A New Class of Precision UTC and Frequency Reference Using IS-95 CDMA Base Station Transmissions

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Abstract

This paper introduces a new class of precision timing and frequency reference that indirectly receives GPS timing and frequency information via the transmissions from Code Division

IS-95 SYSTEM OVERVIEW

Figure 1 depicts the general architecture of an IS-95 CDMA network [4]. One or more transceiver sites (base stations) are connected via dedicated wire lines to a Mobile Telephone Switching Office (MTSO). The MTSO is responsible for coordinating the base stations that are connected to it and interfacing their voice and data traffic to the Public Switched Telephone Network (PSTN). In a CDMA system, the MTSO is also responsible for maintaining system time and monitoring the timing status of its connected base stations. This function requires the co-location of at least one GPS time and frequency reference receiver. Each base station must also independently maintain system time and frequency, so a co-located GPS time and frequency receiver is required at those locations as well.

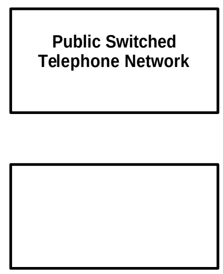

Figure 1 – CDMA Mobile Telecommunications System

There are two types of IS-95 CDMA systems operating today. They are distinguished by the carrier frequency bands in which they operate. The original analog cellular mobile telecommunications system, also known as the Advanced Mobile Phone System (AMPS), occupies the 800 to 900 MHz band which has become known as the *cellular* band. In North America the largest CDMA provider using the AMPS cellular band is Verizon Wireless [5]. In more recent years, demand for spectrum has opened up a band in the 1900 MHz region for cellular mobile telecommunications use. This band is known as the Personal Communications Systems (PCS) band. U. S. Sprint is the largest CDMA provider using the PCS band in North America. In other parts of the world, CDMA providers operate in the same two general regions of the spectrum. However, the specific carrier frequency bands used within those regions are in general not the same as those used in North America.

Cellular systems offer better performance in terms of range and building penetration [4]. For the purpose of transferring time and frequency to stationary users inside of buildings or at the fringes of a coverage area, this is a definite advantage. Due to the more rapid signal attenuation at the PCS carrier frequency, PCS offers the ability to space the coverage cells more densely in heavily populated urban environments and thereby handle more traffic. For the passive transfer of time and frequency, this offers no advantage. The implication is that the preferred system for time and frequency transfer using IS-95 CDMA uses the cellular frequency band. Unfortunately, there are locations having PCS coverage only. In these areas a PCS time and frequency receiver is the only option and performance inside buildings is less predictable.

In a mobile telecommunications system, transmissions from the base station to the mobile user are on the *forward link*

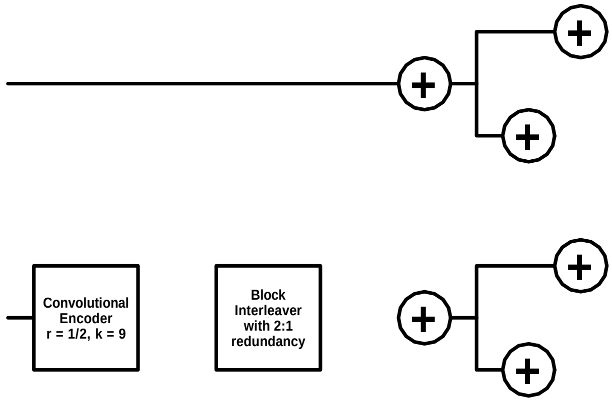

Figure 2 – Pilot and Sync Channel Signal Structure

The sync channel is broadcast at a level approximately 9 dB below that of the pilot channel. The data contained in the sync channel broadcast is a fixed-length *message* that enables the mobile receiver to establish GPS, UTC and local time. In order to access the paging and traffic channels, mobile phones need the current state of the *long PN code* which is also contained in the message. The long PN code is not used for the purpose of time and frequency transfer and is mentioned here for completeness and because its use has an interesting resemblance to that of the GPS P-code. The long PN code is 2^{42} bits long and repeats every 41 days. It is used in the forward link to scramble paging and traffic data sent from the base station to the mobile unit. On the reverse link, each mobile unit uses a non-overlapping piece of the long PN code, assigned to it by the base station, to distinguish its transmissions to the base station from those from other mobile units.

