CDMA Forward Link Coverage and Channel Sounding

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Abstract

CDMA challenges system designers with new requirements in planning re-use patterns and system coverage. Frequency re-use has been replaced by code re-use patterns. The authors present a method and system of propagation analysis to measure interference from both neighboring CDMA transmitters and multipath reflections. The system has many advantages over carrier wave (CW) coverage propagation analysis because it uses pseudo noise (PN) modulation, measures interference from neighboring transmitters with PN time offsets and measures multipath from the local base station (BS) and neighboring BS. The system can make these CDMA measurements at any stage of deployment from planning to final system coverage verification. The system is based on the Duet Channel Sounder, a transmitter and receiver system used for multipath analysis. Modifications to the Duet are presented that enhances the Duet for these custom CDMA system measurements. These modifications include: a technique to lock the transmitter to GPS time and to provide time offsets to the transmitter's PN code. Discussion of the data collected by the system and preliminary analysis is presented.

Introduction

IS-95 Code Division Multiple Access (CDMA) challenges system designers with new planning requirements[1]. It is the authors' experience that most CDMA system designers make use of tools designed for FDMA and TDMA systems. Typically, the tools and methods employ CW transmitters and receivers for propagation analysis. Verification of coverage with modulated signals does not typically occur until actual BS sites have been at least partially constructed. This verification uses the actual Base Station (BS) hardware and subscriber units and occurs relatively late in the system planning cycle. Effects from multipath and BER performance cannot be estimated or considered until this late stage. This paper presents modifications to the Duet Channel sounder that enables the system designer to sound the channel and measure multipath and BER in the early stages of system planning.

Rational for Multipath Channel Sounding

Digitally-modulated RF signals manifest unique characteristics in the presence of reflections at PCS frequencies. These reflections cause unphased additions of data symbols which result in bit errors. Simple signal strength measurements at PCS frequencies (envelope detectors measuring narrow bandwidth signals such as CW) are deceiving because the signal may measure strong, but when digitally-modulated, the Bit Error Rate (BER) can be surprisingly poor. Multipath reflections (also known as time dispersion) of the RF carrier is when two or more signals of the same origin arrive at the receive antenna delayed in time because they traveled different path lengths or because of reflections and scattering in the propagation environment. This deterioration of the signal must be considered when planning and optimizing high-rate digital radio systems[2].

CDMA systems are unique in the RAKE type receiver employed for demodulation. The RAKE receiver can demodulate different multipath reflections that are sufficiently distant in time, but Multipath reflections too close in time cannot be combined and represent interference to the receiver.

CDMA systems are also unique in the way BS exist in re-use patterns. BS transmit on the same frequency

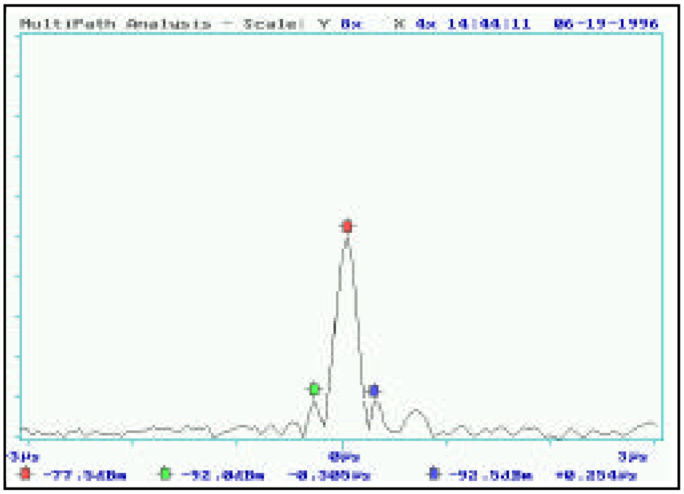

Figure 1. Screen shot of the Duet Multipath Analyzer. This screen depicts magnitude of multipath components versus time of arrival. This waveform is later defined as the Power Delay Profile(PDP) of the system and channel , and should be of primary interest to CDMA system planners.

