum window defining the slot.

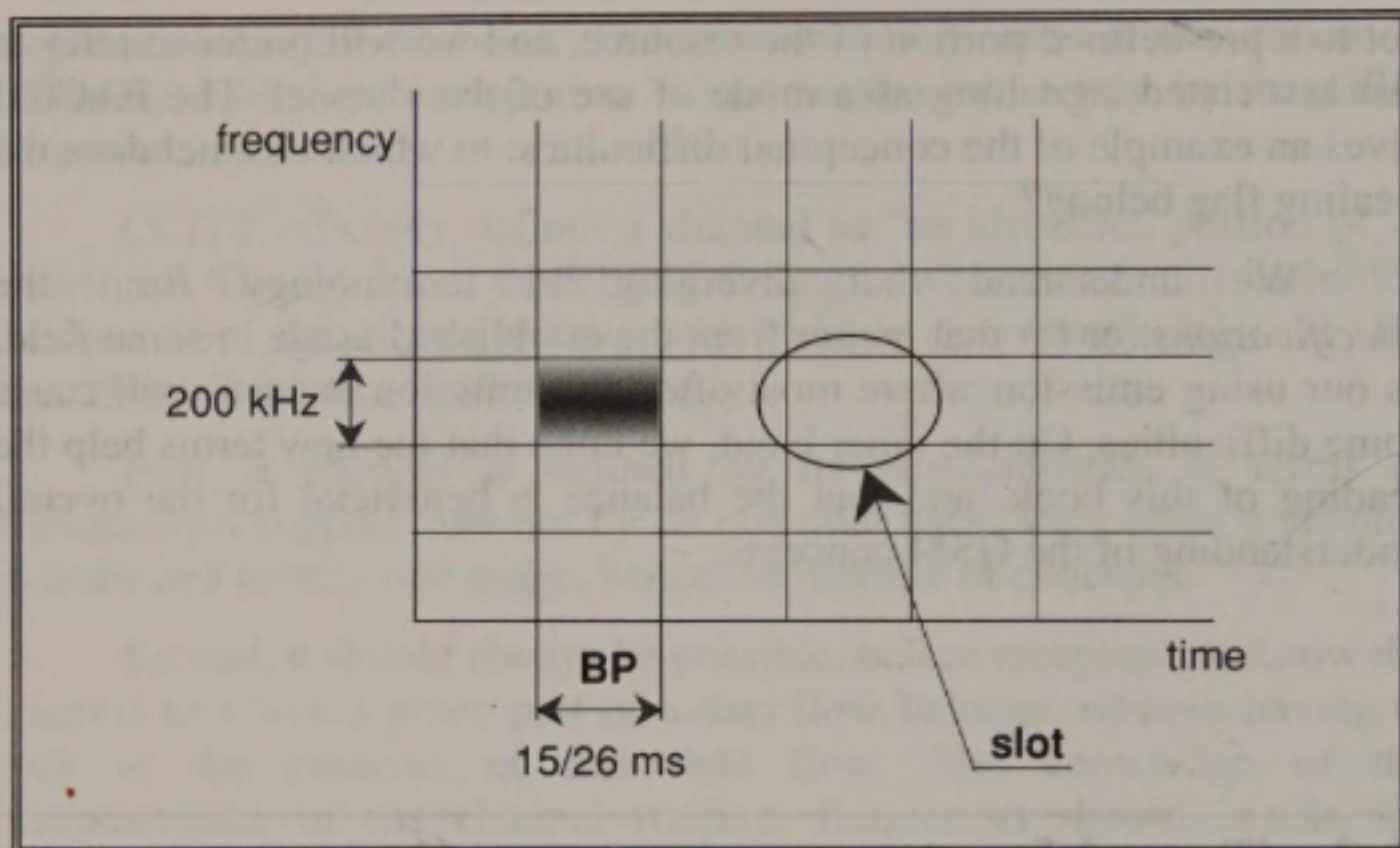


Figure 4.1 – A slot in the time and frequency domain

A transmission quantum in GSM (a burst) fits in a time and frequency window called a slot, which lasts about $577\ \mu\text{s}$ and occupies a bandwidth of 200 kHz.

