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Assessment Methods for a CDMA Trial System

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CDMA, LINK,
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This document proposes assessment methods for a CDMA trial system, which is currently under development as part of the research toward a Universal Mobile Telecommunication System (UMTS) standard. After providing some background information on the experimental setup that will be the object of the measurement, the document addresses the definition of a set of tests for the suitable evaluation of various services on the system. Furthermore, the impact of a few structural issues on the performance and on the testing is discussed. Finally, the assessment tools and the proposed methods of measurement and network loading are described.

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1 Introduction

This paper proposes assessment methods for a CDMA trial system, which is being developed to identify key parameters in the next generation of mobile radio systems for the Universal Mobile Telecommunication Systems (UMTS), and to enable their comparison against other competing technologies. The project will culminate with the operation of a field trial system, supporting a variety of teleservices in a variety of environments. This work is part of a DTI/SERC LINK Programme with the Universities of Bristol and Bradford, AT&T N.S. UK and Hewlett-Packard Laboratories to carry out an examination of CDMA for third generation mobile radio systems.

After providing a description of the structure of the field trial system (Section 2), this document addresses the definition of a set of tests for the suitable evaluation of the teleservices (Section 3). Furthermore, since the trial will be focused on the performance issues highlighted by our earlier studies, these are discussed, together with the impact they have had on the structuring of our assessment trial (Section 4). Finally, the assessment tools and the proposed methods of measurement and network loading are described (Section 5).

1.1 UMTS: A Paradigm Shift in Personal Communications

The services that will be supported by UMTS go far beyond the simple telephone conversation, into multimedia communications.

We believe that the world is on the verge of a social revolution, with changes in lifestyle similar to those brought about by the introduction of the car, the television, or the telephone itself. At the heart of this is an entire range of new mobile multimedia services that will be made available to the man in the street: one of the challenges is now to identify the best technical way to support these services in a truly mobile and flexible manner.

1.2 Why the LINK CDMA Project

During the past few years many claims have been published about the advantages of an air interface based on spread spectrum, for digital cellular radios. We now face a long list of unanswered questions:

- Are the claims on capacity testable and fully documentable in an experimental way?
- Is spread spectrum well suited to simultaneously support a wide range of teleservices?

- Is spread spectrum well suited to operate within radically different types of enironment?
- How flexible, in the most general sense, is spread spectrum?
- What are the most important characteristics of a spread spectrum system?

In order to answer these and many other questions, we formulated a project that aims to evaluate the advantages and disadvantages of CDMA as the candidate air interface for UMTS. The goal of the project is to build a CDMA-based field trial, with up to three Base Stations and ten Mobiles, on which to experimentally evaluate the air interface.

In this paper we describe our plans for the measures to be taken in the field trial, our reasoning, and how we intend to solve the many technical issues arising from the design of suitable assessment methods.

2 The Field Trial Setup

In our field trial we will implement the configuration shown in Figure 1. In this configuration, a Direct Sequence (DS) spread spectrum air interface will provide up-link and down-link connections between up to ten Mobile Stations (MS) and three Base Stations (BS). The Base Stations will be connected via fixed links to a Switching Centre, providing mobility management control and the interface to the ISDN and PSTN networks and related terminals.

