Simulated BER Performance of, and Initial Hardware Results from, the Uplink in the U.K. LINK-CDMA Testbed

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ABSTRACT
A brief description is given of the background to the U.K.'s LINK CDMA initiative which has now reached a successful conclusion. The digital architecture of the up-link base station rake receiver is outlined along with the multipath channel simulator. Bit error rate results are presented from the hardware demonstrator of the rake receiver operating over a hardware two tap channel emulator. In addition, further results are presented of simulations of the receiver on a simulated multipath channel with Doppler fading. The effect of the channel estimation system is investigated and shown to introduce a 2dB to 4dB degradation in performance when estimating the channel compared to having perfect knowledge of the channel. Furthermore, it was found that there was no appreciable difference in overall BER performance of the receiver when channel estimation was performed on quasi-static or time-varying channels.

INTRODUCTION TO THE LINK CDMA PROJECT

Similarly to the European RACE project, the Department of Trade and Industry (DTI), and the Engineering and Physical Sciences Research Council (EPSRC) of the U.K. government under the "LINK" initiative funded a number of projects between academia and industry. These projects were to ensure that Europe, and particularly the U.K., stayed at the forefront of communications development. The LINK code division multiple access (CDMA) project was one of these and aimed to make "A Rigorous Evaluation of CDMA for Third Generation Personal Communications Systems". This successful project has been undertaken by a consortium of four organisations: AT&T Network Systems U.K. (project leader), Hewlett-Packard Laboratories Bristol, the Telecommunications Research Group at The University of Bradford and the Centre for Communications Research at The University of Bristol.

The LINK-CDMA project has now reached a successful conclusion and details of the whole project are contained in the final report [1]. Also, a paper is currently being prepared for publication [2] and a further paper concentrating on the field trial results and consequent conclusions is planned.

A primary aim of this project was to develop a CDMA testbed to allow evaluation of various important CDMA parameters in for example: power control, handover, and channel estimation. The testbed, which is a simple cellular system, was intended to consist of a switching centre, mobility manager, two base stations and two mobile stations. In the event, as a result of time and financial constraints, the project has been "down sized" during its life and the completed hardware has one base station and one mobile station as well as the mobility manager, and switching centre. The communication link between the mobile and base station is full duplex, multiple access being provided on both forward and reverse links by the mechanism of CDMA.

The section of this project which is reported here developed an uplink simulator for use as a system performance evaluation tool in particular to investigate the tracking ability of the channel estimator and as a testbed for optimum parameter selection. In addition, a software channel simulator was developed to test the operation of the receiver simulator under various channel conditions. The performance predictions from this simulation and initial hardware results are presented in this paper.

PHYSICAL LAYER PARAMETERS

The CDMA demonstration system consists of a base station, a mobile station and a mobility manager. Full duplex links are supported between the ISDN terminals attached to the mobility manager and those attached to the mobile stations. The user bit rate is 64 kb/s which is obtained from one or both of the two ISDN ‘B’ channels in the basic rate interface. The ISDN ‘D’ channel which carries the connection set-up and maintenance information operates at 64 kb/s in the physical layer but is only used as required and is therefore inactive for the majority of the time. The details of the air-interface design have been presented elsewhere [3,4], in summary the important parameters are:

1. Frequency division duplex: forward link carrier frequency 1823 MHz, reverse link carrier frequency 1727.5MHz
2. Modulation: BPSK (reverse link), QPSK (forward link)
3. Chip rate (BPSK or QPSK symbol rate): 8.192 MHz
4. Transmit bandwidth < 9.8 MHz
5. Bit rate: 64 kb/s ISDN-B channel
6. Spreading sequences: length 229-1 m-sequences (period approx 66s)
7. Convolutional coding, L=7, r =1/2.
8. Closed loop power control on reverse link.

BASE STATION RECEIVER DIGITAL PROCESSING

A block diagram of the base station receiver architecture is shown in figure 1. There are four subsections within the receiver: channel estimator, peak searcher, rake receiver and maximal-ratio combiner.

The rake receiver is made up of four identical tines, each of which comprises a programmable delay element followed by a serial correlator. The delay elements are fed from the channel estimator with estimates of the delays associated with the four strongest received components from the multipath channel. Each suitably delayed signal is correlated against a locally generated pseudo-random bit sequence (prbs) corresponding to the particular spreading code used in the transmitter. This local prbs sequence is updated every symbol period. The output of each rake tine is sampled at the symbol rate and passed on to the maximal ratio combiner.