A slot may therefore be pictured in a time/frequency diagram as a small rectangle $15/26\ \text{ms}$ long and 200 kHz wide (see figure 4.1). Similarly, we will call a frequency slot (a radio frequency channel in the *Specifications*) a 200 kHz bandwidth as specified for GSM.

The above paragraph is heavy with terms and definitions. Once again, there is some difference between the choice of terms here and the one of the *Specifications*, because the terms such as timeslot or burst are used with several different meanings in the *Specifications*. For instance, burst refers sometimes to the unit time-frequency “rectangle”, and sometimes to its contents. Likewise, timeslot is used to mean either what we call here “slot”, or its time value, or also the cycle using one slot every eight slots in time.

To use a given channel means to transmit bursts at specific instants in time, and at specific frequencies, that is to say in specific slots. To define a channel consists then to specify which slots can be used by, or are part of, the channel. Usually the slots of a channel are not contiguous

in time. A channel has therefore a temporal definition giving, for each time slot, the number of slots which are part of the channel. For the time being—and probably for quite a while...—a channel may only consist of 0 or 1 time/frequency slot per time slot,. The temporal definition of a channel is cyclic, that is to say it repeats itself after some time. The simplest case of a cyclic definition is “1 burst every n ”. As will be seen on the next pages, the GSM channels are rarely as simple.

In parallel to the time definition, the frequency definition of a channel gives the frequency of every slot belonging to a channel. It consists basically of a function allocating a frequency to each time slot where a channel has a slot. There exists fixed frequency channels, for which the frequency is the same for every slot, and frequency hopping channels, whose slots may use different frequencies.

For bi-directional channels (e.g., a TCH), the two directions could have been defined in different ways. However, for simplicity reasons, the channel definitions for the two directions are always related in a very elementary manner: a fixed frequency gap (the “duplex separation”) of 45 MHz (in the 900 MHz band) and of 75 MHz (in the 1.8 GHz band) and a time shift, which depends on the channel type, separate two corresponding slots of a given channel. In more academic terms, one direction is related to the other by a translation in time and in frequency.

4.2.1. THE TIME AXIS

The organisation of a channel along the time axis can be quite complex. This organisation is always cyclic, but the length of the cycle as well as the number of slots in a cycle vary according to the type of channel.

The positioning of the cycles in time is achieved through system synchronisation. Each cell provides a reference clock, defining the time slots, but also a “dating” scheme to which the cycles of all the channels are referred. In GSM, each time slot (and hence all the corresponding slots on the different frequencies) is given a number, which is known both by the base station and the mobile station, and which is part of the synchronisation information. The description of a given channel (e.g., sent by the base station to the mobile station) refers to this numbering scheme. The time slot numbering is cyclic, but of a very long cycle (3.5

hours), which has been chosen as a multiple of all cycles needed for multiple access. Within each period, any slot can be unambiguously referred to by its time slot number and its frequency slot number.

4.2.1.1. Dedicated Channels

TCH/F and its SACCH

A TCH/F is always allocated together with its associated slow-rate channel (SACCH). The resulting group of channels bears unfortunately no specific name in the *Specifications*, and is therefore often confused with the TCH/F part only. Because we found the distinction useful, and to avoid long paraphrases, we choose to introduce a non GSM term. The group TCH/F plus SACCH shall be referred to in this book as a **TACH/F**.

A TACH/F has a simple cyclic definition. It consists of one slot every 8 BP in each direction, i.e., one slot every 4.615 ms (or, better, 60/13 ms). A consequence of this definition is that it consists in the slots whose time slot number is 8 times an integer plus a value k between 0 and 7 specific to the channel. This value k is the phase modulo 8 of the numbers of the slots of the channel. It is called in the *Specifications* the *Time slot Number* (TN) of the channel. Let us point out that this meaning of *Time slot Number* is not the same as a few lines above, but TN is the GSM term and is the abbreviation of *Time slot Number*. In the following, we will use TN only in short form, to limit the confusion.