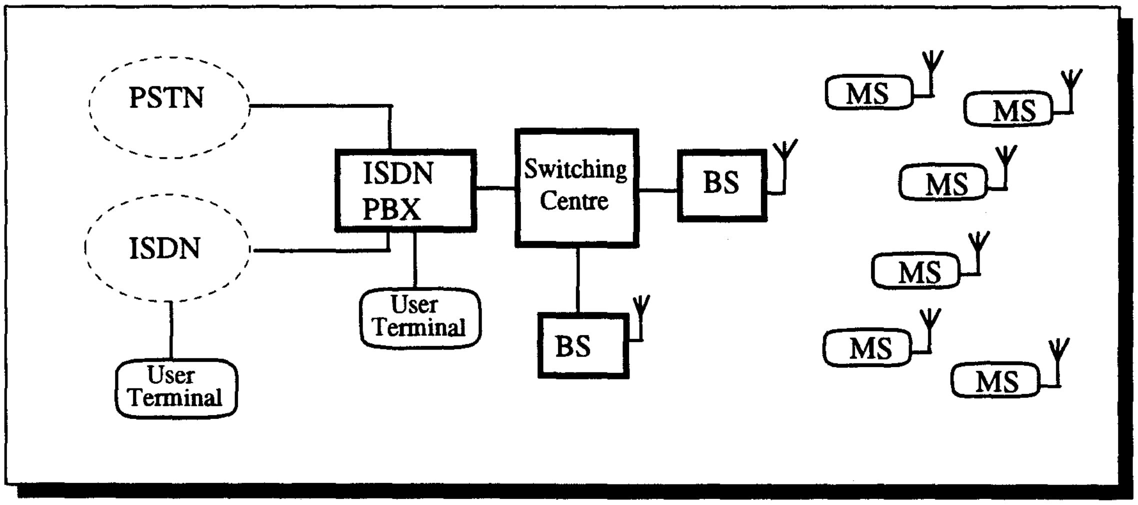

Figure 1 - The Field Trial Setup

The DS spread spectrum link will operate at 1.8 GHz, and in order to provide adequate resources for various teleservices it will support several types of radio bearers, with data rates up to 128 kb/s and error rates and delays specified to match the requirements of the different teleservices; the chipping rate will be around 8 Mchips/s

One of the key concepts of UMTS is the provision of a wide range of teleservices, within a large set of environments, and it is this that will make UMTS a truly ubiquitous provision of novel forms of communication. Our field trial attempts to implement part of the UMTS vision by demonstrating a set of five teleservices and by testing them within seven different environments:

Teleservices:	*Environments*
• Voice	• Macrocell in Urban Vehicular
• Fax	• Macrocell in Urban Vehicular during Diversity Handover
• Data at 64kb/s	• Microcell in Urban Pedestrian
• ISDN data at 128kb/s	• Microcell in Urban Pedestrian during Diversity Handover
• Integrated Voice and Data (IVD)	• Picocell in Office
	• Micro-Macro cell Overlay
	• Macrocell Rural

The choice of these teleservices acknowledges the drive towards a wide range of services, wider than the range currently available on a cellular network; this is central to the UMTS concept. In particular, the bearers simultaneously provide different bit rates. In our trial the maximum bit rate is intended to support the current ISDN standard. In addition, IVD and Fax teleservices will be demonstrated in the field trial: this is according to the growing emphasis on data services as opposed to speech-based services in the current personal communication networks.

The choice of environments reflects the need to test the air interface bearing in mind the need of ubiquity for UMTS. In addition, the combination of these teleservices and environments will address several issues highlighted by the theoretical work carried out prior to the definition of the field trial (these are summarized in Section 4, as they are pertinent to the concept of the field trial itself).

3 The Test Plan

In order to fully evaluate the CDMA air interface we have chosen the following set of tests, that ideally should be performed on each combination of teleservice and environment:

• Quality of Service (QoS) at the Base Station (BS)	Vs.	E_b/N_0 at the BS;
• QoS at the BS	Vs.	Power Control Update Rate;
• QoS at the Mobile Station (MS)	Vs.	E_b/N_0 at the MS;
• QoS at the BS	Vs.	E_b/N_0 at the MS;
• QoS at the BS	Vs.	Bit rate, (Voice only).

Before considering in more detail each of these tests, it must be underlined that the choice of QoS parameters will depend on the particular teleservice. This concept of "user driven" QoS is now well accepted among the organisations currently trying to define a common framework for the Quality of Service in Telecommunications [2].

In our project, we have identified the following QoS parameters:[1]

- Voice: MOS, delay;
- Data: BER, delay;
- IVD: MOS, BER, delay.

Let us now consider each of the tests proposed above.[1]

[1] The Qos for Fax is still under study, but it is expected to include measures of image quality, transmission speed and call completion success rate