Sync channel data is sent at 1200 bits per second (bps). Prior to transmission it is convolutionally encoded using a rate ½, constraint length 9 encoder. This effectively creates two *symbols* for each bit of data and allows error correction at the receiver. Each symbol is then repeated once, and a *block* of 128 of these is then *interleaved*, which means to re-order (scatter) them within the block to provide temporal diversity. This is a means of mitigating burst errors to improve error correction when the symbols are decoded at the receiver. This block of symbols is then transmitted at 4800 bps as a *frame* with each frame being aligned with, and having the duration of, one repetition of the PN code. Three contiguous frames compose a *superframe*. The entire sync channel message, including the 30 bit cyclic redundancy code (CRC), occupies less than three superframes so it is zero padded to fill them completely. The time-of-day information contained in the message is valid four superframes after the end of the last superframe containing the message. Since each base station transmits its PN code with an offset delay relative to the zero offset PN code, the PN code offset of the specific base station is also contained in the sync channel message so that this fixed delay can be corrected.

The resulting pilot and sync channel 1.2288 Mcps I and Q streams are sampled and digitally lowpass fil-

Quadrature downconversion is necessary to demodulate the complex CDMA signal structure. Prior to digitizing, the I and Q signals are bandpass filtered to match the IS-95 bandwidth of 1.25 MHz.

Frequency Plan

The receiver is designed to operate using a 10 MHz reference oscillator. The signals required for IS-95 demodulation are synthesized from this reference in two stages. Since the clocking frequencies needed for the digital signal processing (DSP) of the IS-95 signal are not obtainable via direct division of the 10 MHz reference frequency, a DSP reference frequency is synthesized using a separate crystal oscillator inside of a phase locked loop (PLL). This DSP reference oscillator frequency is divided as needed in the DSP field programmable gate array (DSPFPGA) to perform the final downconversion and baseband processing. The DSP reference oscillator also provides the reference for the RF PLL synthesizer that generates the 1st local oscillator (LO) signal for the initial quadrature downconversion.

Digital Signal Processing

The DSPFPGA performs the high speed multiply-and-accumulate (MAC) arithmetic for the final conversion to baseband of the digitized I and Q signals. It synthesizes I and Q replica waveforms by modulo-2 additions of the various divisions of the DSP reference frequency and generates the I and Q PN codes via linear feedback shift registers (LFSR). The I and Q PN codes then spread the replica waveforms, which are then multiplied with the received signal and accumulated for some integer number of symbol intervals. These accumulations are then passed to the microcontroller for interpretation.

The high-performance microcontroller receives the raw baseband data from the DSPFPGA and controls the stepping of the phase of the DSPFPGA correlators to implement the pilot channel PN code search. After pilot detection, the early-late correlator powers are used to phase-step the correlator so as to maintain PN code phase lock. While PN code locking, the I and Q correlator sums are used to phase adjust the

