CODE-DIVISION-DUPLEXING

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Abstract:

Reducing interference in a cellular system is the most effective approach to increasing radio capacity and transmission data rate in the wireless environment. Therefore, reducing interference is a difficult and important challenge in wireless communications.

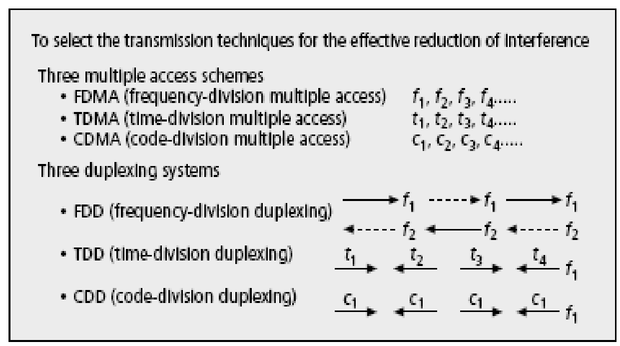
In every two-way communication system it is necessary to use separate channels to transmit information in each direction. This is called duplexing. Currently there exist only two duplexing technologies in wireless communications, Frequency division duplexing (FDD) and time division duplexing (TDD). FDD has been the primary technology used in the first three generations of mobile wireless because of its ability to isolate interference. TDD is seemingly a more spectral efficient technology but has found limited use because of interference and coverage problems.

Code-division duplexing (CDD) is an innovative solution that can eliminate all kinds of interference. CDMA is the best multiple access scheme when compared to all others for combating interference. However, the codes in CDMA can be more than one type of code. A set of smart codes can make a high-capacity CDMA system very effective without adding other technologies. The smart code plus TDD is called CDD.

This paper will elaborate on a set of smart codes that will make an efficient CDD system a reality. The CDMA system based on this is known as the LAS-CDMA, where LAS is a set of smart codes. LAS-CDMA is a new coding technology that will increase the capacity and spectral efficiency of mobile networks. The advanced technology uses a set of smart codes to restrict interference, a property that adversely affects the efficiency of CDMA networks.

INTRODUCTION:

To utilize spectrum efficiently, two transmission techniques need to be considered: one is a multiple access scheme and the other a duplexing system. There are three multiple access schemes namely TDMA, FDMA and CDMA. The industry has already established the best multiple access scheme, code-division multiple access (CDMA), for 3G systems. The next step is to select the best duplexing system. Duplexing systems are used for two-way communications. Presently, there are only two duplexing systems used: frequency-division duplexing (FDD), and time-division duplexing (TDD). The former uses different frequencies to handle incoming and outgoing signals. The latter uses a single frequency but different time slots to handle incoming and outgoing signals.



■ Figure 1. *The selection of transmission techniques for wireless communications systems.*

In the current cellular duplexing systems, FDD has been the appropriate choice, not TDD. Currently, all cellular systems use frequency-division duplexing in an attempt to eliminate interference from adjacent cells. The use of many technologies has limited the effects of interference but still certain types of interference remain. Time-division duplexing has not been used for mobile cellular systems because it is even more susceptible to different forms of interference. TDD can only be used for small confined area systems.

Code-division duplexing is an innovative solution that can eliminate all kinds of interference. Eliminating all types of interference makes CDD the most spectrum efficient duplexing system.

CDMA OVERVIEW:

➢ Interference and Capacity

One of the key criteria in evaluating a communication system is its spectral efficiency, or the system capacity, for a given system bandwidth, or sometimes, the total data rate supported by the system. For a given bandwidth, the system capacity for narrow band radio systems is dimension limited, while the system capacity of a traditional CDMA system is interference limited. Traditional CDMA systems are all self-interference system.