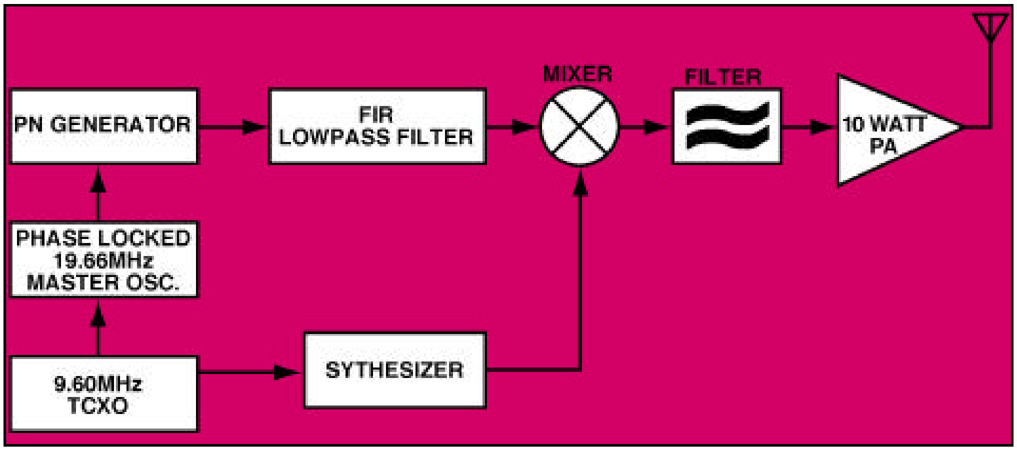

Figure 2. Block Diagram of the Duet Transmitter.

and at the same time; they do not interfere excessively with one another through code division techniques. Neighboring BS have unique identification numbers and each identification number corresponds to a different time offset used to delay the start of the BS's pilot code. A very useful artifact of the time offset is that the user's handset can demodulate the neighboring BS as "multipath". The same RAKE receiver can be used to demodulate and combine multiple paths from the nearest BS and paths from neighboring BS. The paths from neighboring BS are necessary for hand-off. As stated, multiple path reception from the nearest BS and "multipath" reception from neighboring BS can be beneficial. These multipaths can also degrade CDMA system performance. Multipaths too close together cannot be demodulated, but represent interference. Neighboring BS signals that propagate too far should not be considered for hand-off and also represent interference.

The ideal tool for CDMA system planing should be: simple, practical for use in the early stages of system planning, measure multipath reflections desirable for CDMA operation from both the nearest BS and neighboring BS and measure multipaths that are not desirable because they are too close in time or from a BS not suitable for hand-off.

The Duet Transmitter and the CDMA Forward Link

The Duet transmitter produces a user selectable direct digital spread signal in the PCS frequency band. A functional block diagram of the transmitter system is shown in Figure 2.

The PN signal for the transmitter is produced by a pair of 15 bit programmable code generators. These shift register based code generators can produce any 15 state (or less) linear code, of which PN codes are a subset. The code rate of the PN can also be selected, to adjust the bandwidth of the transmitted signal and to vary the resolution of multipath detection. Included in this selection are PN codes and chip rates that have the same bandwidth and spectral properties as IS-95 CDMA's published I or Q pilot signals[1]. The code generators do have the capability to append a zero to the end of the PN code to form the pilot code as specified. The output of the code generator is over sampled to bring the sampling rate up to approximately 20 MHz (this is a minimum of 4 times over sampling). This data stream is then low pass filtered with a sixty four stage FIR filter to eliminate out of band components. The output of the filter drives a D/A converter and is sent to the I/Q modulator.

The I/Q modulator is used to produce a BPSK modulated signal. This signal resembles the I and Q pilot signal for the CDMA format. The signal is then up converted to the PCS frequency band and amplified to a maximum of 10 Watts CDMA output.

The Duet Receiver

The Duet receiver is a wide bandwidth (6 MHz or 12 MHz) spread spectrum receiver with ability to analyze channel characteristics and graphically present the magnitude of the channel's impulse response, report signal strength (in a spectrum analyzer like display), and perform bit error analysis for any arbitrary signal path. The functional block diagram for the receiver system is shown in Figure 3.

The received spread signal is down converted to an intermediate frequency (70 MHz IF). The IF amplifier and receiver signal strength indicator (RSSI) are used as a signal strength detector with a narrow bandwidth to plot the signal strength across frequency, and also as an AGC system to maximize the dynamic range of the receiver during multipath analysis.