PERFORMANCE CHARACTERISTICS

Spread spectrum systems are ideal for high precision

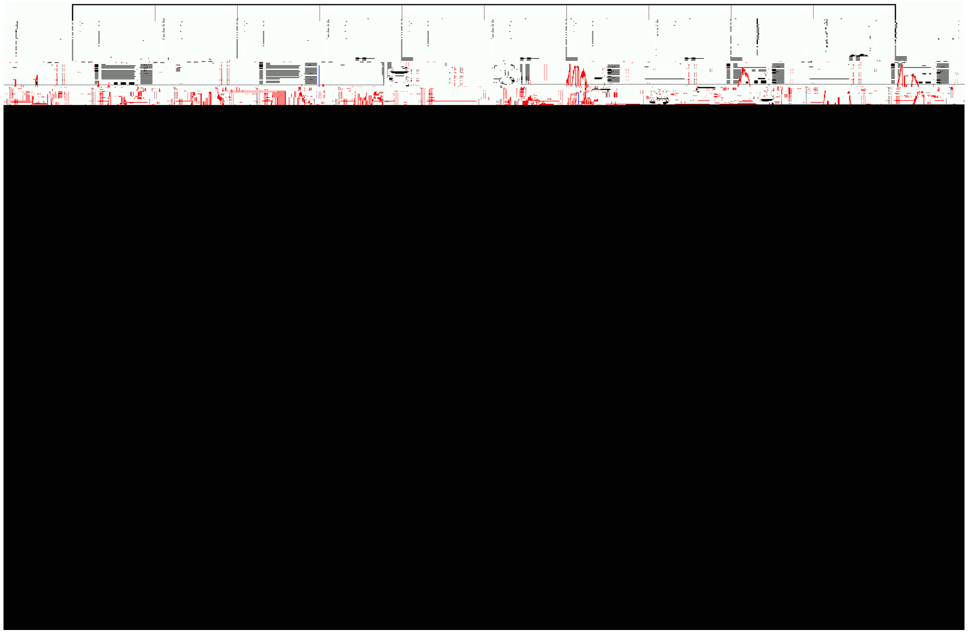

Figure 4 – GPS Disciplined Rubidium Residuals Nov. 14-24, 2001

Figure 5 shows the time interval measurements of the CDMA receiver 1PPS versus the GPS 1PPS plotted with the ambient temperature. Data was collected at 10 second intervals and the plot was smoothed over ten samples. The propagation delay is about 2.5 microseconds. The peak-to-peak phase "wander" of about 600 nanoseconds, not seemingly diurnal in nature, seems to be typical of this base station, the timing sub-system of which is believed to have been supplied by Lucent [5].

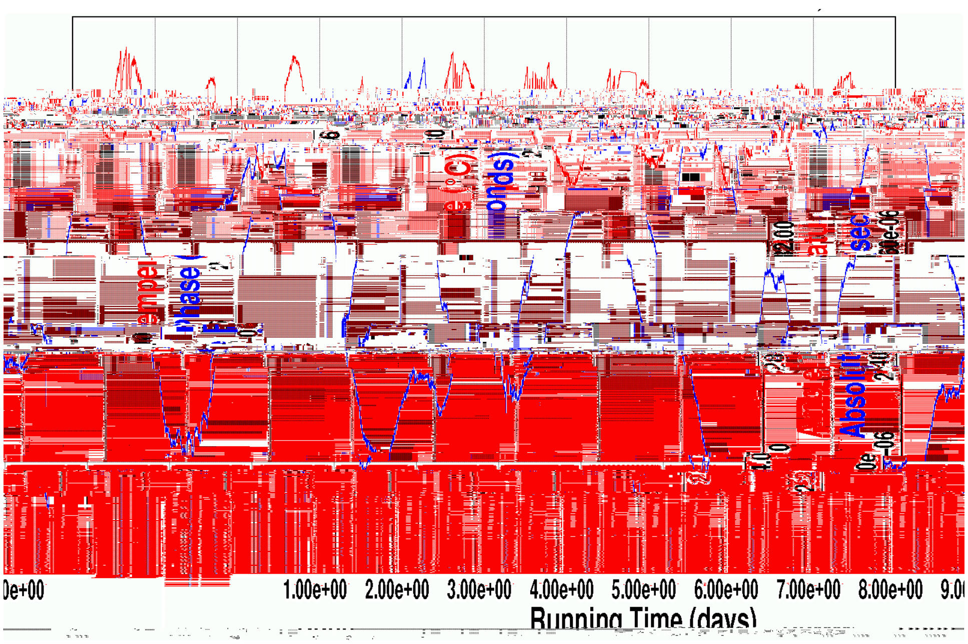

Figure 5 - CDMA 1PPS vs GPS 1PPS Phase Nov. 14-24, 2001

Figure 6 shows the Allan deviation of these time interval measurements, again with 10 sample smoothing applied to the raw time intervals. The short term stability is similar to what would be expected from a conventional direct GPS receiver with an equivalent oscillator. The longer term stability is degraded relative to direct GPS due to the characteristics of this particular base station. It is not known if this wander is typical of all Lucent-supplied GPS timing sub-systems.