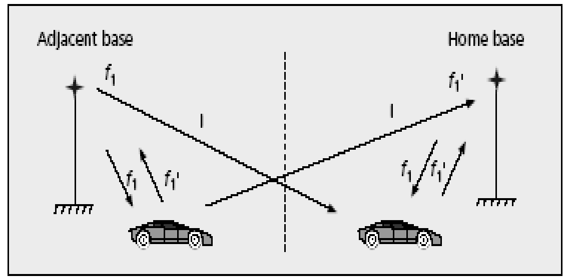
Three types of interference are usually considered. By ISI we mean InterSymbol Interference, which is created by the multi-path replica of the useful signal itself; MAI, or Mutual Access Interference, which is the interference created by the signals and their multi-path replica from the other users onto the useful signal; and ACI, or Adjacent Cell Interference, which is all the interfering signals from the adjacent cells onto the useful signal.

Traditional synchronous CDMA systems employ almost exclusively Walsh-Hadamard orthogonal codes, jointly with PN sequence, and Gold codes, Kasami codes, etc. In these systems, due to the difficulty in timing synchronization and the large cross-correlation values around the origin, there exists a "near far" effect, such that in some typical system, fast power control has to be employed in order to keep an uniform received signal level at the base station. On the other hand, in forward channel all the signals' power must be kept at an uniform level. Since the transmitting power of a user would interfere others and even may interfere itself, if one of the users in the system increases its power unilaterally, all other users power should be simultaneously increased; otherwise the controlled system power regime will be destroyed, and the capacity would be drastically decreased. This is because any radio channel, especially mobile channel, is a random time-varying time dispersion channel due to the multi-path effect, so that the received signal can not be reached at the receiver simultaneously.

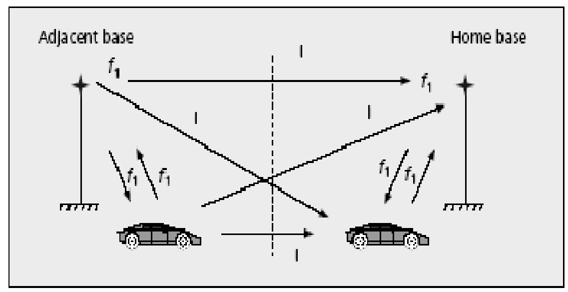
In traditional CDMA, the auto-correlation functions as well as the cross-correlation functions are all not ideal, so that the signals at different arrival time can not be separated properly at the receiver. It is just such effect that makes the traditional CDMA a self-interference system. It would be practically impossible to enhance the traditional CDMA's robustness in terms of interference resistance by increasing the user's power when the network traffic load is high.

➢ Why Reduce Interference In A Cellular System

Reducing interference in a cellular system is the most effective approach to increasing radio capacity and/or transmission data rate in the wireless environment. Therefore, reducing interference is a difficult and important challenge in wireless communications. The interference in an FDD system using a CDMA scheme is shown in Fig. 2. Looking at Fig. 3, we realize that a TDD system is very undesirable to use in a large-area cellular system.

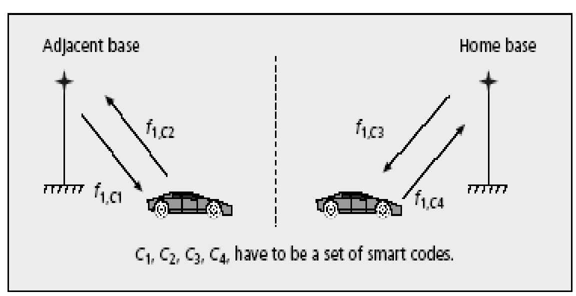


■ **Figure 2.** *Using a CDMA scheme in FDD.*



■ **Figure 3.** *Using a CDMA scheme in TDD.*

Although FDD is the right choice for cellular systems, the interference is still very high. Today many enhanced technologies have been added together to reduce interference in FDD systems, but none of these technologies can be used solely and effectively. The Large Area Synchronous (LAS) Codes are a set of smart codes that can reduce interference very effectively. The effectiveness of smart codes applied to TDD makes it the right choice in cellular systems. The application of LAS Codes in a TDD system (called TD-LAS system) creates a CDD system.



