Cell searching in WCDMA

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a brief overview

In Europe, the digital second generation (2G) systems, IS-136 and the Global System for Mobile communications (GSM), developed were based on time division multiple access (TDMA) and in the US, the IS-95 system developed was based on code division multiple access (CDMA). The 2G technologies developed both in Europe and US suffered from a number of limitations that included: low bit rate for 2G systems and non-interoperability between the standards. The low bit rate for 2G systems could not meet subscriber demands for new and faster non-voice services while on the move. Hence, the third generation (3G) systems were developed with the aim to solve these problems by promising global roaming across 3G standards, as well as support for multimedia applications. These 3G services are based on CDMA.

Spread spectrum CDMA

In a spread spectrum CDMA system, the transmitted signal is spread over a wide frequency band. The band is wider than the minimum bandwidth required to transmit the information being sent.

In a typical scenario, where there are multiple users or mobile stations in a cell, each user has a unique scrambling code. This scrambling code should be such that it has low cross correlation properties with the other user codes. The signal received by the mobile station from the transmitting base station is correlated with the user's scrambling code. This despreads only the signal of that particular user while the other spread spectrum signals remain spread.

A block diagram of a Direct Sequence-Code Division Multiple Access (DS-CDMA) transmitter and receiver is shown in Fig. 1. Spreading consists of multiplying the input data by a scrambling code sequence whose bit rate is much higher than the data bit rate. At the receiving side, the signal is multiplied with the same scrambling code sequence that is exactly synchronized to the received code sequence. The encoding block shown in Fig. 1 is used to add error correcting bits and to perform interleaving in order to protect information bits from channel noise and interference. Interleaving spreads a burst of errors, so that error correction circuits at the receiver have a better chance of correcting the data. The reverse operations are performed in the decoding stage at the receiver to recover the original data. The inverse interleaver is referred to as a "de-interleaver."

The most popular candidates

The most popular candidates for providing 3G services include CDMA2000 and Wideband Code Division Multiple Access (WCDMA). Both these schemes are based on the DS-CDMA. The main difference between WCDMA and CDMA2000 is that WCDMA supports *asynchronous* base stations whereas CDMA2000 relies on synchronized base stations.

Synchronous CDMA systems need an external time reference at all the base stations. For instance, a Global Position Systems (GPS) clock can be used by all the base stations to synchronize their operations. This allows the mobile station to use different phases of the same scrambling code to distinguish between adjacent base stations. Figure 2 illustrates a *synchronous* CDMA system.

In an *asynchronous* CDMA system, each base station has an independent time reference. The mobile station does not have prior knowledge of the relative time difference between various base stations. The advantage of an asynchronous operation is that it eliminates the need to synchronize the base stations to an accurate external timing source.

Cell searching

However, since there is no external time synchronization between the adjacent base stations, different phases of the same code cannot be used to distinguish adjacent base stations. Thus, in an *asynchronous* CDMA system, adjacent base stations can only be identified by distinct scrambling codes. Consequently, cell search takes longer for an a*synchronous* CDMA system compared to a *synchronous* CDMA system. (Cell search involves the process of achieving code, time and frequency synchronization of the mobile station with the base station.) Cell search is also complicated because of interference from the other mobile stations present in a cell. Thus, it is very important to develop algorithms and hardware implementations to perform cell search using lower acquisition time and minimum hardware resources for *asynchronous* CDMA systems.

Cell search is performed when a mobile station is switched on (initial cell search) and during active or idle modes (target cell search). Target cell search is used to find handover candidates during a call.

In target cell search, the mobile station is already camping on a cell when it receives a neighbor cell list from the network. This simplifies the cell search procedure, since the scrambling codes of the other cells are already known. From the camped state, the mobile station needs to decide whether or not a new cell needs to be selected. The possible new cells are ranked according to certain standardized criteria. The mobile station then reselects the cell with the highest ranking. It is important that the new cell is properly selected otherwise it might select a cell with a high path loss. This could result in increased interference.

Soft cell

In WCDMA systems, the handovers are triggered by the mobile station in response to events observed among the cells, which it monitors. The handover to a new cell can be performed using the soft handover algorithm. During soft handover, the mobile set is simultaneously communicating with more than one base station.