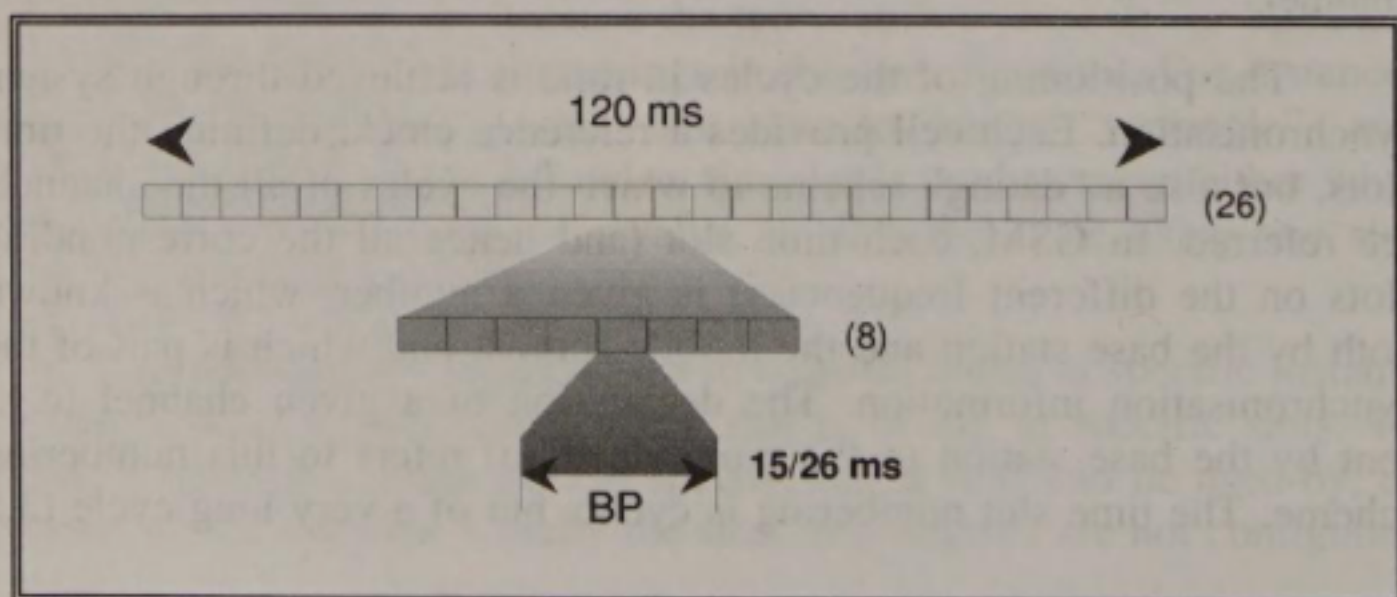


Figure 4.2 – Choice of value of a burst period

The exact value of a burst period is derived from a multiple of 20 ms by applying two multiplexing schemes ($\times 26$, $\times 8$).

