Testing 3GPP UMTS Terminals

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The new generation of Cellular Telephone system which is currently under development, will be introduced in Japan in the middle of next year and into the UK, and many other European countries from the middle of 2002. The UTRA-FDD scheme uses Wideband CDMA for modulation and multiplexing and will provide integrated support for voice and IP data services in the 1.9 - 2.2 GHz bands. This paper looks at some of the measurement challenges that are generated by this emerging standard.

Introduction

The introduction of analog cellular radio telephone systems in the mid 1980's saw the requirement for the development of test systems for design, conformance test manufacturing and repair of user terminals (ie handsets) and base stations. Each successive generation seems to have greater complexity than its predecessors. This paper looks at the test requirements for the 3rd Generation Wideband CDMA system that is the access scheme for UMTS.

Basic Concepts of W-CDMA

In all cellular communications systems many users need to share the same RF efficiently. In first generation analog systems this was achieved by allowing frequency reuse between base stations (BS) serving cell that are then separated by two or three cell diameters. In the second-generation GSM systems digital modulation, combination with digital processing and error correcting receivers allowed cell sizes to be reduced to increase the overall capacity of the networks. Now, with the imminent introduction of 3rd generation (3G) systems the idea of using a frequency channel, or channel and timeslot to define a channel is overturned and channelization is implemented with orthogonal coding, for the 3G system is a CDMA system.

Within the standards being developed for the 3G system there are, in fact, a number of variants of CDMA used. The two versions being developed for implementation within Europe are known as the UTRA-FDD WCDMA and UTRA-TDD WCDMA system. The UTRA-FDD system is also called the 3GPP system.

In the 3GPP system many users share the same carrier frequency, time, and geographic vicinity. Also, the radio link between the BS and User Equipment (UE) supports multiple simultaneous data channels.

To allow multiple BS to coexist in the same vicinity, at the same time, and on the same carrier frequency, WCDMA employs Direct Sequence Spread Spectrum Multiple Access (DS-SSMA) scheme. In DS-SSMA, each BS output signal is "scrambled" by multiplying all of its data channels by a unique pseudo-noise (PN) Gold code referred to in the specification as a "Scrambling Code". The scrambling code provides the final random spreading for the signal. A UE receiver can distinguish one base station from another by correlating the received signal spectrum with a Scrambling Code that is identical to that used in the desired BS. Similarly, each UE output signal is scrambled with a unique Scrambling Code that allows the BS receiver to discern one UE from another. The scrambling codes are applied at a fixed rate of 3.840 million chips per second (Mcps).

Data Channelization

Besides distinguishing which transmitter is being listened to, a CDMA receiver must further distinguish between the various data channels originating from that transmitter. For example, a BS will transmit unique data channels to many mobile users, and each UE receiver must distinguish each of its own data channels from all of the others transmitted by the BS. In WCDMA, this function is provided by using "Channelization Codes", also known as Orthogonal Variable Spreading Factor (OVSF) codes.

These OVSF codes are similar to the 64-bit Walsh codes used in the existing US CDMA systems. However, in the 3GPP system the

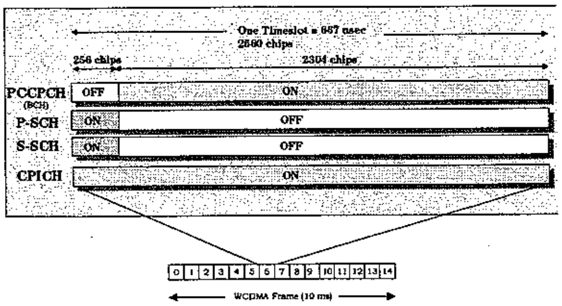

Fig 2 CPICH, PCCPCH and SCH slot and frame structure.

The user's digitised voice and/or digital data, along with layer 3 signalling data, are carried on the DPDCH. These two types of data are individually treated with error protection coding and interleaving, then multiplexed together to form the DPDCH. The DPDCH is then multiplexed with the DPCCH, which contains the Transmit Power Control bits to control the UE transmit power), Transport Format Combination Indicator bits and embedded Pilot bits. The DPDCH/DPCCH are multiplexed to form the DPCH, (the Dedicated Physical Channel (figure 3).

