Asynchronous CDMA

The previous example of orthogonal Walsh sequences describes how 2 users can be multiplexed together in a synchronous system, a technique that is commonly referred to as Code Division Multiplexing (CDM). The set of 4 Walsh sequences shown in the figure will afford up to 4 users, and in general, an NxN Walsh matrix can be used to multiplex N users. Multiplexing requires all of the users to be coordinated so that each transmits their assigned sequence v (or the complement, -v) starting at exactly the same time. Thus, this technique finds use in base-to-mobile links, where all of the transmissions originate from the same transmitter and can be perfectly coordinated.

On the other hand, the mobile-to-base links cannot be precisely coordinated, particularly due to the mobility of the handsets, and require a somewhat different approach. Since it is not mathematically possible to create signature sequences that are orthogonal for arbitrarily random starting points, unique "pseudo-random" or "pseudo-noise" (PN) sequences are used in Asynchronous CDMA systems. A PN code is a binary sequence that appears random but can be reproduced in a deterministic manner by intended receivers. These PN codes are used to encode and decode a users signal in Asynchronous CDMA in the same manner as the orthogonal codes in synchrous CDMA (shown in the example above). These PN sequences are statistically uncorrelated, and the sum of a large number of PN sequences results in Multiple Access Interference (MAI) that is approximated by a Gaussian noise process (following the "central limit theorem" in statistics). If all of the users are received with the same power level, then the variance (e.g., the noise power) of the MAI increases in direct proportion to the number of users. In other words, unlike synchronous CDMA, the signals of other users will appear as noise to the signal of interest and interfere slightly with the desired signal in proportion to number of users.

All forms of CDMA use spread spectrum process gain to allow receivers to partially discriminate against unwanted signals. Signals encoded with the specified PN sequence (code) are received, while signals with different codes (or the same code but a different timing offset) appear as wideband noise reduced by the process gain.

Since each user generates MAI, controlling the signal strength is an important issue with CDMA transmitters. A CDM (Synchronous CDMA), TDMA or FDMA receiver can in theory completely reject arbitrarily strong signals using different codes, time slots or frequency channels due to the orthogonality of these systems. This is not true for Asynchronous CDMA; rejection of unwanted signals is only partial. If any or all of the unwanted signals are much stronger than the desired signal, they will overwhelm it. This leads to a general requirement in any Asynchronous CDMA system to approximately match the various signal power levels as seen at the receiver. In CDMA cellular, the base station uses a fast closed-loop power control scheme to tightly control each mobile's transmit power. See Near-far problem for further information on this problem.

Advantages of Asynchronous CDMA over other techniques

Asynchronous CDMA's main advantage over CDM (Synchronous CDMA), TDMA and FDMA is that it can use the spectrum more efficiently in mobile telephony applications.

(In theory, CDMA, TDMA and FDMA have exactly the same spectral efficiency but practically, each has its own challenges - power control in the case of CDMA, timing in the case of TDMA, and frequency generation/filtering in the case of FDMA.) TDMA systems must carefully synchronize the transmission times of all the users to ensure that they are received in the correct timeslot and do not cause interference. Since this cannot be perfectly controlled in a mobile environment, each timeslot must have a guard-time, which reduces the probability that users will interfere, but decreases the spectral efficiency. Similarly, FDMA systems must use a guard-band between adjacent channels, due to the random doppler shift of the signal spectrum which occurs due to the user's mobility. The guard-bands will reduce the probability that adjacent channels will interfere, but decrease the utilization of the spectrum.

Most importantly, Asynchronous CDMA offers a key advantage in the flexible allocation of resources. There are a fixed number of orthogonal codes, timeslots or frequency bands that can be allocated for CDM, TDMA and FDMA systems, which remain underutilized due to the bursty nature of telephony and packetized data transmissions. There is no strict limit to the number of users that can be supported in an Asynchronous CDMA system, only a practical limit governed by the desired bit error probability, since the SIR (Signal to Interference Ratio) varies inversely with the number of users. In a bursty traffic environment like mobile telephony, the advantage afforded by Asynchronous CDMA is that the performance (bit error rate) is allowed to fluctuate randomly, with an average value determined by the number of users times the percentage of utilization. Suppose there are 2N users that only talk half of the time, then 2N users can be accommodated with the same average bit error probability as N users that talk all of the time. The key difference here is that the bit error probability for N users talking all of the time is constant, whereas it is a random quantity (with the same mean) for 2N users talking half of the time.

In other words, Asynchronous CDMA is ideally suited to a mobile network where large numbers of transmitters each generate a relatively small amount of traffic at irregular intervals. CDM (Synchronous CDMA), TDMA and FDMA systems cannot recover the underutilized resources inherent to bursty traffic due to the fixed number of orthogonal codes, time slots or frequency channels that can be assigned to individual transmitters. For instance, if there are N time slots in a TDMA system and 2N users that talk half of the time, then half of the time there will be more than N users needing to use more than N timeslots. Furthermore, it would require significant overhead to continually allocate and deallocate the orthogonal code, time-slot or frequency channel resources. By comparison, Asynchronous CDMA transmitters simply send when they have something to say, and go off the air when they don't, keeping the same PN signature sequence as long as they are connected to the system.