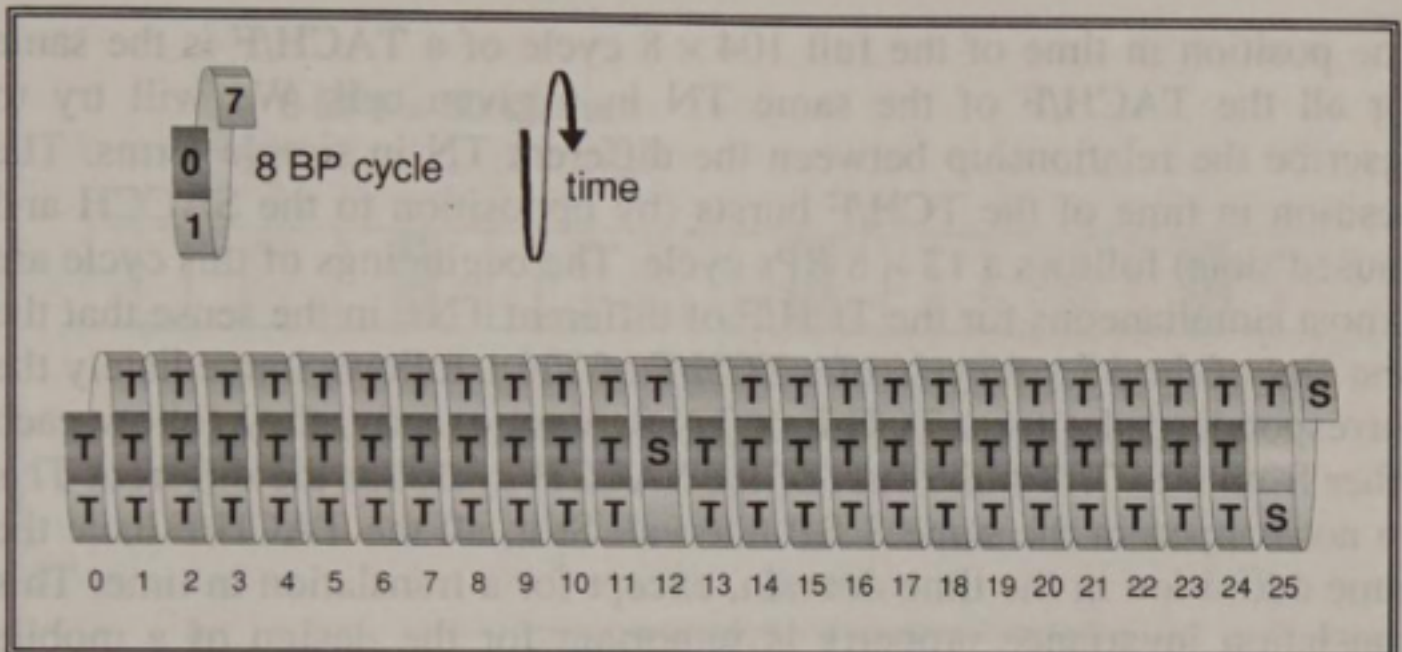


Figure 4.3 – Time organisation of a TACH/F

A full rate TACH uses a cycle of 26×8 slots. Within each of these cycles, 24 slots are used for the TCH and one slot for the corresponding SACCH.

In order to spread the arrival of SACCH messages at the base station, the cycles of two TACHs using successive slots are separated by 97 BPs (i.e., 12×8 , plus the difference of one slot).

Eight different types of TACH/F can therefore be defined depending on their phase modulo 8 (their TN). Two TACH/F with the same phase consist of simultaneous slots.

On the network side, 8 TACH/F with different TNs may be emitted by a single transmitter: at any given moment, a single TACH/F of the group is to be emitted. This is the core of the concept of TDM (Time Division Multiplex). This is an important aspect of the system, leading to substantial savings in the base station.

A TACH/F contains a TCH/F and an SACCH. The split between these two channels is also specified in the time domain, using a cycle of 26 TACH/F slots, i.e., 26×8 successive slots, or a period of 120 ms. The value 120 ms is an exact one; which was chosen as a multiple of 20 ms in order to obtain some synchronism with fixed networks, ISDN in particular. We then can explain the reason of the strange value of BP: the BP is therefore exactly $120/26 \times 8$ ms, i.e., $15/26$ ms (see figure 4.2).

The TACH/F 26 slot cycle includes 24 slots on which TCH/F bursts are sent, 1 slot on which an SACCH burst is sent, and one slot where no transmission takes place (see figure 4.3).

Coding follows cycles based on the grouping of 4 successive bursts, as will be explained on page 247. For the TCH/F, a cycle contains 6 times 4 bursts. However, for the SACCH, the full cycle, taking into account this grouping 4 by 4, lasts $4 \times 26 \times 8 = 104 \times 8$ BPs, i.e., 480 ms.