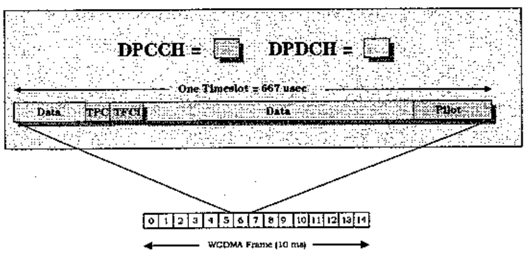

Fig 3 Downlink Dedicated Physical channel.

Uplink Physical Channel

The WCDMA uplink consists of a Random Access Channel (RACH), a Common Packet Access Channel (CPCH), and Dedicated Physical Data and Control Channels (DPDCH/DPCCH). The RACH is transmitted by the UE to request registration on the network. RACH transmissions begin with a short preamble pattern, which alerts the BS of the forthcoming RACH access message.

The CPCH is used for uplink packet data transmission. The CPCH is an efficient way to send uplink packet data, since it requires fewer system resources as compared with a dedicated data channel. It is a random access channel, and uses access procedures similar to the RACH. However, since a packet transmission may span several frames, it is necessary for the BS to control the CPCH transmit power. After the CPCH access attempt is successfully acknowledged, the UE begins transmitting, and the BS responds with power control bits. Once transmit power has stabilised, the UE may commence transmission of a multi-frame packet.

The UL DPDCH/DPCCH carries the user's digitised voice and data channels along with layer 3 signalling data. The payload data and signalling data (DPDCH) are transmitted on the "I" path of a QPSK modulator; the power control, pilot, and other overhead bits (DPCCH) are transmitted on the "Q" path. Multiple DPDCH may be transmitted to account for the high data rates. In this case they are consecutively assigned to either the I or Q paths. Each channel is spread by an OVSF code and its gain can be individually adjusted. Before modulation, the composite I & Q channels, which form the spread signal, is scrambled with a special function, to form the IQ modulation basebands. This modulation scheme is known as Hybrid Pase Shift Keyed (or HPSK). HPSK is a variation of complex scrambling that limits the signal transitions. This improves, or reduces, the peak-to-average power ratio of the signal.

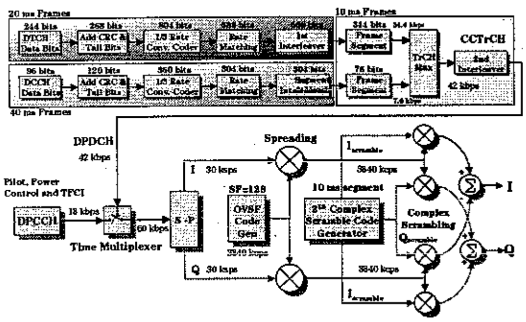

Fig 4 DPDCH/DPCCH Multiplexing

Test requirements for 3GPP System operation

The operating requirements of a WCDMA radio communications system have many similarities and a few major differences from the requirements for more conventional cellular systems. Thus, for both BS and UE transmitters, there are overall requirements to meet specifications for power, spectral occupancy and modulation performance.

spectral characteristics and modulation quality analysis.

Peak-to-average and CCDF

An R&D engineer, developing a power amplifier for 3G BS will need to consider the signal peak and average statistics of WCDMA signals. Peaks of the signal will tend to drive his amplifier into compression giving rise to a breakdown in the modulation characteristics of the amplified signal and spectral re-growth which may push the signal outside the bandwidth limits defined for the signal.

Peak-to-average power ratio has long been used to define the ratio of the peak envelope power to the average power of a signal during a given time interval. The Complementary Cumulative Distribution Function (CCDF) extends this concept to fully characterise the power statistics of the signal. It provides the distribution of particular peak-to-average ratios versus probability. Figure 11 shows the CCDF curves for two W-CDMA signals with different channel configurations.

