Mobile radio of the third generation and measurements

The mobile radio networks of the **first generation**

- NMT Nordic Mobile Telephone System
- AMPS Advanced Mobile Phone Service
- TACS Total Access Communication System
- C network

are characterized by the following:

- – Analog technology
- – Use mostly restricted to one country (exception: NMT)
- – Services provided: mobile telephony

The mobile radio networks of the **second generation**

- GSM (originally European, used also in south-east Asia)
- IS-136 and IS-95 (originally US, used also in Asia and South America)
- PDC (originally Japanese, not used elsewhere)

are characterized by the following:

- – Fully digital technology
- – Use in various countries but mostly in the regions of the world where they were developed
- – Services provided: mobile telephony and some low-rate data services

The current status of the **third** mobile radio **generation** is as follows:

- – Several system proposals are at present available
- – Work on standardization has been taken up

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The following are targeted as global characteristics for the third mobile-radio generation:

- Worldwide standard
- Efficient utilization of radio resources
- No new problems with EMC
- Versatile and extendible range of services
- Universal coverage
- Indoor to long-range
- Stationary to high-speed
- Mass product

The target "efficient utilization of radio resources" requires an understanding of the technical and physical background. Some elements of the proposed systems can be understood more easily if one is aware of this target and possible solutions. These factors shall be discussed in more detail in this article. The other targets will also require arguments that are not of a technical nature. These targets shall not be discussed in this article.

Efficient utilization of radio resources

If the mobile radio of the third generation is to become a mass medium and at the same time offer high-rate services, spectral efficiency is an essential requirement, because (in contrast to cable transmission) there is only one ether serving as a transmission medium for the whole radio traffic. Regrettably, this spectral efficiency cannot be attained by one brilliant idea. Rather the opposite: the whole system must be tailored to this end to guarantee success.

Small cells allow the same radio resources to be used at short distances, but they mean additional requirements on the wire-line network. Also, if small cells are used with highly mobile users, a considerable overhead is needed for managing the large number of handover procedures. This may easily wipe out the savings gained from increased radio channel efficiency.

The use of the same radio resources in different directions is always a problem, in particular with mobile radio. **Smart antennas** (adaptive directivity characteristic controlled by software) have been suggested as a solution, but this new technology is still in the research phase.

A particular modulation type and channel coding is usually optimally suited only for a particular radio channel scenario, not for others. This calls for **adaptive technologies:** adaptive modulation types, adaptive channel coding and adaptive power control help to attain optimal utilization in changing communication scenarios; however this means extensive expenditure to be spent on mobiles and base stations.

Much higher efficiency can be achieved by reallocating radio channel resources according to the user's needs, aiming at utilizing the existing resources for maximum radio traffic. Technically, this can be suitably done by an air interface adapting to application-specific requirements (e g bandwidth), adaptive source coding or adaptive **reallocation of uplink-downlink resources in the TDD band.**

Dense radio traffic can be compromised by all kinds of interference. This is particularly annoying if those interferers are correlated to the wanted signal. The problem can partly be avoided by using decorrelation or **diversity:** time diversity (interleaving), frequency diversity (spread spectrum), scrambling, antenna diversity (micro or macro diversity, transmitter or receiver diversity) and multipath diversity are commonly used techniques, which are found in the system proposals for the third generation.

A more profound solution than "avoiding interference" by means of decorrelation is the elimination of detected interference. **Joint detection** is a technique requiring extensive computing operations which allows system-inherent (e g known) interfering signals to be detected together with the wanted signal so that the wanted signal can then be cleaned.

Are there unused radio resources?

Polarization is probably not suitable for terrestrial mobile radio, but its use for satellite mobile communication is under discussion.

Mobiles that are momentarily not engaged in radio traffic but remain switched on might be used as **relay stations,** so the mean power needed for a particular link could be reduced. The same method can also be used for **path diversity** to bypass shadowed areas.

Most of these ideas are to be found in the proposed systems. However the technologies used must not become too complicated and expensive, as this would endanger the use of third-generation mobile radio as a mass medium.

The proposed wideband CDMA system

It seems the most worthwhile to present the W-CDMA system proposed by Europe and Japan, because this proposal currently has a dominating positions among the numerous other proposals. Much of the description also applies to the American CDMA2000 proposal, as the differences are to be found in the details.