■ **Figure 4.** *Using a CDMA scheme in CDD.*

LAS-CDMA (Large Area Code Division Multiple Access) employs a novel multiple access scheme, which is different from all the known traditional CDMA. The auto-correlation functions of all LAS-CDMA codes are ideal, and there exists an IFW (Interference Free Window), or a "zero correlation zone" (ZCZ) in their cross-correlation functions of its access codes around the origin. Due to the existence of IFW or ZCZ, a LAS-CDMA system can have a much higher system capacity and spectral efficiency than that of a traditional CDMA.

A SET OF SMART CODES:

The code used in today's CDMA scheme is the Walsh code, which is not too smart. Walsh codes have the orthogonality property among codes while the time shift t = 0 (i.e., no time shift *t* or time delay spread). However, in the mobile radio environment the signal arrival can have a long time shift. The property of Walsh codes cannot properly be applied to this environment. Now there is a set of smart codes that have orthogonality among the codes for time shift $t \neq 0$. The codes arrive at the terminals at different time shifts; because of the orthogonal nature, all undesired codes are blocked. Thus, smart codes are the proper codes to handle this situation. Therefore, in the future we can use different kinds of codes for CDMA schemes, which we will name a type of CDMA with a specified code (e.g., CDMA/Code A and CDMA/Code B). The properties of smart codes have to meet the following requirements:

- Auto-correlation

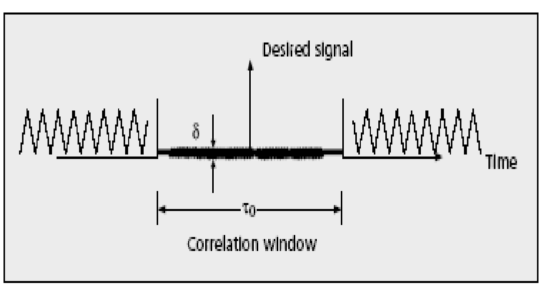
$R_{xx}(\tau) = 0$ for $\tau = 0$

δ for $\tau \neq 0$, within window τ_0

- Cross-correlation

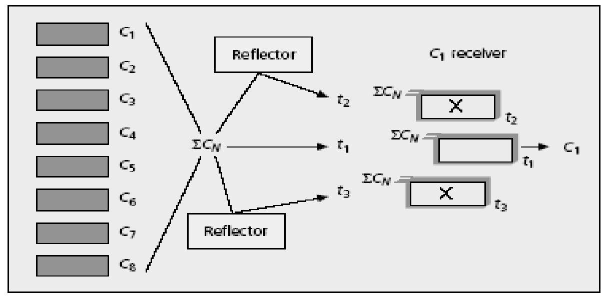
$R_{xy}(\tau) = \delta$ for all τ, within window τ_0

Where τ_0 is a correlation window, δ can be zero or low correlation value. Outside the correlation window is beyond the time delay spread range of the received signal. Although the correlation value outside the range is high, there is no impact on our desired signal, as shown in Fig. 5.



■ Figure 5. *The properties of smart codes.*

With this property, we can illustrate the merit of using this smart code. Assume that eight smart codes are transmitted, as shown in Fig. 6. They arrive at the receiver of Code *C*1 at different times due to the multipath caused by different reflectors. Because of the cross-correlation property, the desired code to be received is *C*1. However, many *C*1 codes can be received due to the effects of the multipath. This does not occur though; due to the auto-correlation property, only Code *C*1 at time *t*1 is received, as shown in Fig. 6. We do not need the strength of more than one path signal to be added for increasing carrier-to-interference ratio (C/I) since we are only receiving carrier-to-noise ratio (C/N), not C/I. The rest of the signals from different paths do not cause any interference, and there is no need to use any means to collect them for the purpose of reducing interference. Hence, with this smart code property we can effectively eliminate interference, and we do not need other technologies.