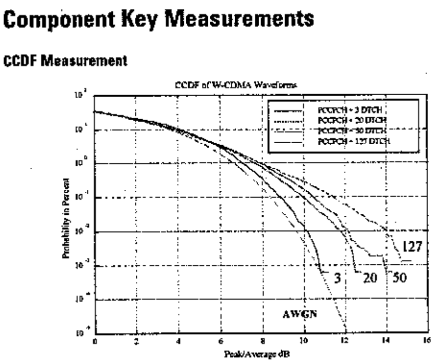

Figure 6. CCDF of a W-CDMA signal with various channel combinations

Interference and spectral occupancy

In the 3GPP system all active users communicate at the same time, and on the same frequency. The communication between each user and the BS is coded with a different spreading code, so each channel looks like random interference to all the other channels.

In addition to interference from orthogonally coded co-channels there is the additional interference from users on the adjacent channels.

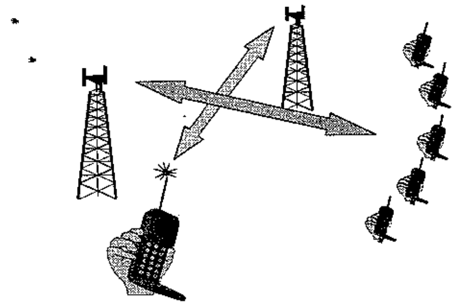

Fig 7. Near Far problem can cause interference from adjacent channel leakage.

Users sharing a channel operate within a common power control scheme that ensures that signals from the different channels are received as the same signal. Users of another, adjacent channel may be operating in completely different network and so operate at completely different power levels.

Power leakage from adjacent channels contributes to the noise floor of the channel. It directly reduces the available margin and hence system capacity. The following sections describe some of the key tests to characterize these RF power performance factors.

Adjacent Channel Interference

The acronym ACPR is usually taken to mean Adjacent Channel Power Ratio but has also been used to mean Adjacent Channel Protection Ratio. The 3GPP standard has introduced new terms to describe generation and susceptibility to adjacent channel emissions. Adjacent Channel Leakage power Ratio (ACLR), Adjacent Channel Selectivity (ACS), and Adjacent Channel Interference Ratio(ACIR).

ACLR is a measure of transmitter performance. It is defined as the ratio of the transmitted power to the power measured after a receiver filter in the adjacent RF channel. This is what we formerly called Adjacent Channel Power Ratio.

ACS is a measure of receiver performance. It is a measure of the ability of a receiver to reject interference in the adjacent channel. It is defined as the ratio of the receiver filter attenuation on the assigned channel frequency to the receiver filter attenuation on the adjacent channel frequency.

ACIR is a measure of overall system performance. It is defined as the ratio of the total power transmitted from a source (base station or UE) to the total interference power affecting a victim receiver, resulting from locations in the I/Q plane. WCDMA uses a QPSK format to modulate the spread signal (chips). However, the signal consists of several code channels, so the final constellation at the RF does not typically look like QPSK or any other known constellation, except for some specific channel configurations. For example, a signal with a single code channel does map onto a QPSK constellation. Hence EVM measurement can only be used to evaluate modulation quality of a transmitter carrying a single-code signal.

In the US IS-95 CDMA standard, the measurement specified for modulation accuracy is called ρ or rho. Rho is the ratio of the correlated power to the total power. The correlated power is computed by removing frequency, phase and time offsets, and performing a cross correlation between the corrected signal and an ideal reference.

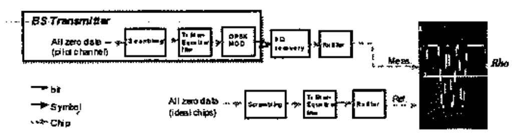

Fig 11. Traditional IS-95 Rho measurement

The IS95 rho measurement is made on a channel carrying a single carrier pilot channel. As we have seen the peak-to-average (or CCDF) statistics of a signal depends on the number of channels that it is carrying. A composite rho measurement can be defined for a composite channel and gives a single measurement that accounts for all spreading and scrambling problems in the active channels, and for all baseband, IF and RF impairments in the transmitter chain.