The output of the IF amplifier goes to an I/Q demodulator. The I/Q demodulator is used to receive a signal regardless of incoming RF phase. Since the incoming signal will arrive at an arbitrary RF phase, both in the inphase and quadrature components of arriving signal have to be used to reconstruct the true signal strength at the receiver.

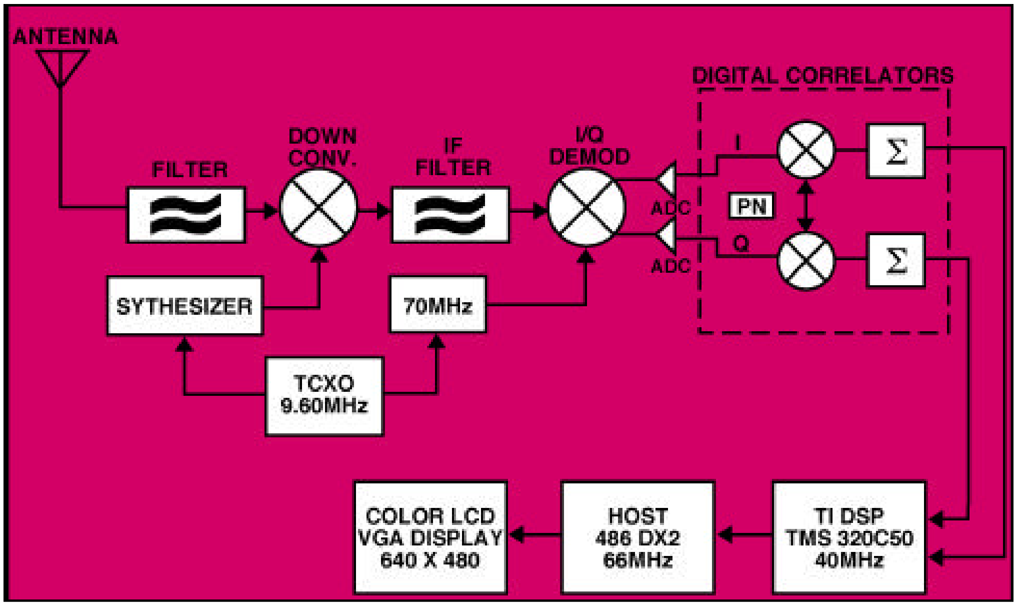

Figure 3. Block Diagram of the Duet Receiver.

The output of the I/Q demodulator is sampled with a pair of A/D converters running at a sampling rate of approximately 20 MHz. This pair of digitally sampled data streams is then fed to four independent PN correlators. Each of these correlators actually contains two correlators one for the I channel and one for the Q channel. The correlators work together with the programmable code generators to reconstruct the impulse response of the channel. These code generators differ from the code generators in the transmitter only in that they can be made to instantaneously jump to a different code phase without stopping - a property that is required in order to find the correlation at each phase alignment. Each of the power correlators can be controlled independently and can take their source from either code generator. This allows one or more of the power correlators to be used as a demodulator for bit error analysis, while freeing the remaining correlators to be used as high-speed delay lock loops (DLL) to keep the demodulator locked to a path. The systemís internal DSP tracks any slowly drifting phase errors due to differences in clocks between the transmitter and receiver as well as compensates for any Doppler drifts that may occur due to motion at either end of the link.

The detection hardware is directly controlled by a digital signal processor, which performs high speed computations and control of the digital logic. Collected and processed data is then transferred to a 80486, which controls the supervisory functions, display, logging, and communications. The display is a color VGA LCD. Data can also be logged to a non-volatile PCMCIA memory card, for post-processing.

Figures 1 and 4 show the screen of the Duetô receiver. This data is updated in real time at about four times a second.

Modifications to the Duet: GPS Genlock and Base Station Time Offsets

CDMA systems, as well as may other PCS formats, typically lock the BS's system time and clocks to the Global Positioning System's (GPS) time. The GPS receiver, located at the BS, determines time and position by measuring the time of arrival of spread spectrum signal from orbital satellites. Of particular interest is the Pulse Per Second (PPS) signal generated by the GPS. This signal is a seconds tick with jitter in the 200 SYMBOL 104 \f “Symbol”s range[3]. The PPS is used to control the start of the Pilot code generator at each BS and to phase lock the Pilot code generator to the PPS and to other code generators in the system.