■ Figure 6. *The merit of smart codes received at the terminal.*

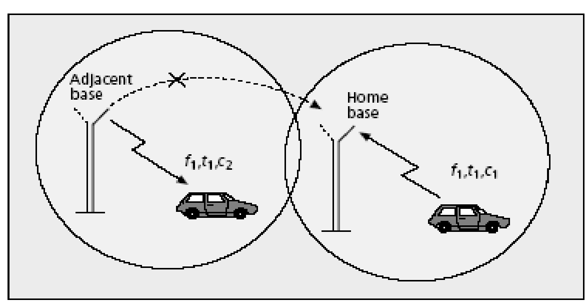
USING SMART CODE SEQUENCES TO REDUCE INTERFERENCE:

Smart code sequences have two properties:

- Auto-correlation equals zero, which causes no multipath interference.

- Cross-correlation equals zero, which causes no multi-user interference.

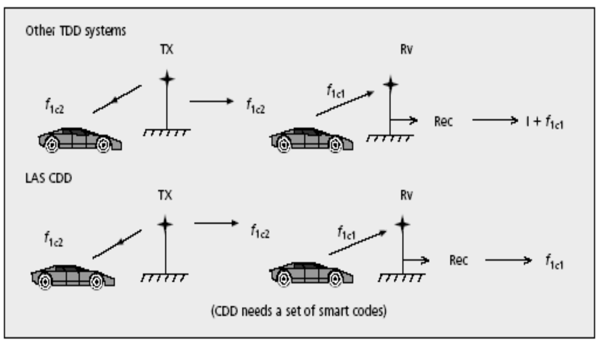
Smart code sequences will effectively work in TDD scenarios and become a CDD system, as shown in Fig. 7. The two different smart codes can isolate interference at the same frequency and in the same time frame. The capabilities of smart codes eliminate the known near-far effect in mobile communication systems. The inherent properties of smart codes eliminate the need for the following technologies: rake receiver, power control, joint detection, smart antenna, and soft handoff.



■ Figure 7. *Smart codes reduce interference in a CDD system.*

ADDITIONAL ADVANTAGES OF USING CDD:

Any single (unpaired) spectrum band with a bandwidth equal to 1.6 MHz can be used for the CDD application. The system is simple. The handset is also simple. Since no duplexer is needed, the handset cost can be lower and the size of the handset smaller. Power consumption is lower due to only one single spectrum band being operable. CDD is like TDD, the ideal system for asymmetrical traffic. CDD has the highest spectrum efficiency and can be used in the new third-generation (3G) systems. The differences in TDD and CDD for cellular systems can be shown in Fig. 8. In other TDD systems the codes are not smart, so the receiver not only receives its desired code, but also receives interference (I) from other cells. Sometimes, the interference is so high it can mask the desired signal. In the LAS CDD system, because of the smart codes, the receiver only receives the desired code, no interference.



■ **Figure 8.** *Differences in TDD and CDD for large area systems.*

LAS-CDMA:

The LAS- CDMA utilizes the LAS codes which are a set of smart codes. The spreading sequences exhibit zero correlation values, when the relative delay-induced code offset is in the so-called Zero Correlation Zone (ZCZ) or Interference Free Window (IFW) of the spreading code. The attractive family of Large Area Synchronized (LAS) CDMA spreading sequences is constituted by the combination of the so-called Large Area (LA) codes and Loosely Synchronous (LS) codes. The resultant LAS codes exhibit an IFW, where the off-peak aperiodic autocorrelation values as well as the aperiodic cross-correlation values become zero, resulting in zero ISI and zero MAI, provided that the time-offset of the codes is within the IFW. In order to ensure that the relative time-offsets between the codes are within the IFW, the mobiles are expected to operate in a quasi-synchronous manner. More specifically, interference-free CDMA communications become possible, when the total time-offset expressed in terms of the number of chip intervals, which is the sum of the time-offset of the mobiles plus the maximum channel-induced delay spread is within the designed IFW. In case of high transmission-delay differences accurate timing-advance control has to be used, as it was also advocated in the GSM system. Provided that these conditions are satisfied, a major benefit of the LAS codes is that they are capable of achieving a near-single-user performance without multi-user detectors.