Soft handover requires careful planning and the use of advanced algorithms. The soft handover window must be of the optimum size as shown in Figure 3. If the window is too small, then the mobile station, which is nearing the edge of a cell, will not receive support from the neighboring cells in time. If the window is too large, then too many mobile stations will receive support from multiple cells leading to wastage of resources.

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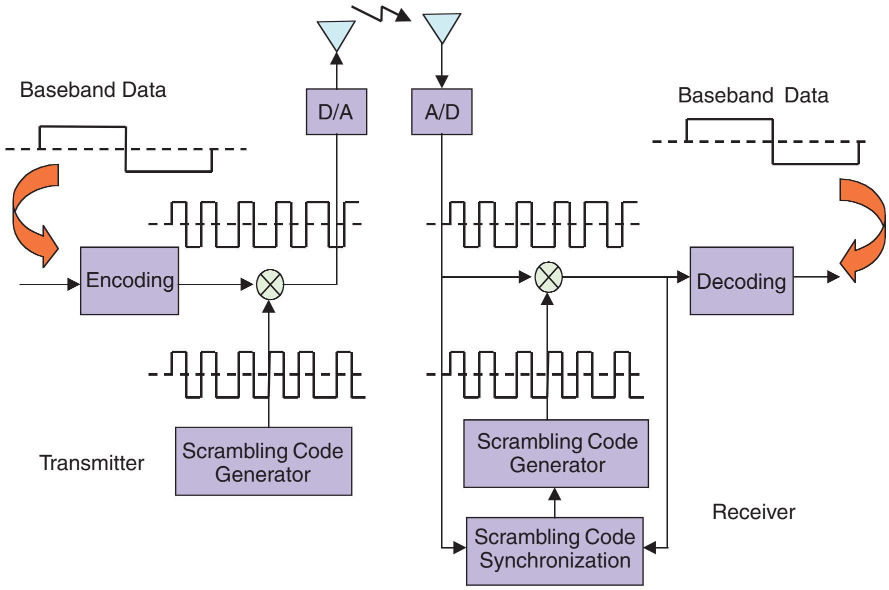

Fig. 1 Block diagram of a DS-CDMA transmitter and receiver

The synchronization

The process of achieving synchronization of the mobile station with the base station is divided into five stages. They are: 1) slot synchronization, 2) frame synchronization and code group identification, 3) scrambling code identification, 4) frequency synchronization, and 5) cell identification.

Each cell in a CDMA system is identified by its downlink scrambling code, which are 38,400 chips long. The 38,400 chips form a radio frame, which is divided into 15 slots. Each slot in the radio frame has 2,560 chips. Figure 4 shows the slot and frame structure of the three synchronization channels used in a cell search for WCDMA: the Primary-Synchronization Channel (P-SCH), Secondary-Synchronization Channel (S-SCH) and the Common Pilot Channel (CPICH). The P-SCH together with the S-SCH is also called the Synchronization Channel (SCH). The synchronization channels are used by the base station for transmitting the synchronization code sequences to the mobile station.

In the P-SCH, a 256 chip sequence is transmitted at the start of each slot. The same P-SCH sequence is used by all the base stations and is transmitted once every slot. As all the transmitting stations use the same sequence, one matched filter is sufficient to detect the slot boundary value.

The S-SCH is used for carrying 15 different sequences, one in each slot, for the different code groups and is repeated after every frame. These sequences are used in identifying the code group.

The CPICH is used to carry the downlink common pilot symbols scrambled by the scrambling code of the base station. Each slot of this channel is divided into 10 symbols; each symbol is 256 chips in length.

To reduce the complexity of the cell search in WCDMA, the scrambling codes are grouped into code groups. The group indicator codes (GIC) are used to identify these code groups. These GICs are transmitted on the S-SCH. After the code group is identified, only the scrambling code used by the cell needs to be detected.

The number of scrambling codes is fixed at 512; however, the number of code groups can be increased from 32 to 256. For example, if 32 code groups are used in stage 2 of the cell search algorithm, then the number of scrambling codes in stage 3 is 16 (32 code groups x 16 codes in each code group = 512 codes). Similarly, if 64 code groups are used, then there will be 8 possible scrambling codes (64 code groups x 8 codes in each code group = 512 codes). The number of possible scrambling codes from which one code needs to be identified depends on how many code groups are selected in stage 2 of the cell search design. Combining frame synchronization and code group identification in stage 2 further reduces complexity of the cell search algorithm.