The channel estimator performs a cross-correlation between the received signal and the locally generated prbs sequence. This cross-correlation against the 'real' part of the prbs provides the relative amplitude variation and the extent of the phase rotation introduced by the multipath channel. The outputs of the correlator are stored in two 192-stage shift registers. This channel estimate can be improved by averaging over a given number of previous estimates to reduce the noise content. At the end of this averaging interval the accumulator is reset to zero.

The peak searcher takes the output of the channel averager and searches for the four largest peaks. These peaks correspond to the four strongest multipath components in the channel. The peak searching algorithm is constrained so that no two of the detected peaks are ever within one chip period of one another. This is done to ensure that the fading on each tine will be statistically independent. The temporal position of the peaks is fed to the programmable delay elements in the rake to equalise the channel delays so that all the outputs of the rake are time aligned.

The magnitude and complex conjugate phase of the four detected peaks are passed into the maximal ratio combiner along with outputs of the four rake tines. The combiner multiplies the output of each tine with the corresponding magnitude and conjugate phase from the peak searcher. The effect of this operation is to compensate for the phase rotation introduced by the channel and to weight each component relative to its received strength. The real output from the combiners for each tine are summed together to form the reverse traffic channel (rtc) data stream and likewise the four imaginary outputs which when summed together form the reverse control channel (rcc) stream.

CHANNEL MODEL

Figure 2 illustrates the complex-baseband model used to simulate the multi-path fading channel used in the overall system simulation. The Rayleigh fading pattern is generated using complex multipliers obtained from pairs of independent Gaussian random number generators. To simulate the Doppler spread of the channel, the Rayleigh distribution is filtered using a moving average filter with a 1 dB bandwidth of 176 Hz (Doppler shift at 100 km/hr on a transmission frequency of 1823 MHz). The power delay profile is the ‘typical urban (non-hilly)’ scenario.

SIMULATION RESULTS

Figure 3 illustrates the results achieved with the actual hardware receiver. The implemented system had a chip rate of 8.192 MHz and a processing gain of 64 leading to a coded bit rate of 64 kbps. The preliminary hardware results are raw BER measurements for the reverse link at 128 kbps, without rate ½ coding and interleaving. An implementation loss of between 1dB and 2dB can be seen in the discrepancy between the actual results and those for a perfect coherent receiver in an awgn channel. It will be observed that as further paths are added, the system performance degrades, however this degradation is not as severe were there to be no rake receiver. A full description of these and further results is presented elsewhere [2]. In this particular instance, to match the test conditions used for the hardware, the software simulation was tested with a quasi-static two-tap channel model with arbitrary phase rotation on both paths and unity magnitude path responses. In the receiver simulator, two of the four tines were disabled leaving the remaining two tines to collect the output signal energy from the channel. The simulation results showed close agreement with the theoretically predicted results for an additive white Gaussian noise channel within the bounds of statistical fluctuations on the BER measurements. In addition these results provided a confidence check on the performance of the software realisation of the system.

With the four tines of the rake receiver now operating, a more comprehensive test was conducted over a Rayleigh fading channel with a ‘typical urban (non-hilly)’ power delay profile (figure 2). Again a quasi-static assumption was made about the channel. The first experiment involved supplying the channel estimator in the receiver with the actual taps of the channel model. There would therefore be no degradation in receiver performance introduced by the channel estimator. As would be expected, these initial conditions on the experiment provided the best BER results for the receiver (figure 4). When the channel estimator in the receiver itself was used to estimate the channel, the BER results degraded by between 2 and 4 dB for the same probability of error (figure 4). It should be noted that the BER measurements were begun only after the first ten symbols in each channel had passed through the receiver in order to allow the channel estimate to converge.

The final and most comprehensive test of receiver performance was to abandon the assumption of channel quasi-stationarity and to allow the channel to vary on a per-symbol basis. The receiver was able to accommodate this extra degree of freedom without a noticeable degradation in performance from the quasi-static simulation results (figure 4). No hardware performance results were available at the time of writing with which to compare these findings.

CONCLUSION

After three years, the U.K. LINK-CDMA project, whose objective was to evaluate CDMA for third generation personal communications systems, has reached a successful conclusion. BER performance results were produced for the hardware operating over one, two and three static path channels. Simulation results presented in this paper have extended the hardware results for the four-tine receiver operating over a multipath channel with Doppler fading in a typical urban scenario.

The effect of the channel estimation system was investigated. When the receiver is forming its own channel estimates there is a 2 to 4 dB degradation in performance from the case when perfect knowledge of the channel is made available to the receiver. There was no appreciable difference in BER performance when channel estimation was performed on quasi-static or time-varying channels.

REFERENCES

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4 The work described in this paper was supported by the Department of Trade and Industry, and the Engineering and Physical Sciences Research Council (EPSRC), LINK project PC019, partly under EPSRC grant reference: GF/H26307.