3.1 QoS at the BS Vs. E_b/N_0 at the Base Station (BS)

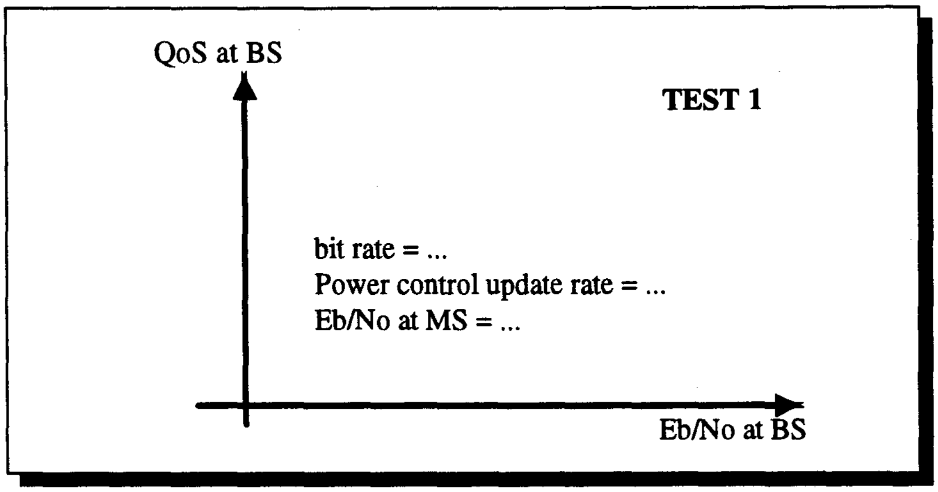

Figure 2 - Up-link assessment

In this test, shown in Figure 2, we focus on evaluating the performance of the up-link, and hence estimate the up-link capacity. Therefore conditions on the down-link are kept ideal, with a high E_b/N_0 at the MS. The power control update rate is fixed at the maximum possible value, and the bit rate is fixed for each teleservice.

The knowledge of the E_b/N_0 requirement at the BS allows us to estimate the capacity of the CDMA network on the up-link. In fact, the capacity in a CDMA system is interference limited by the transmissions from other users, and analytical figures are available on the amount of interference generated by a given population of users. Consequently, by knowing the required E_b/N_0 for each user we can estimate the maximum number of users that can be accommodated at any given time [3]. In addition, the graph will provide a measure of the robustness of the QoS at the BS with respect to variations in the received power. Real time monitoring of E_b/N_0 will allow monitoring of the effectiveness of the power control algorithm.

In summary, this test will provide:

- a way of assessing the capacity of the up-link;
- a measure of the robustness of the QoS at the BS;
- a first indication of the effectiveness of our power control algorithm at the maximum rate.

3.2 QoS at the BS Vs. Power Control Update Rate

The sensitivity to power control error is believed to critically impact the capacity of a Direct Sequence CDMA system. In this test, shown in Figure 3, we investigate the sensitivity of the QoS on the up-link with respect to the power control update rate. The conditions at the MS are kept ideal, as before, while the E_b/N_0 at the BS is fixed at the minimum possible value found during Test 1. The value of the E_b/N_0 at the BS can be fixed by using the power control algorithm itself: in fact, as explained in Section 5.4 and in Section 5.5, the E_b/N_0 depends on the ratio of the received power from the MS to the total noise density at the BS. The noise density at the BS depends on thermal noise and on all the inteference generated by other users.

By controlling the transmitted power from the MS, which is done through the power control mechanism, we can control the E_b/N_0 at the BS. By fixing the threshold of the power control algorithm at the BS at a certain value, found during Test 1, we can investigate the behaviour of the system at different power control update rates.