The system is characterized by the following key parameters:

Multiple-access scheme	DS-CDMA
Duplex scheme	FDD
Chip rate	4.096 Mcps (extendible to 8.192/16.384)
Channel spacing	4.4 to 5.2 MHz (raster 200 kHz)
Inter-BS synchronization	asynchronous
Multirate/variable-rate scheme	variable spreading factor + multicode (+DTX)

The most important characteristics at the air interface are:

- Orthogonal code channels in downlink
  - system-immanent decoupling of code channels within a cell

  Normally, the orthogonal code may be used again in an adjacent cell, so downlink orthogonality is lost towards the edges of the cell (at frequency reuse factor 1). Identical spreading codes from adjacent cells are decorrelated by BS-specific scrambling codes to enable selection.

- Uplink not always orthogonal

  As the various mobile-station codes can never be made to coincide exactly in the uplink, a strictly orthogonal design of the CDMA component of a mobile radio system for all subscribers, at least with binary codes, is not possible in the uplink. Orthogonality within one link will suffice in this case: orthogonal I/Q and code channels.

- Pilot symbols in up- and downlink
  - for coherent reception

- Open-loop, closed-loop and outer-loop power control in the uplink and the downlink for each code and I/Q channel individually
  - in this way the desired QoS (quality of service) can be obtained at minimum transmission power, which reduces the interference level for other cells and non-orthogonal code channels

- Frequency reuse factor 1
  - all adjacent cells may have the same frequency
  - this facilitates frequency planning and the expansion of an existing cell structure
  - it allows (requires) soft handover (around the cell boundary, the mobile station is simultaneously in contact with the previous and the new cell)

- Despite frequency reuse factor 1, frequency handover in the network is planned in order to permit hierarchical cell structures and allow for the handling of peak traffic with several frequencies (example of a hierarchical cell structure with three levels: an indoor cell can exist in a micro cell which is in turn embedded in a macro cell if different frequencies are used

- Orthogonal variable spreading factor
  - for services requiring different rates

- Service multiplexing
  - different services can be offered on a link simultaneously, even at different rates, this can be done by means of code multiplexing or time multiplexing

- Circuit-switched and packet data
  - another dimension for multiple services

- Continuous wave in the uplink
  - to avoid EMC problems

- DTX possible in the downlink
  - facilitates the detection of changing rates. Blind rate detection allows simpler mobile station receiver design

- Slotted downlink transmission:
  - mobile station receiver not permanently occupied for traffic. Spare time for qualified handover strategies

- Asynchronous base station
  - if network operation depended on synchronization between the base stations, indoor operation would be difficult to realize (for indoor operation, it cannot be assumed that the base stations can "see" each other or can all synchronize to the GPS satellite)

The proposed TD-CDMA system

The proposed W-CDMA system in FDD band offers particularly high performance and spectral efficiency in real-time operation with symmetrical utilization of uplink and downlink. However with some of the above-mentioned characteristics it is obvious that they primarily serve for providing a way around the inherent disadvantages of this model (e g slotted downlink transmission). Certain desirable characteristics cannot be attained at all, e g asymmetric utilization of the available uplink and downlink capacities combined with spectral efficiency. The proposed TD-CDMA system to be used in the TDD band could help to positively supplement the W-CDMA system.

The system is characterized by the following key parameters:

Multiple access scheme	TDMA with CDMA

Duplex scheme	TDD
Chip rate	4.096 Mcps (extendible to 8.192/16.384)
Channel width	5 MHz
Inter-BS synchronization	synchronous
Multirate/variable-rate scheme	variable spreading factor + multicode

The key characteristics at the air interface are. Radio resources are allocated as follows:

- Frequency reuse factor 1
  - all adjacent cells may have the same frequency
  - this facilitates frequency planning and the expansion of an existing cell structure

- 16 time slots in 10 ms frame

  Time slot 0 is exclusively for downlink and is used by all adjacent cells simultaneously. In this time slot, a mobile station will also receive the adjacent cells. (Joint detection.) It is used for administrative tasks.

  The other time slots are allocated individually to adjacent cells to avoid interference between the cells. They are primarily used for traffic.

- 16 codes are defined

  8 to 10 of them are used to select several users communicating at the same frequency at the same time.