The disadvantage of LAS codes is that the number of codes having an IFW is limited. For example, when we consider a spreading factor of 151, we only have 32 LAS codes exhibiting an IFW of width $3T_c$, where T_c is the chip duration. Furthermore, the auto-correlation and cross-correlation function of LAS codes typically exhibits a higher value outside the IFW than traditional random codes. More explicitly, when the LASCDMA system operates in an asynchronous manner, such as for example the third-generation W-CDMA system, it will encounter more serious MAI and Multipath Interference (MPI) than traditional DS-CDMA.

ACCESS CODES IN TRADITIONAL CDMA AND LAS-CDMA:

Fig.9 shows a typical example of the auto-correlation function and cross-correlation function employed in traditional CDMA systems. According to Welch bound, firstly, it is well known that the side-lobes of the correlation functions, including both the auto-correlation and the cross-correlation functions, cannot be zero everywhere. Secondly, to keep low side-lobes of auto-correlations functions and those of the cross-correlation functions are contradicted with each other. In practical system designs for traditional CDMA systems, trade-off has to be made; people usually accept that the side-lobes of auto-correlation functions and the cross-correlation functions are set around $G^{-1/2}$, with G the processing gain of the system, following Welch bound. This implies that the interference created mutually by users can not be totally eliminated, and that the traditional CDMA systems are interference-limited.

LAS-CDMA introduces a novel multiple access scheme, based on two families of CDMA codes, LA codes and LS codes. LA codes are a family of pulse train with carefully designed pulse intervals. LA codes are mainly used to reduce the ACI (Adjacent Cell Interference). The pulses of LA code are formed by passing through a LS code to its matched filter at the required pulse positions. LS codes are used for spreading. The family of LS codes has interesting correlation properties. An example is shown in Fig.10a, where the auto-correlation is perfect, while some of the cross-correlation functions are also perfect, most of its cross-correlations only have a few pairs of side-lobe (Fig.10b). There are some regions where no cross-correlation side-lobes exist. We define the one around the origin the "Zero Correlation Zone" (ZCZ) or "Interference Free Window" (IFW). For a synchronized LAS-CDMA system, if the time dispersion (multi-path spread) of the channel is within such IFW, there is practically neither inter-symbol interferences nor multiple access interferences.

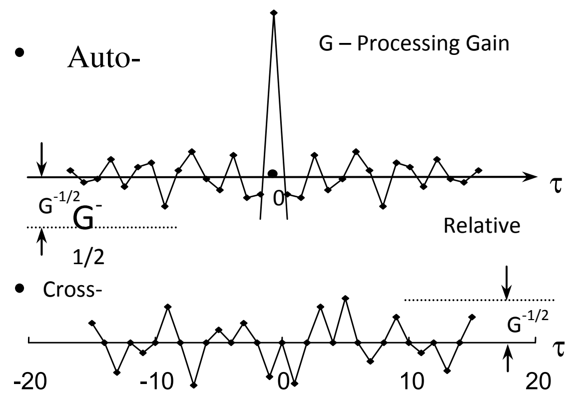


Fig.9 Multiple Access Codes Correlations of Traditional CDMA

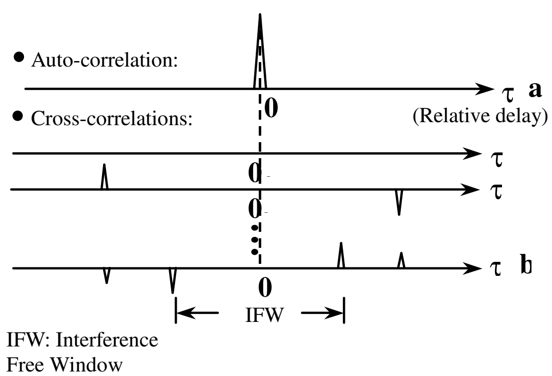


Fig.10 Multiple Access Codes Correlations of LAS-CDMA

GENERATION OF LAS-CODES:

➢ LA Codes

LA codes belong to a family of ternary codes having elements of ±1 or 0. Their maximum correlation magnitude is unity and they also exhibit an IFW. Let us denote the family of the K number of orthogonal ternary codes employing K number of binary ±1 pulses by LA(L_A;M;K), which exhibit a minimum spacing of M chip durations between non-zero pulses, while having a total code length of L_A chips, as shown in Figure 11.