Cell search algorithm

The last two stages of the cell search algorithm (frequency synchronization and cell identification) only need to be performed during the initial cell search. They are not needed during a target cell search.

To simplify the synchronization process, the initial cell search algorithm assumes a large frequency error to achieve code and time synchronization. After code and time synchronization is determined with sufficient accuracy, the next stage of frequency acquisition is completed. The code and time synchronization process follows the three-stage cell search algorithm described next.

Stage 1: slot synchronization

During stage 1 of the cell search procedure, the mobile station uses the SCHs Primary Synchronization Code (PSC) to acquire slot synchronization to a cell. This is typically done with a single filter matched to the PSC, which is common to all cells. The slot timing of the cell can be obtained by detecting peak values in the matched filter output.

The starting position of the synchronization code may be determined from observations over one slot duration. However, decisions based on observations over a single slot may be unreliable, when the signal-to-noise ratio (SNR) is low or if fading is severe. Reliable slot synchronization is required to minimize cell search time. To increase reliability, observations are made over multiple slots and the results are then combined. This ensures that the correct slot boundary is identified.

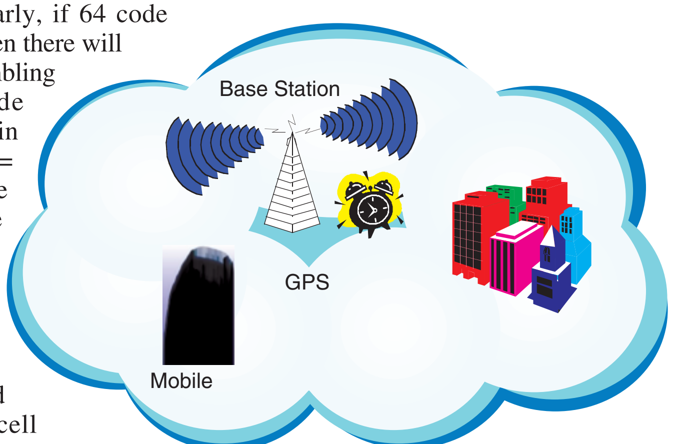

Fig. 2 Synchronous CDMA system

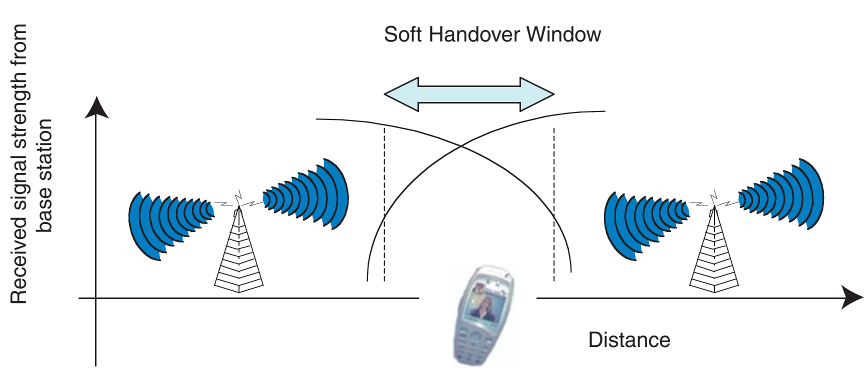

Fig. 3 Soft handover

Stage 2: frame synchronization & code group ID

During stage 2 of the cell search procedure, the mobile station uses the SCHs Secondary Synchronization Code (SSC) to achieve frame synchronization and to identify the code group of the cell found in stage 1. This is done by correlating the received signal with all the possible SSC sequences and identifying the maximum correlation value. Since the cyclic shifts of the sequences are unique, the code group as well as the frame synchronization is determined.