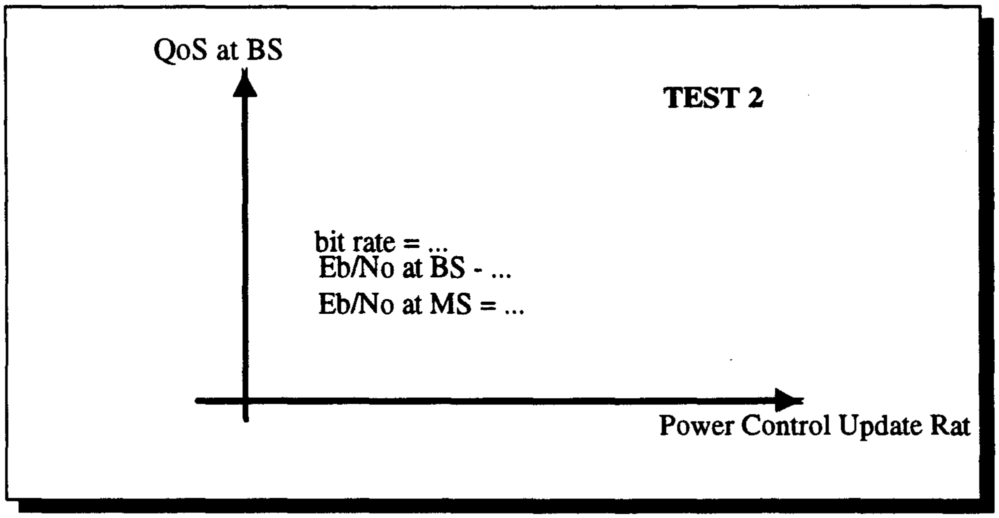

Figure 3 - Further up-link assessment

In summary, this test will provide:
- an indication of the robustness of the QoS with respect to the power control update rate, i.e. increasing variance in the received E_b/N_0;
- a measure of the variance of the received E_b/N_0 for different power control update rates.

3.3 QoS at the Mobile Station Vs. E_b/N_0 at the Mobile Station

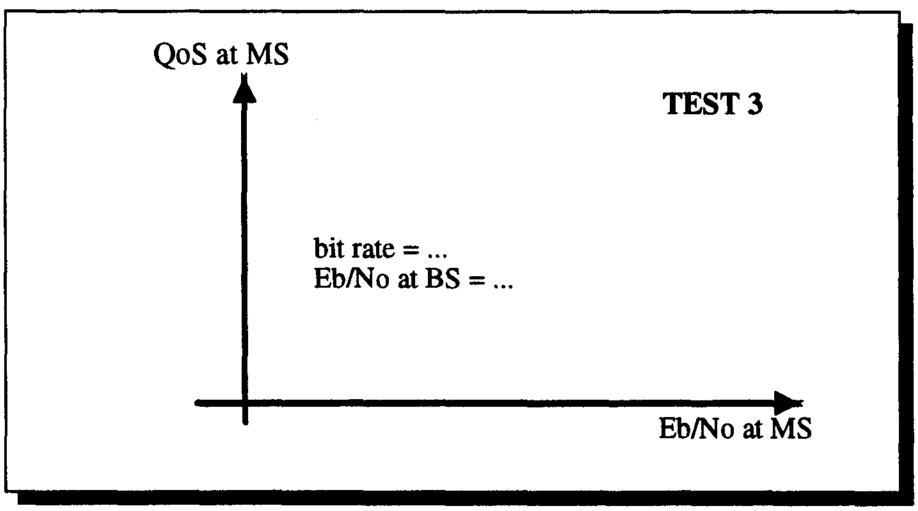

Figure 4 - Down-link assessment

This test, reported in Figure 4, evaluates the down-link just as Tests 1 and 2 evaluate the up-link. By measuring the variations of the QoS at the MS due to the changes in the received E_b/N_0 at the MS, we will be able to assess the capacity of the system on the down-link.

In this case, however, we cannot rely on the power control algorithm to set the received E_b/N_0 at a certain wanted value. We have instead to carefully set the power transmitted towards the mobile, and monitor the received E_b/N_0 in real time in order to make sure that its short-term average value is constant (the instantaneous value will vary due to fast fading, but further variations due to shading or path loss changes are unwanted).

In summary, this test will provide:

- a way of assessing the capacity of the down-link;
- a measure of the robustness of the QoS in the down-link.

3.4 QoS at the Base Station Vs. E_b/N_0 at the Mobile Station

This test is especially designed to evaluate the effect of errors in the power control channel. The power control channel will be affected by a certain error rate induced by the received E_b/N_0 at the MS.

As it can be seen from Figure 5, this test will monitor the variations in the QoS at the BS with respect to variations in the E_b/N_0 at the MS, i.e. different error rates in the power control channel. The other conditions (power control update rate, E_b/N_0 at the BS) are fixed at the minimum values which have been found to guarantee acceptable performance during the previous tests.