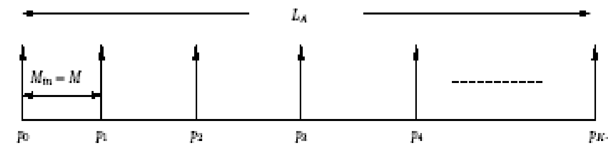


Fig 11: Stylized pulse-positions in the LA(L_A;M;K) code having K number of binary ±1 pulses, and exhibiting a minimum spacing of M chip durations between non-zero pulses, while having a total code length of LA chips.

All the codes corresponding to an LA code family share the same legitimate pulse positions. However, a specific drawback of this family of sequences is their relatively low duty ratio, quantifying the density of the non-zero pulses, since this limits the number of codes available and hence the number of users supported. In the LAS-CDMA 2000 system, the LA codes used constitute a modified version of the LA(L_A;M;K)=LA(2552, 136, 17) code, where the K = 17 non-zero pulse positions, pk, k = 0,…,16, are given by:

{p_k}= {0; 136; 274; 414; 556; 700; 846; 994; 1144;1296; 1450; 1606; 1764; 1924; 2086; 2250; 2416}

Again, observe in this code construction that the pulse positions are not exactly equidistant. For example, the distance between the second, third and fourth pulses is 274-138=138 and 414-174=140, respectively, which is larger than M = 136, since M is the minimum spacing.

➢ Loosely Synchronized (LS) Codes

Apart from the LA codes , there exists another specific family of spreading codes, which also exhibits an IFW. Specifically, Loosely Synchronized (LS) codes exploit the properties of the so-called orthogonal complementary sets . To expound further, let us introduce the notation of LS(N; P;W_0) for denoting the family of LS codes generated by applying a (P * P)-dimensional Walsh-Hadamard (WH) matrix to an orthogonal complementary code set of length N, as it is exemplified in the context of Figure 12. More specifically, we generate a complementary code pair inserting W_0 number of zeros both in the center and at the beginning of the complementary pair, as shown in Figure 12(a). As mentioned above, the polarity of the codes c_0 and s_0 seen in Figure12(b) during the constitution of the LS codes is determined by the polarity of the components of a Walsh-Hadamard matrix, namely by (1; 1; 1; 1) and (1;-1; 1;-1).

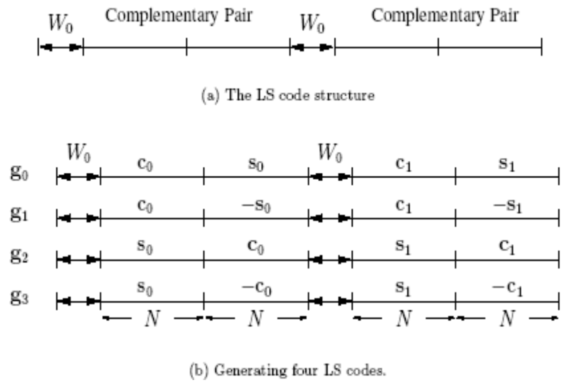


Fig 12: Generating the LS(N; P;W_0) code using the (P * P) = (4* 4)

Walsh-Hadamard matrix components (1; 1; 1; 1) and (1;-1; 1;-1).

The first set of four LS codes can be generated using the first two rows of a (P * P) = (4 * 4)-dimensional Walsh-Hadamard matrix, namely using w_0 = (+1; +1; +1; +1) and w_1 = (+1;_1; +1;_1), as shown in Figure 12(b). Another set of four LS codes can be obtained by exchanging the subscripts 0 and 1. Finally, eight additional LS codes can be generated by applying the same principle, but with the aid of the last two rows of the (4 * 4)- dimensional Walsh-Hadamard matrix, namely using w_2 =(+1; +1;-1;-1) and w_3 = (+1;-1;-1; +1). Hence, the total number of available codes in the family of LS(N, P, W_0) is given by 4P.