For combining the results of the matched filter operations over the "in-phase" (I-phase) and "quadrature-phase" channel (Q-phase), either non-coherent or coherent detection can be used. In non-coherent systems, no attempt is made to determine the actual phase value of the incoming signal. However in coherent detection schemes, accurate channel estimation is needed to determine the phase of the incoming signal. This is difficult especially in fading environments. Coherent detection can use the Primary Synchronization Code sequences as pilot symbols to derive the channel estimate. The channel estimate is used to correct the phase of the Secondary Synchronization Code sequences before they are combined. It is therefore necessary to correctly determine the Primary Synchronization Code sequences in stage 1 of the cell search algorithm

Stage 3: scrambling code ID

During stage 3 of the cell search, the mobile station determines the exact primary scrambling code used by the cell. The primary scrambling code is typically identified through symbol-by-symbol correlation over the CPICH. It's done using all the codes within the code group identified in stage 2, with a scrambling code generator shown in Fig. 5 and a descrambler. In this stage, a threshold value is used to decide whether the code has been identified.

Frequency acquisition

At the receiver, a local oscillator is used to generate the carrier frequency. There is a frequency offset at the receiver, as it is not possible to generate an accurate carrier frequency. The effects of frequency offset can severely degrade the performance of the system.

During the initial cell search, this frequency error needs to be reduced to a suitable range to correctly decode the cell identity transmitted on the broadcast channel. In a target cell search, it is sufficient to achieve time synchronization and identify the downlink scrambling code. Frequency acquisition need not be performed during a target cell search.

Acronym glossary

2G	Second Generation
3G	Third Generation
AWGN	Additive White Gaussian Noise
CDMA	Code Division Multiple Access
CPICH	Common Pilot Channel
DS-CDMA	Direct Sequence-Code Division Multiple Access
GIC	Group Indicator Code
GPS	Global Positioning System
GSM	Global System for Mobile communications
P-SCH	Primary Synchronization Channel
PSC	Primary Synchronization Code
SCH	Synchronization Channel
SNR	Signal-to-Noise Ratio
SSC	Secondary Synchronization Code
S-SCH	Secondary Synchronization Channel
TDMA	Time Division Multiple Access
WCDMA	Wideband Code Division Multiple Access
NrtVBR	Non-Real Time Variable Bit Rate
FIFO	First-in-First-Out

Fading multipath channel

In an additive white gaussian noise (AWGN) channel, the noise is simply added to the signal vector. Whereas in a multipath channel, multiple copies of the same signal are received after reflecting off of objects such as buildings, trees and towers. These signals arrive with different delays. For example, the signal transmitted on the direct path from the base station to the mobile station is received at time t = t1. The multipath faded signals will then be received at different delay intervals, $t = t1 + \tau_{d1}$, $t = t1 + \tau_{d2}$ and so forth.

A rake receiver is typically used to combine the signals over all the paths to

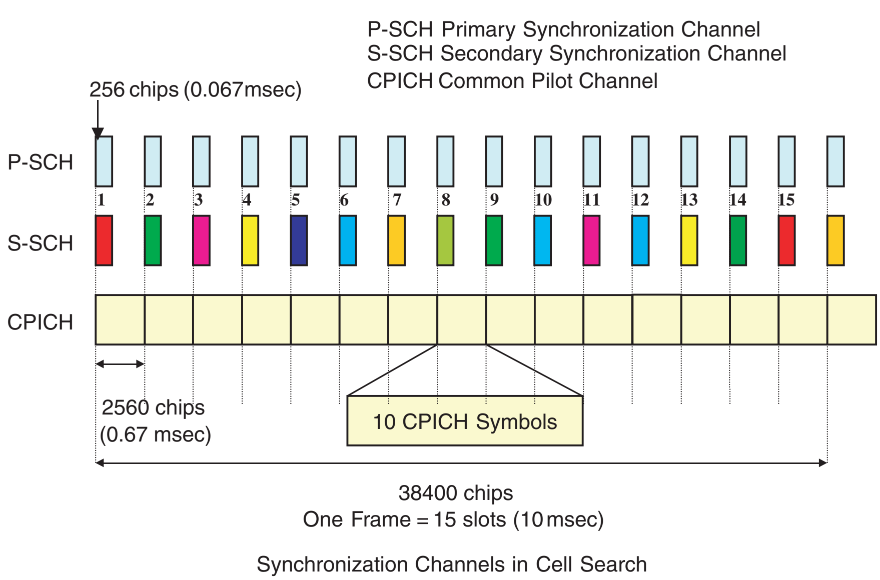

Fig. 4 Synchronization channels in a cell search for WCDMA

produce one signal, which is stronger than the individual components. A rake receiver consists of multiple "fingers" each consisting of a correlator. To combine the signals, the rake receiver needs to correct the phase caused by the fading channel and then combine the received signals from the different paths proportionally to the strength of each path.