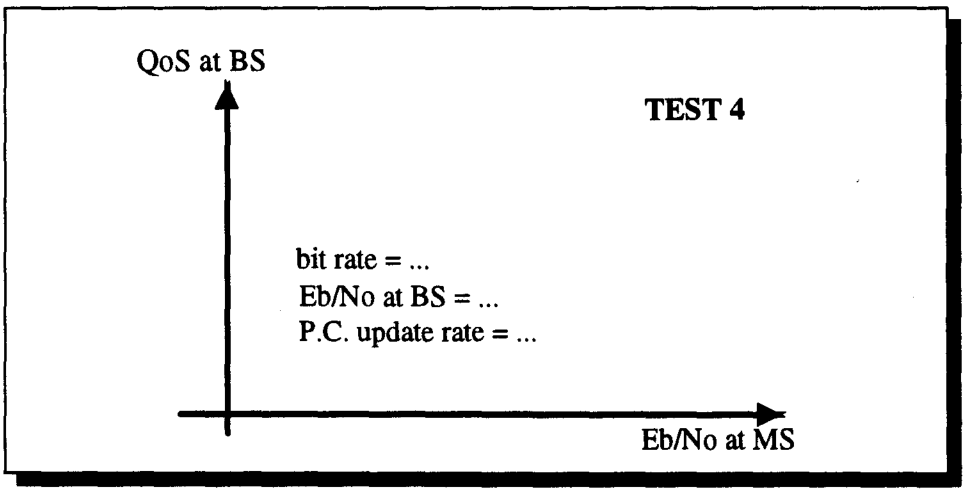

Figure 5 - Effects of the down-link quality on the up-link

In summary, this test will provide:

- a measure of the sensitivity of the QoS at the BS to errors in the power control channel;
- an indication of the effectiveness of the power control algorithm, by monitoring the received E_b/N_0 and checking its variance at different bit error rates in the power control channel.

3.5 QoS at the Base Station Vs. Bit Rate (Voice Only)

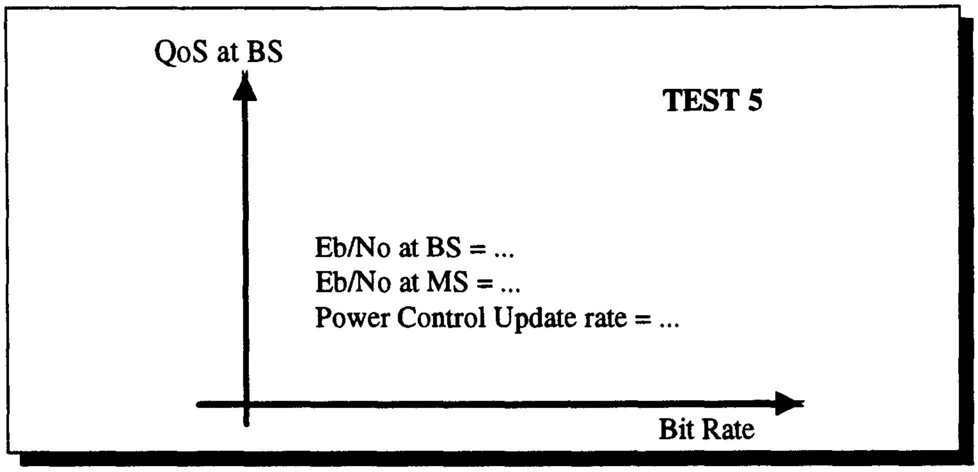

Figure 6 - Evaluation of DS CDMA link for different voice coding techniques

This test is only applicable to the Voice teleservice, and the type of characteristic to be studied is shown in Figure 6.

In the field trial the Voice teleservice will be supported with a standard 64 kb/s PCM voice coder, as opposed to more bandwidth-efficient algorithms. However, we do believe that a measure of how the CDMA air interface could impact different and more bandwidth-efficient voice coding techniques would be of value. We intend, therefore, to take recordings of BER and Channel Error Distribution of the raw CDMA channel at different bit rates, and then use these recordings as a channel model within software simulations of different voice coding techniques and channel coders. This should produce an assessment of the quality of the Voice teleservice on our DS CDMA link at different bit rates.

In summary, this test will provide:

- an assessment of the QoS for the Voice teleservice carried out with different voice coding techniques at different bit rates.

4 Test Plan Rationale

In this section we highlight some of the issues that have been identified by previous theoretical work, and that the field trial test plan attempts to address.

4.1 Macro-Micro cell Overlay

Simulations of a CDMA system have shown a decrease of capacity in a Microcell when overlaid by a Macrocell. Unfortunately, the UMTS concept is very likely to require this kind of arrangement, since high mobility and low mobility users must be served within the same area (e.g. vehicular and pedestrian traffic in a city centre). Clearly the Macrocell structure is best suited to high mobility users, such as car drivers, while the Microcell arrangement is necessary to guarantee enough capacity to serve a large population of users, such as pedestrians in the city centre.