Thus the family of LS(N; P;W_0) codes can be constructed for almost any arbitrary code-length related parameter N by employing binary sequences. Having discussed the construction of LA and LS codes, let us now consider how LS codes are implanted at the non-zero pulse-positions of the LA codes for the sake of generating LAS codes.

- **Seeding LS Codes in LA Codes to Generate LAS codes**

The main problems associated with applying LA codes in practical CDMA systems are related to their low duty ratio and to the resultant small number of available codes. A specific family of LAS codes mitigates this problem by combining the LA codes and the LS codes. More specifically, LS codes are inserted between the non-zero pulses of the LA code sequence, in an effort to generate an increased number of spreading codes having an increased duty ratio, while maintaining attractive correlation properties. For example, in the LAS-2000 system, the LS spreading codes are inserted into the LA code's zero space, as shown in Figure 13.

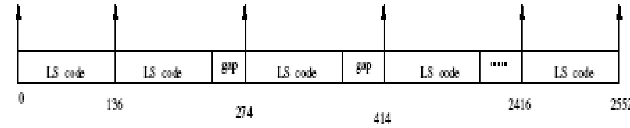


Fig 13: LAS(L_A;M;K;N;P;W_0)=LAS(2552,136,17;4,32,4) spreading, inserting the LS codes of Figure 12 into the zero-space of the LA codes of Figure 11. The gap seen in the figure indicates that the M = 136-chip LS code does not always fill the spacing between the consecutive pulse of the constituent LA code.

Let us denote the combined code generated from the LA(L_A;M;K) and LS(N;P;W_0) codes as LAS(L_A;M;K;N; P;W0), which is generated by employing the so-called absolute encoding method. For the sake of preserving the original IFW size of the constituent LS(N;P;W_0) code when combined with an LA(L_A;M;K) code employing the absolute encoding scheme, the length of the LS code, including W_0 number of trailing zeros, should not exceed the minimum pulse spacing M of the LA code.

PERSPECTIVES OF LAS-CDMA FOR THE 4G WIRELESS SYSTEMS:

Due to the existence of IFW, LAS-CDMA may have a much smaller interference level than traditional CDMA. Consequently, LAS-CDMA system may have a much higher capacity as well as a higher spectral efficiency than a traditional CDMA.

According to the basic multi-user information theory, the optimum way to share (not to distribute) a channel capacity is the "Waveform Division" Multiple Access or CDMA technology. However, since traditional CDMA is a self-interference limited, that would drastically limit its capacity, in studying 4G systems, many people focus their attention on OFDM/OFDMA technology, space-time coding for MIMO channels, smart antennas, etc., rather than the "Waveform Division" Multiple Access technologies. In this paper, we address this topic in a preliminary way, just providing some views on the potentiality of LAS-CDMA to be applied to a high spectral efficiency system for a 4G system.

The criteria of the assessments cover mainly radio transmission performance over multi-path fading channel with time variant scenarios, which represents the most frequently encountered situations in mobile systems. The emphasis is put on LAS-CDMA capability of resisting multi-path fading thanks to the special properties of the LAS CDMA codes, i.e., LA codes and LS codes for radio transmission and access schemes over mobile transmission channels. It is interesting, although preliminarily, to do a simple comparative study on the main access schemes of OFDM/OFDMA and LAS-CDMA.