Since each path undergoes different attenuations, combining them with different weights yields an optimum solution. Figure 6 shows a rake receiver with four "fingers" for the multipath signals arriving at different delay times. The signals are then combined after scaling them with the attenuation factors.

This technique of combining the signals is called maximum ratio combining. As the mobile station moves, the delay and the attenuation factors will keep on changing. It is important to track these changes, which is performed by correctly estimating the channel.

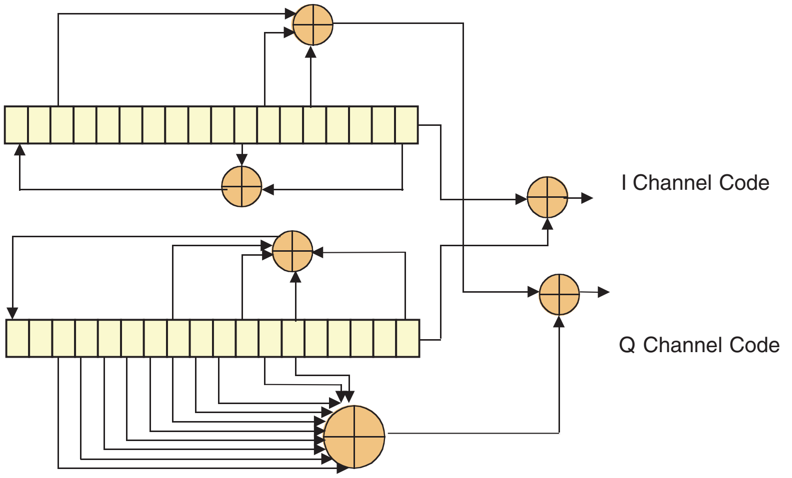

Fig. 5 Scrambling code generator

Conclusion

Cell search design is an important research area since it impacts the mobile system performance. This is because it needs to be performed whenever a mobile station is switched on or when a call moves from one cell to the other.

Efficient hardware designs to perform cell searches faster need to be studied especially for fading environments. The reduced cell search time will minimize the number of calls getting dropped during the synchronization process and also lower the power consumption. With future 3G applications, such as streaming video, music, web browsing, the pressure will be even greater to complete the cell search quickly using minimum hardware resources.

Read more about it

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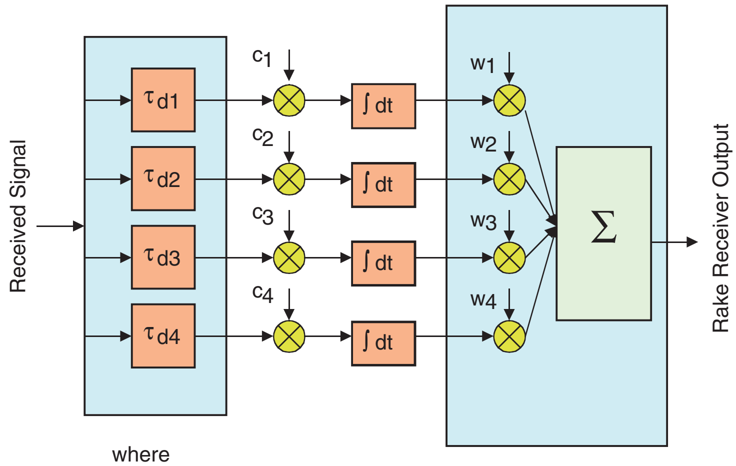
Sanat Kamal Bahl (a Student member of IEEE and ACM) has completed his Masters degree in Computer Science from University of Maryland, Baltimore County. He obtained his Bachelors degree in Electronics Engineering from VJTI, University of Bombay, India. His current research interests are in the area of VLSI design for wireless applications, software defined radio, reconfigurable systems and synchronization techniques for WCDMA. Details of his research are available on his web page: http://www.gl.umbcc.edu/~skamal2



where
$\tau_{d1}, \tau_{d2}, \tau_{d3}, \tau_{d4}$ are the delays for the multipath signals
c_1, c_2, c_3, c_4 are the scrambling codes
w_1, w_2, w_3, w_4 are the attenuation factors

Fig. 6 Block diagram of a rake receiver