The field trial will expressly consider the Macro-Micro cell overlay environment, and the tests will measure the changes in the required E_b/N_0 at the BS and at the MS in a Microcell due to the concurrent activity in the overlying "umbrella type" Macro cell.

These changes in required E_b/N_0 can be mapped directly into variations in system capacity.

4.2 Effect of Diversity Handover

One of the characteristics that makes CDMA so attractive from a UMTS standpoint is the possibility to offer diversity handover. That is, a handover in which the MS begins the connection with the new BS before actually releasing the connection with the previous BS. Under these circumstances the MS is effectively connected to two BSs at the same time.

Obviously this feature is very important for higher QoS during handover, making advantageous use of the macro diversity represented by the simultaneous communication with two BSs.

The field trial will include within its test plan two environments which expressly specify diversity handover in operation during a test. By performing the test plan within these environments we will gather important data on the behaviour of the MS and of the BS receivers during this novel handover technique.

4.3 Performance of the Rake Receiver

The rake receiver architecture is a particular structure for a spread spectrum receiver which allows the exploitation of multipath activity to improve its performance. This is one of the main differences compared with a conventional narrowband receiver, where the multipath nature of the mobile radio channel is compensated using equalisation techniques.

The test plan will provide useful information on the required E_b/N_0 of this kind of receiver under radically different operating environments. This is particularly important given that the multipath activity is obviously very much dependent on the environment.

4.4 Sensitivity to Power Control

As already pointed out in Section 3.2, DS CDMA is sensitive to power control errors, and therefore requires a very stringent power control algorithm. In the field trial this algorithm will use a dedicated channel from BS to MS, to dynamically control the instantaneous value of the transmitted power from the MS itself. The channel will be of variable data rate, with a maximum rate of 4 kb/s. Test 2 and Test 4 are especially designed to evaluate the impact of the power control update rate, and of errors in the power control channel.

In the test plan, great importance is given to the activity of gathering data on the complex interactions between the receiver performance, the power control update rate, the power control channel errors, and the variance in the received E_b/N_0.

5 The Assessment Tools

In this section we describe the set of assessment methods, or tools, that we plan to devise or to use to be able to perform the field trial tests.

5.1 Voice MOS Measurement Techniques

These will be a combination of listener panel tests and the use of objective analysis of received audio spectra and psycho-acoustic analysis techniques [4].

Recordings of "standard" speech phrases will be made and played over the system. Recordings of the received speech will then be returned to the laboratory for off-line assessment and analysis. High quality Digital Audio Tape (DAT) recorders will be used for the generation and collection of audio data, and a PC-based speech analysis system will be used for the objective analysis of speech.

5.2 BER and Error Distribution

It is envisaged that we will use both normal BER testing equipment (e.g. HP 3784A), and an "ad hoc" set up with a means of recording the received data. Indeed, access to the data received at different points in the system (e.g. after demodulator and after FEC decoder) will be needed. The measurement of BER in real time, using the BER testing equipment, will be possible either by transmitting a predefined PRBS, or by having both ends of the link made simultaneously accessible to the BER testing equipment.

5.3 Delay Measurement

For this measurement we plan to deploy the HP Vector Signal Analyser HP 89410A in order to measure the correlation between the received and the transmitted waveforms. This will allow us to have a reasonably precise measure of the delay between the two ends. Note that the correlation can be performed between digital waveforms as well as analog ones, so that the delays due to interleaver, FEC decoder, etc. can be taken into account.

Note, however, that the vector signal analyser needs access to both waveforms, at the transmitter and at the receiver, simultaneously. Naturally this can only be achieved by putting the receiver close to the transmitter, a different condition from the usual one, in which the distance between the two ends can be up to a few kilometres. However the delay introduced only by the radio channel (the free-space propagation delay) can be considered negligible compared to that introduced by DSP in the transceiver, thus end-to-end delay will be fully characterised on the bench, with only one measurement in the field in a loop-back mode, to confirm our assumption for the free-space propagation delay.

5.4 Signal to Noise Ratio (SNR) at the Output of the Despreader

The SNR is a key parameter of the system, and needs to be measured both at the base and at the mobile receivers. We propose two different techniques for the measurement, and the choice between the two will depend upon the situation case by case.