The position in time of the full 104×8 cycle of a TACH/F is the same for all the TACH/F of the same TN in a given cell. We will try to describe the relationship between the different TN in simple terms. The position in time of the TCH/F bursts (by opposition to the SACCH and unused slots) follows a 13×8 BPs cycle. The beginnings of this cycle are almost simultaneous for the TCH/F of different TNs, in the sense that the first slot of the 13×8 cycle of a TCH/F of TN 1 follows immediately the corresponding slot for a TCH/F of TN 0. Very exactly, they follow each other from 0 to 7. But the start of the SACCH cycle for the different TNs do not happen in the same 8 BP interval. Still, all the TACH/F have the same definition in the time domain, except for a translation in time. This translation invariance property is important for the design of a mobile station: it means that the scheduling of the treatment for all TACH/F is the same, the only impact of the TN is that the scheduling starts at different moments.

The reason for the shifting of the 104×8 BP cycles comes from load considerations in the infrastructure. If the SACCH had been almost simultaneous, the base station would have received the SACCH messages from all the mobile stations almost simultaneously every 480 ms, resulting in a very uneven load. In order to avoid that drawback, the cycle of a TACH/F using TN $n+1$ (for n from 1 to 7) is shifted $(12 \times 8) + 1 = 97$ BPs from the one of a TACH/F using TN n . This shift can be seen in figure 4.3; since four bursts are necessary to build an SACCH message, the base station will process the SACCH messages corresponding to 8 TACH/F of TN 0..7 at 8 different moments evenly spread in time.

Relationship between Uplink and Downlink

As seen from the base station point of view, the organisation in the uplink direction is derived from the downlink one by a delay of 3 BPs. This delay of 3 BPs is a constant throughout GSM. In fact, the convention is that the numbering of the uplink slots is derived from that of the downlink ones by a shift of 3 BPs; this choice allows the slots of one channel to bear the same TN in both directions.

But the point of view of the mobile station is affected by considerations about propagation delays which, even at the speed of light, are not negligible compared to the burst duration (the round-trip delay between an MS and a BTS 30 km apart is 200 μ s). In a first step, we will ignore the problems due to propagation delays, and consider that a mobile station very close to the BTS sees the 8 BP cycle as shown in figure 4.4.