- Dynamic channel allocation (demand-oriented allocation/reallocation of radio channel resources, especially reallocation of uplink and downlink resources). Almost every time slot may be used for uplink or downlink

Uplink-downlink reallocation can be performed independently within a cell provided only the time slots allocated to this cell are concerned. However for services with higher data rates (2 Mbit/s) nearly all time slots are required. If resources are to be allocated for services of this type, usually the adjacent cells need to be included in the dynamic channel allocation.

- Selection between two midambles of different lengths

  Every burst conveys at its center a trace whose shape is known to the receiver. The receiver uses it for radio channel measurements, frequency estimation, determination of the burst position in the time domain and as an aid for coherent reception. This enables the receiver to receive the codes of the time slot in question without further synchronization measures.

  The shorter of the midambles is used primarily in the downlink. The selection of a midamble in the downlink is not dependent on the selection of the various codes for the code multiplexing. Furthermore, the (identical) midambles of the various subscribers reach the mobile station at exactly the same time, which can therefore receive the midamble free of interference and determine its position in the time domain, especially if the midambles in the adjacent time slots are also observed.

  The longer of the midambles is used primarily in the uplink. In the uplink, one midamble is assigned to each code, so different midambles are received at the base station receiver with slightly different delays. The resulting selection problems can be compensated for by the greater length of these midambles. (This is exactly the reason why the timeslot 0 midamble is particularly long.)

- Synchronized base stations

  As soon as there is an overlap between areas covered by different base stations, they have to be synchronized. It is essential for smooth operation that the timing in two adjacent cells be identical. A special synchronization procedure is suggested.

- Open-loop and slow closed-loop power control in the uplink with dynamic range of 80 dB and with 30 dB in the downlink, assigned to each code channel individually
  - in this way the desired QoS (quality of service) can be attained at minimum power, and the interferences level of other cells and non-orthogonal code channels are reduced

- Variable spreading factors (2 to 16)
  - for various services
  - for increased granularity, time slots can be packetized

- Service multiplexing
  - several services, also with different rates, can be offered on a link, this can be done by means of code multiplexing or time multiplexing

- Circuit-switched and packet data
  - while for W-CDMA the circuit-switched mode suits the nature of the proposed system better, the packet mode is more "natural" with TD-CDMA

Consequences for measurements

Transmitter measurements

Adjacent-channel power measurement
Undesired adjacent-channel power results from distortions of the wanted signal. It can be avoided by preventing distortions (usually by using extra circuitry and at the expense of transmitter efficiency) or by designing the modulation type of the wanted signal such that it remains largely unaffected by distortions. The latter solution was given preference with GSM and in IS-95.

Ideally, the envelope of a GSM mobile is constant during the modulation of the signal. IS-95 also envisages a reasonably constant envelope of the mobile-station transmitter (time offset QPSK).

In both proposed systems of the 3rd generation, the modulation type of the mobile station has not been selected under the aspects of a constant envelope. Even in normal operation, the peak-to-average ratio is less favourable than in the above-mentioned systems of the second generation. If multiservice operation is to be realized by means of code multiplexing, the peak-to-average ratio is worse still (similar to a base station). If signals of this type are subjected only to fairly low distortions, this will lead to undesired adjacent-channel power which cannot be eliminated by means of conventional and inexpensive circuitry. Adjacent-channel power measurements are therefore expected to gain considerable importance not only for base stations, but also for mobile stations of this system.

Power measurement
Power measurements were crucial with IS-95 mobile stations. Because of the structure of the system (non-orthogonal operation in the uplink), it was essential for all mobile-station emissions to be received by the base station with the same power, irrespective of the distance between MS and BS.

This aspect is no less critical with the WB-CDMA and TD-CDMA systems, because the uplink is not orthogonal and the correct power of the mobile-station transmitter is essential for the proper functioning of the system. Furthermore, a mobile station is to cover a wide power range, which is to be checked by means of high-precision measurements.

1. The variation of the path attenuation over distances varying from 10 km (macro cell) to only centimeters (100 cm for indoor applications) has a dynamic range of 80 dB for TD- and W-CDMA.

2. Services with data rates varying by a factor of 1 to 64 (W-CDMA), which nevertheless are to attain the same QoS, need a power varying by a factor of 64 to 1. The consequent dynamic range of 18 dB is to be added to the above-mentioned value, which makes power measurement of the dynamic range a demanding task.

Time-dependent power measurement is quite a normal measurement in the TD-CDMA system. The measurement range is expected to be the same as with GSM, but with a much greater bandwidth.