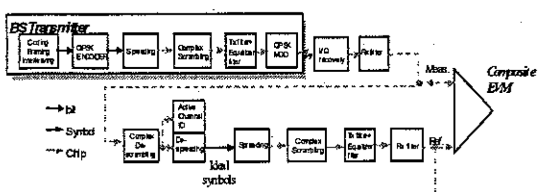

Fig 12 Composite rho measurement

However, unless combined with a constellation diagram and other modulation accuracy measurements, rho (or composite rho) does not help you identify the cause of the error. Like QPSK EVM, composite EVM calculates the error vector difference between the measured and the ideal signal. The difference is that composite EVM uses the same reference as composite rho. Meaning, it descrambles and despreads the measured signal to calculate the reference

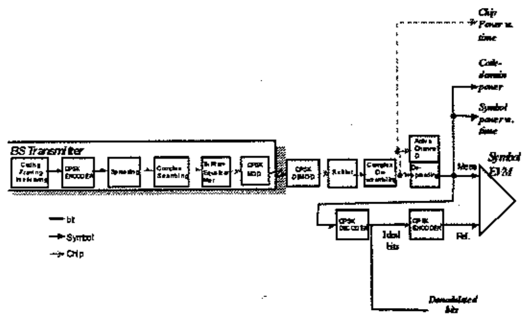

Fig 13 Symbol EVM Measurement

The projection of the error signal over the code domain, known as code domain error, is of even more interest. We would like the error power to be distributed through the code domain rather than concentrated in a few codes to avoid code-dependent channel quality variations. However, many transmitter impairments, such as amplifier compression and LO instability, cause uneven distribution of the error throughout the code domain. In these cases, energy is lost from the active channels and appears in related code channels in deterministic ways. For this reason, it is useful to ensure that the code domain error is under a certain limit.

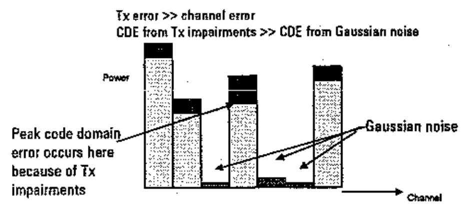

Fig 14 Code domain error measurement

The peak code domain error measurement indicates the maximum code domain error in the signal, and shows to which code channel this error belongs. In case of transmitter impairments, the peak code domain error typically belongs to one of the active channels.

Code Domain Power

Code-domain power is an analysis of the distribution of signal power across the set of

With BER and BLER test functions implemented as test functions the implementation of receiver tests is somewhat simplified. It is necessary to generate a suitable test signal. That is a channel carrying one or more fully transport-layer encoded test signals.

For testing a UE receiver it is then necessary to include synchronisation and pilot channels that will enable to receiver to synchronise to the test channel. It may be necessary or convenient to implement test modes to bypass normal call processing functions and force code-channel assignment. Once this is achieved measuring BER and BLER test can be started.

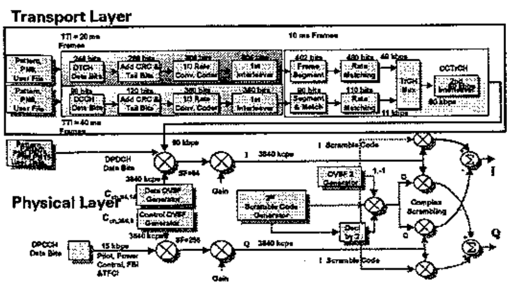

Fig 17 Uplink Physical & Transport coding

Testing the BS receiver is slightly different. Although the test channel is somewhat simpler overall implemented is complicated by the fact that the BS will not synchronise itself to a test signal, and it is necessary firstly to synchronise the frame and slot structure of the test signal generator to the BS frame timing. Probably, this will most simply be achieved by extracting a physical heartbeat, such as a 10 ms frame marker pulse, for the equipment under test.

Other Test Requirements

Besides the specific tests discussed in this document there are other specific tests that will be required to ensure compatibility of both UE and BS terminals to the overall system specification. There is an overall requirement for type approval and this includes several challenges. One specific challenge will be to ensure that test implementations are accurately executed at a time when the specifications are far from stable.

About the Authors

Tim Masson has been an application engineer and consultant with Hewlett Packard® and Agilent Technologies® for more than 18 years. He has specialized in test systems for Wireless Communications and Cellular Telephone systems since before the introduction of the UK TACS first generation test systems in the mid 1980's.

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