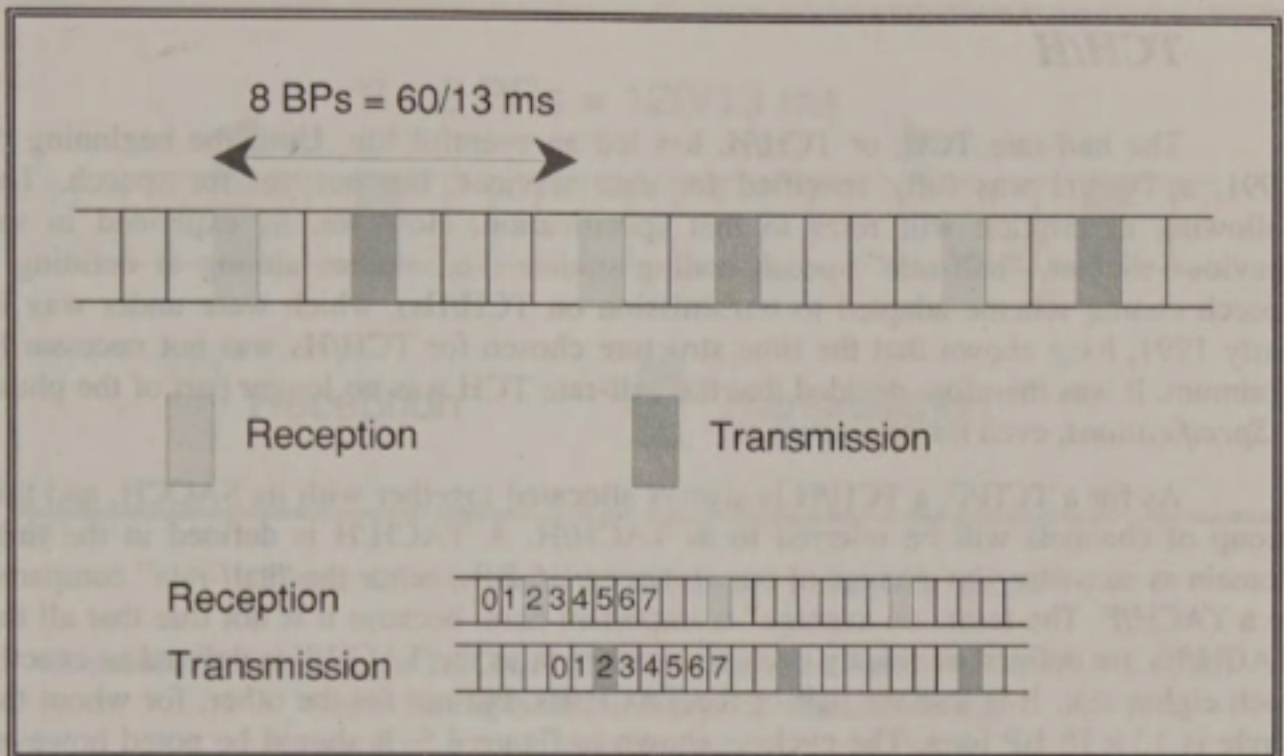


Figure 4.4 – Cycle of 8 BPs seen by a mobile station close to the base

Emission by a mobile station happens 3 BPs later than Reception.

Typically, a mobile station will receive during one time slot, then shift in frequency by 45 MHz to emit some time later

(3 burst periods minus the correction in time for propagation), then possibly shift again to monitor other channels, and move to the adequate receive frequency to start the cycle all over again.

Such a choice allows mobile stations to avoid emitting and receiving simultaneously, thereby promoting easier implementations: the receiver in the mobile station need not be protected from the emitter of the same mobile station.

When the mobile station is far from the BTS, propagation delays cannot be neglected, and an exact 3 BP shift cannot be maintained both at the MS and at the BTS. But it is imperative that the bursts received at the BTS fit correctly into the time slots, and as we will see this is not very roomy. Otherwise, the bursts from mobile stations using adjacent time slots could overlap, resulting in a poor transmission quality or even in a loss of communication. The only solution is that the mobile station advances its emission relatively to its reception by a time compensating the to and fro propagation delay. This value is called the **timing advance**. The exact shift between downlink and uplink as seen by the mobile station is then 3 BP minus the timing advance. The timing advance value can be computed only by the BTS, and is then provided to the mobile station through signalling. This is why we have chosen to deal completely with this subject in Chapter 6.

The authors:

Both authors graduated from the Ecole Polytechnique and the Ecole Nationale Supérieure des Télécommunications in Paris, France. M. B. Pautet has also obtained an M.Sc from Stanford University.

They have both been actively involved with the evolution of GSM since its inception, in particular in the specification of the signalling, security and radio transmission standards.

M. B. Pautet was a member of the permanent GSM expert team which was responsible for the management of the GSM specification. She then chaired the sub-group of the GSM standardisation committee dealing with radio interface signalling. M. Mouly is currently Chairman of the group in charge of the GSM architecture and protocols.

M. B. Pautet worked several years for FRANCE TELECOM, as well as M. Mouly who then joined MATRA COMMUNICATION. They are now both working as private consultant telecommunications engineers, in particular in the area of GSM.

This wealth of experience in standards, manufacturing and network operating gives them the unique opportunity to explain the subtle intricacies and reasoning behind the GSM specification.

The book:

In the field of mobile communications, the European digital standard GSM and its personal communications development, DCS1800, represent an innovative and successful achievement, which will take a major share of the global cellular market in the 1990's.

As many people will have discovered, the 5000 pages of the GSM standard is not easy to read or understand. This book aims to bridge the gap between a basic knowledge of telecommunications and the technical specifications.

It describes the system as a whole, covering all aspects of the standard, encompassing mobile stations as well as switching equipment, the radio interface in addition to the infrastructure and the transmission methods as well as the signalling protocols.

Although this book is primarily concerned with GSM, the non-specialist will find it particularly useful as a general introduction to digital cellular systems. The book will also help the specialist to broaden his detailed knowledge of other areas; and system architects, in particular those involved in the design of personal communications systems, will find a consistent and complete description of a communications system.