Receiving all mobile stations with the same power at the base station, as desired, is made possible for W-CDMA systems by quick power control with 1600 updates per second. Time-dependent power measurement is therefore required also for the W-CDMA system.

In contrast to TDMA systems, CDMA systems do not necessarily have to contain further time-dependent power levels. In practice, however, this is suggested by several system proposals.

- VOX on/off (silence/speaking at the microphone increases/decreases the RF power at certain times)
- DTX in the downlink (the on/off ratio of the RF power is adjusted according to the speech activity)
- Slotted downlink transmission (base-station power interrupted at certain times is to provide spare time for the mobile-station receiver)

All these characteristics require besides high power-measurement range also time-dependent power measurement with high dynamic range and fine time resolution.

Code-domain power meter
These measurements already existed for base station in IS-95. Correlation was used to determine the power values for each code. There was no such test for IS-95 mobile stations, as only one code was used by the transmitting mobile station. If service multiplexing is achieved by means of code multiplexing, this measurement will also have to be made on mobile stations.

The various services usually also work with different data rates, which means that the power values have to be weighted differently.

The timing factor, which was discussed above for power measurements, is of course also of importance in this case and has to be considered in the measurements.

Separate power meters for I and Q
The proposed W-CDMA system used different physical channels for I and Q, whose power is to be controlled individually, so I and Q power have to be measured separately.

Modulation analysis

The modulation analysis is a very powerful transmitter test and produces a much larger number of results than suggested by the name. It can be used for W-CDMA and TD-CDMA in the same way. The trace measured at the transmitter is compared with the ideal trace. To make the two traces suitable for comparison, power adjustment has to be made, a frequency offset correction performed and the timing of the two traces needs to be coordinated. The following results are rendered as by-products:

- power error,
- frequency error,
- timing error.

In a next step, the two traces are compared. Two results are possible:

1. Difference-value formation. The result is the error vector as a function of the time, which allows the deduction of several other results: magnitude error, phase error as a function of the time, and overall evaluations based on all three time characteristics such as peak or rms values.

2. Correlation with the ideal trace shape and normalization to the overall power. As a result, the so-called rho factor is obtained, which correlates to the rms value of the error vector. If the measurements are performed for several multiplexed codes, the second method for modulation measurement is closely related to the code domain power meter.

Although the two types of modulation measurement are closely related, the first one (error vector) is better suited to allow conclusions to be drawn on the cause of the modulation error in the transmitter modulator, while the second one tells the user what the receiver "feels" about an error in the transmitter modulator.

Evaluation The transition from the first to the second mobile-radio generation included a fundamental change in the employed TX measurement technology. For the transition to the third generation, the TX measurement technology is developed further, but not replaced by anything profoundly new. Measurement bandwidths and dynamic range are no doubt more demanding than with the second generation. Some aspects shift in importance because of the inherent nature of the systems, but also because there are different legal requirements and traditions in the various regions of the world. In Japan, for instance, the transmitter test for **spurious emissions** over a relatively wide frequency range has to be performed at the manufacturing stage, whereas in Europe this test tends to be conducted during type-approval. The transmitter test for **occupied bandwidth** may be included in the measurements for the third generation for reasons of tradition. It is a test that was common with the PDC system, and it has come up again in the proposals for third-generation measurements.

Receiver measurements

Again, the most fundamental changes took place with the transition from the first to the second generation. The underlying principle is the same for receiver testing in the second and the third generation: The receiver is exposed to a signal putting it under stress in some way or other. The stress factors are the following:

Small signals	receiver sensitivity
Large signals	receiver dynamic range
Noise	
orthogonal	selectivity
non-orthogonal	co-channel rejection
Faded signals	test of adaptive channel equalizer or rake receiver

The data stream demodulated by the receiver is compared with the one that has modulated the data stream of the signal generator. As a result, BER (bit error rate) FER (frame error rate) or MER (message error rate) is obtained.

Protocol measurements

As a huge variety of services is planned, the associated T&M technology is expected to undergo not only evolutionary, but revolutionary developments. Unlike GSM, the new generation of mobile radio will not have a complete package of protocols, but an open toolbox of algorithms and protocols, that can be permanently extended and will run under a common operating system for **all networks/ the whole network.** This places new requirements on protocol measurements, both in quantity and in quality. However only the access network will be affected by the changes, while the core network is to be taken over from GSM.

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