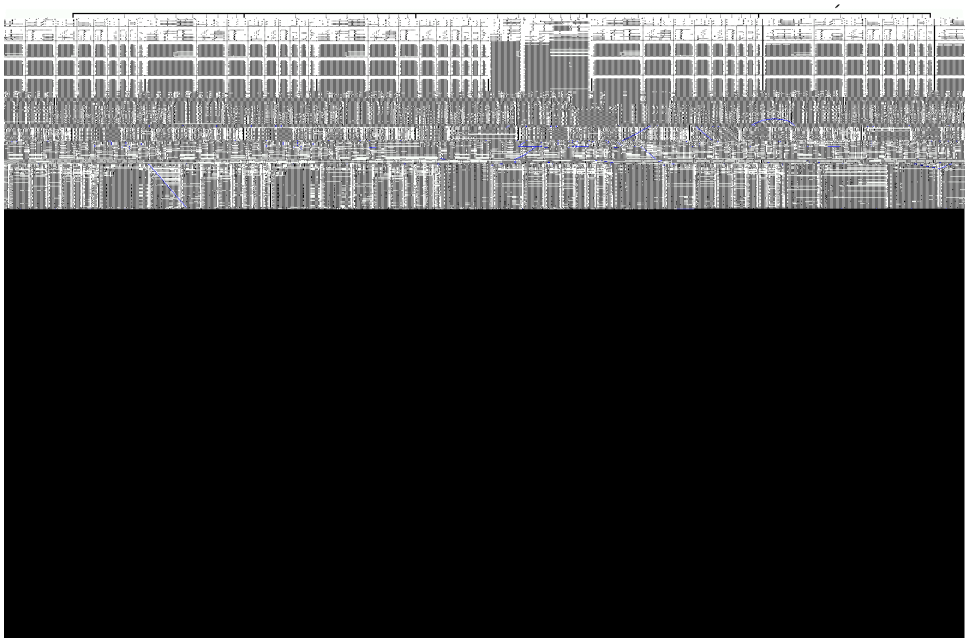

Figure 6 – CDMA 1PPS vs GPS 1PPS Allan Deviation Nov. 14-24, 2001

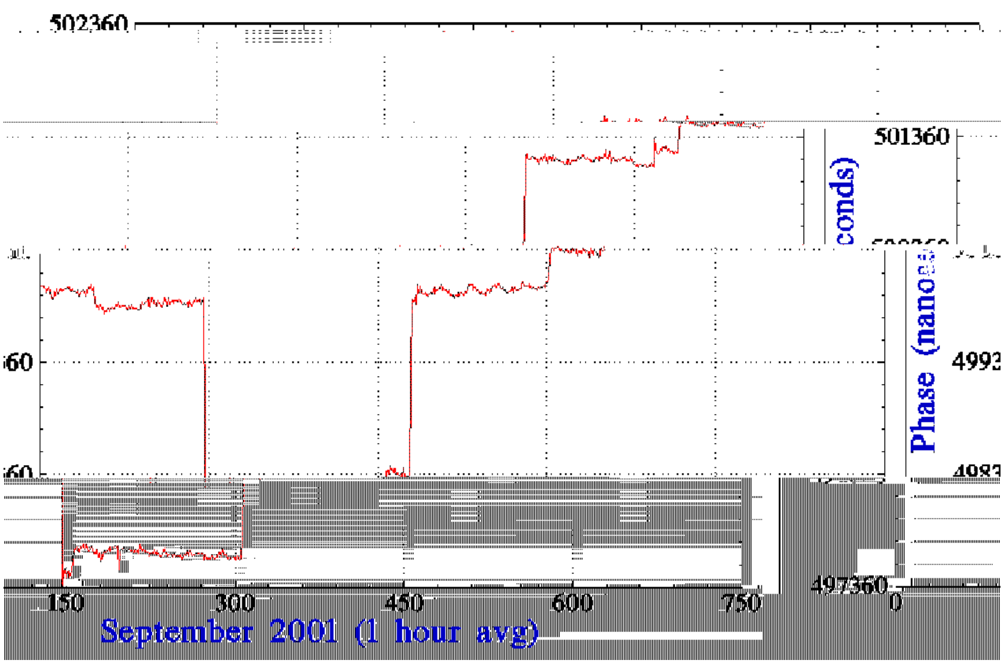

Figure 7 – CDMA Receiver TCXO 10 MHz Phase vs UTC(NIST) September 2001

Figure 7 was provided by Michael Lombardi of the National Institute of Standards and Technology (NIST) in Boulder, CO [6]. It shows data collected over the month of September 2001 on one of these CDMA receivers equipped with the standard temperature compensated crystal oscillator (TCXO). The 10 MHz output was divided down to 1PPS and compared against the UTC (NIST) timescale. As such it provides information only about the frequency accuracy and stability.

Status logging was not performed during the logging period, so the exact cause of the phase steps is not known. They could be either from base station switching or short outages, during which the 10 MHz TCXO frequency would accumulate phase error fairly quickly. Since, the CDMA receiver algorithms currently do not attempt to maintain strict coherence between the phase of the 10 MHz output and the 1PPS output following periods of signal outage, these accumulated phase errors would persist exactly as shown by Figure 7. Phase shifts of the magnitudes shown in Figure 7 would not be seen with higher stability disciplined oscillators.