- The first technique is a substitution method, but does not provide the value of SNR in real time. The procedure is described below. The SNR after the despreader will be measured by firstly measuring the total Noise Power N having the wanted transmitter switched off. This measurement will be performed over the signal bandwidth, i.e. the bandwidth of the filter following the despreader. Obviously this is much smaller than the spreading band-width. As a second step, the wanted transmitter will be switched on, the power measurement repeated, and the difference with the previous value will be the Signal Power S. The ratio of Signal to Noise (S/N) will be the SNR at the output of the despreader.

- The second technique relies on the simultaneous measurement of the useful signal power S and of the total noise power N. This can be possible by using two receivers, one receiving the wanted signal, and the other one correlating with a different code, and therefore only receiving noise.

Another possibility is to use DSP on the despreaded signal to obtain values for the noise power N and the wanted power S.

5.5 E_b/N_0 Measurement

This quantity will be computed from the value of SNR. In fact, from the definition of E_b/N_0:

- E_b will be S/R, where R is the teleservice bit rate;
- N_0 will be N/W, where W is the signal bandwidth.

5.6 Measurement of MOS Vs. Channel Bit Rate

The field trial is only being designed to support 64 kb/s and 128 kb/s bearers. To assess the system's voice performance at lower bit rates and with appropriate coding schemes, techniques involving the combination of measured data and system simulation will be required. It is proposed, therefore, to measure the error characteristics of a user channel operating at bit rates in the range of 4 to 64 kb/s; call set up will be manually achieved for these tests as will be the switching of the 64 kb/s bearer to the lower rates. Error data Vs. time will be recorded under fully loaded conditions, both with and without handover being active.

The error data collected from these tests will then be used as part of a computer simulation of a complete channel including voice coder, Forward Error Correction (FEC) and interleaving. The output resulting from the simulation will then be processed by our MOS speech analysis system to predict a MOS. Comparison of these results will be made with other competing air-access techniques and existing fixed networks.

5.7 System Loading Techniques

To properly assess the performance of the bidirectional MS-BS link, an adequate user load must be provided, both in terms of load to the base station and of load to the mobile station. In other words, the up-link should be loaded with a significant number of interfering mobile stations (a few tens per cell), and the down-link should be loaded with interference from the nearby base stations (not more than 5 or 6).

Resource and budget limitations preclude the manufacture of more than 10 mobiles and of more than three base stations, and so alternative techniques must be employed. In this test plan we will use a combination of functional mobiles, a Frequency Agile Signal Simulator (HP 8791, FASS), and a few dummy BS transmitters in order to load the system.
To load the up-link in the case of a single base station, the 10 mobiles will first be used to create a lightly-loaded system, and measurement of this test configuration will be made. The FASS will then be programmed to emulate the loading of the 10 mobiles, and this set up will be compared against the original set up to confirm the validity of this loading approach. After such confirmation a system loaded with 20 mobiles can be assessed, by loading the base station with the 10 "real" mobiles plus another 10 simulated by the FASS. One or two further iterations of this technique may be required to increase the total load to up to 40 mobiles.

In the case of an up-link with two base stations, the approach is the same, but once the load introduced by the 10 mobiles has been measured, the FASS must be used to load both base stations with interfering power. In the case of two equivalent base stations this is easily achieved by placing the FASS at equal distance from the two bases; in the case of the environment featuring a Macro-Micro cell overlay the position of the FASS will have to be carefully studied.
To load the down-link, the approach will be to use a set of approximately 5 dummy transmitters, placed in fixed locations and transmitting in the same band as the base station (or couple of base stations) involved in the link.

6 Conclusions

This paper has discussed the assessment methods designed to fully evaluate DS-CDMA as a candidate air interface for UMTS.

In the first part of the paper we have presented the test plan that is currently being proposed as the way to evaluate DS-CDMA. We propose to focus on measuring the QoS of each teleservice against the received E_b/N_0, in the up-link and the down-link. In addition, an assessment of how the air interface affects different voice coding algorithms is proposed. Secondly, an explanation of the reasons behind the field trial is given. We explain how the theoretical work carried out by the LINK consortium has highlighted the issues that we will try to address within the test plan. Finally, the last part of the paper overviews the assessment methods that are under development at HP Laboratories in Bristol, and that will be used in performing the field trial itself.

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