Code division in the forward link is not accomplished by using different spreading codes. Actually, the same code is used at neighboring BS, but the codes are started at different times. As described earlier, a correlator will respond when it's code phase is aligned to the code phase of the received signal. A code, regardless if it is from multipath or from a BS producing the same code offset in time, will not highly correlate when not aligned to the correlator's code phase.

It is evident that the alignment between pilot code generators in a CDMA system is critical. The same alignment is also critical for Duet transmitter set at candidate BS sites.

Another use for the GPS Genlock circuit is at the Duet receiver. A GPS receiver is not practical for a subscriber unit, but is very useful for a test instrument. The Duet receiver's code generator can be started and kept in-phase to a BS's generator. The propagation delays for paths between the transmitter and receiver can be calculated and displayed as:

$$T_p = T_cN - T_{tpl} - T_{rpl}$$

where

T_c=chip period
N=correlation phase
(chip offset form code phase 0)
T_{tpl}=pipe-line delay from the code generator to the TX antenna
T_{rpl}=receiver pipe-line delay from antenna to correlator

The values of T_{tpl} an T_{rpl} are constants of the instrument and are measured for the Duet. The correlation results can be displayed so that the position of a multipath component's peak is marked in absolute time or arrival or the propagation distance. Reception from any BS or Duet Transmitter can easily be examined by scrolling the time scale to the amount of time corresponding to its offset in time. The Duet receiver's correlator will respond for multiple paths signals from the nearest Duet Transmitter or other Duet transmitters with different Pilot offsets.

A combination of Duet transmitter can be set with different offsets at different candidate BS sites. A Duet receiver can then measure multiple path strength from the nearest transmitter and multiple path strength from neighboring transmitters.

The major modification to the Duet for CDMA specific measurements is the GPS Genlock circuit. The reference VCTCXO oscillator in both the transmitter and receiver is phase locked to the PPS. This option reduces the relative phase difference between the RF modulator and demodulator. Importantly, the code generators and chip rates of the transmitter and receiver are phase locked to a standard reference, the PPS. The frequency of the PPS is too low to be used in a conventional phase lock loop circuit. Instead, the PPS is used to estimate the frequency of the reference oscillator during each second. The processor reads the number of pulses accumulated in the counter, CNT, during a second, compares this number with the expected count and increases or decreases the frequency of the VCTCXO. This servo-system regulates the chip frequency in the transmitter and receiver for changes in temperature and inaccuracy of the oscillators. The measured accuracy of the oscillators was improved from 2.5 ppm to .15 ppm.

To keep the code generators that are located at different sites with different clocks phases locked, which is necessary so that the code generators in Duet transmitters do not drift relative to the PPS or each other, a second counter is used to accumulate any difference between the PPS and the code generator's clock. The algorithm attempts to keep this counter equal to zero for perfect phase locking.

Lab testing verifies that the system can phase lock a Duet transmitter and receiver with a jitter of about ± $^1/_4$ chip at a chip period of 1.2288 MHz. A block diagram of the phase locking system appears in figure 4.

The Power Delay Profile

When a component of the received signal is aligned in phase with the receiver's code generator, it will correlate and its magnitude is recorded. This waveform of correlated energy versus time graphically displays the different multipath components within the system and channel and is defined as the Power Delay Profile. Different paths from the same Duet or paths from neighboring Duets with different time offsets will correlate at different times and be displayed. This Power Delay Profile should be of primary interest to the CDMA system planner, and providing this information is the goal of the modified Duet system.

The time resolution ($\Delta\tau$) of multipath components using the Duet sys-

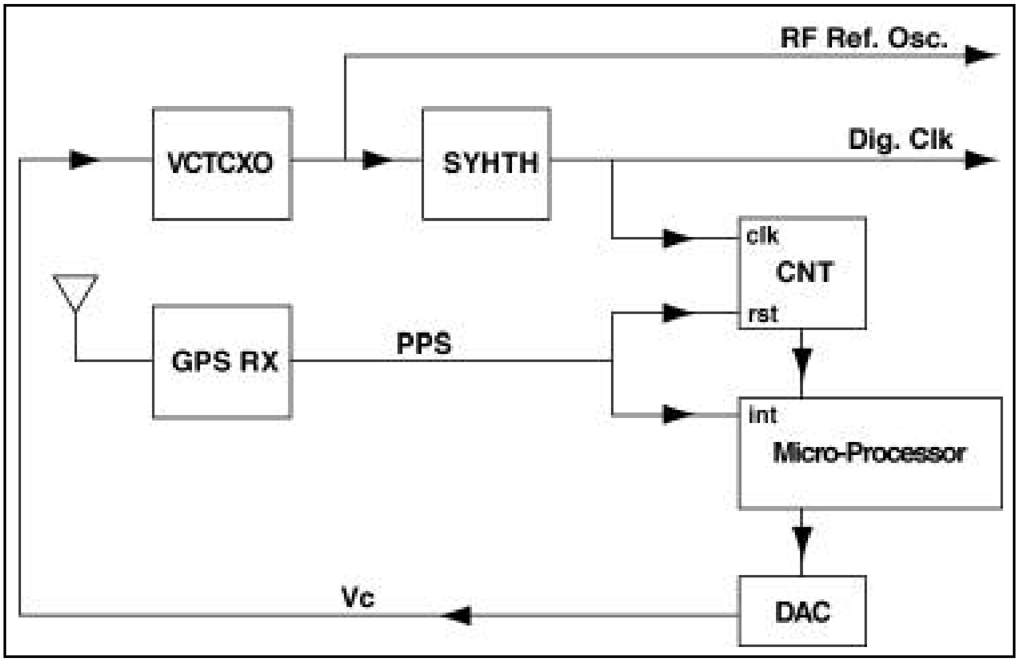

Figure 4. The Genlock circuit.

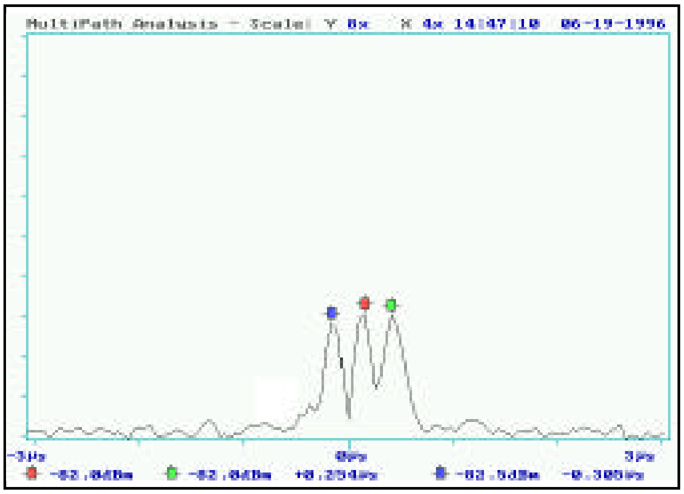

Figure 5. Example of a Power Delay Profile, from the Duet screen, showing 3 distinct paths of nearly equal amplitude.

tem or a spread spectrum system is related to the chip period, and for the CDMA rate is:

$$\Delta\tau > T_C = 1/R_C$$

where
T_C= chip period = 813.8ηs
R_C= chip rate = 1.2288MHz

The system can resolve two multipath components as long as they are greater then T_C seconds apart [4]. Figure 5 shows three multipath components delayed slightly more than Tc from each other. Note that the Duet system was set to a chip rate 4X the CDMA rate.

The Duet set to the CDMA chip period is limited to resolving multipath to about 813 ηs and the subscriber handset also has the same limit when detecting and combing multiple paths. Paths that are shorter than the chip period will combine in and out of phase and appear to fade the received path.

The Duet's chip rate can be increased to 2X, 4X or 8X the CDMA rate. Correspondingly, this will increase the time resolution and the bandwidth occupied by the transmit signal. of the Duet by the same amount.

Results and Conclusions.

The Modified Duet System meets the authors' requirements for the CDMA system planing tool: it is simple, practical for use in the early stages of system planning, measures multipath reflections desirable for CDMA operation from both the nearest BS and neighboring BS and measure multipaths that are not desirable because they are too close in time or from a BS not suitable for hand-off. Multiple Duet transmitters can be located at proposed BS sites with the proposed BS Identification (time) offset, and one Duet receiver can measure multiple paths from the Duet transmitters. The chip rate of the system can be increased up to 8X and measure close-in multipaths that the IS-95 CDMA chip rate cannot measure.

Acknowledgments

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