In principle, OFDM overcomes multi-path by using cyclic-prefix, added to each OFDM symbol, which insures the orthogonality between the main path component and the multi-path components, provided that the length of the cyclic-prefix is larger than the maximum multi-path delay. In a LAS-CDMA system, the same multi-path interference immunity is achieved by introducing some time gaps between the spread symbols using LS codes. If the maximum delay of the multi-path is within the length of the time gap, the multi-path components will all fall in the IFW or ZCZ, either vanishing totally, if only the main path component is processed by the receiver, or more advantageously all the multi-path components are combined with the main one by an orthogonal multi-path combination receiver. Similarly but differently to a Rake receiver, the second approach will drastically improve the performance by exploiting the multi-path diversity. As far as the interference suppression capability is concerned in a general way, it is well known that CDMA presents some obvious advantages. In fact, narrow band interference will be suppressed by a factor equal to the processing gain. This means that the more the available bandwidth that the signal can occupy, the better the capability of the resistance of interference for the system. This property is not shared by the systems based on OFDM waveforms. If in 4G systems, bandwidth will be larger, LAS-CDMA alternatives for access schemes would remain a very promising candidate for the future. Finally, OFDM scheme was not proposed for multiple accesses by its nature. Recently OFDMA has been developed for the systems to have the multiple access capability. However, OFDMA is essentially a special case of FDMA system, so it will share all the properties with FDMA, both the advantages and the shortcomings. The key to a proper system operation is how to keep the orthogonality between sub-carriers of OFDM/OFDMA signals. With a mobile and fading background, much would remain to be studied for OFDM/OFDMA to be a robust solution of radio transmission.

Although it is not the right time at present to do an in-depth comparative study on LAS-CDMA and OFDM/OFDMA, the motivation of proposing LAS-CDMA to 4G-system study is strong.

A WIRELESS IP NETWORK SOLUTION:

A CDD system is ideal for Internet communications, which makes a total wireless IP network solution highly desirable. The iBTS connects to the IP core network, as shown in Fig. 14. The function of the switch is broken down into two: mobility management and call processing. The handoff function is carried by the selective distribution unit (SDU). The separated functions are placed on the gateways to the core network. The demo of carrying voice over IP from mobile to mobile and mobile to landline was successful. This event was a historical milestone. The CDD system's future IP core network will follow this approach. The cost will be lower, and add-on features can be very flexible and easy.

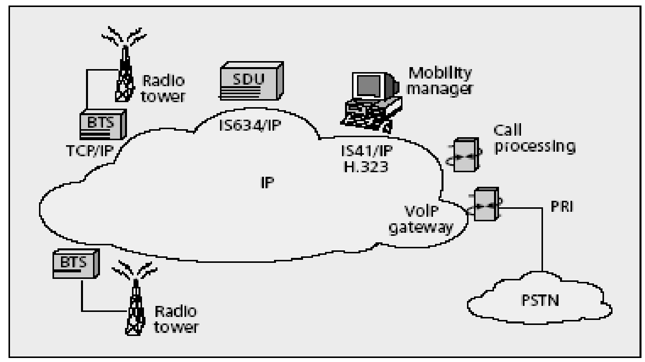


Fig 14 - The top level architecture of a wireless IP core network.

CDD-A NEW MILESTONE :

- **Cdd Technology Is A New Milestone From Fdd Systems To Cdd Systems**

Cellular technology before 1989 utilized frequency reuse in FDMA and TDMA networks. After 1989, CDMA was a breakthrough technology for maintaining the same frequency being used in all the cells. Until today, all three multiple access schemes (FDMA, TDMA, and CDMA) use FDD systems.

The LAS smart codes are the next breakthrough technology. Applying LAS technology to a TDD system becomes a CDD system. The benefit of using a TDD system for communications is that the sending and receiving are alternating in time at a single frequency. Without the sending and receiving occurring at the same time we can use the same smart code for both sending and receiving; thus, LAS + TDD = CDD. CDD is no more like TDD and is a better system for cellular.

- **Reduce Interference-Limited Environment To Noise-Limited Environment**

Before 1989, cellular systems were using multiple cells with multiple frequencies assigned in each cell. These systems generate an interference-limited environment. After 1989, multiple cells used the same frequency. Although the capacity increased using CDMA, the system is still in an interference-limited environment. Now, the CDD system is developed. This system changes the environment from an interference-limited one to a noise-limited one.

CONCLUSION:

We are convinced that CDMA is the best multiple access scheme when compared to all others for combating interference. However, the codes in CDMA can be more than one type of code. A set of smart codes can make a high-capacity CDMA system very effective without adding other technologies. The smart code plus TDD is called CDD, which is a new 3G technology. A CDD system is simpler in design and lower cost. CDD is an ideal system for a total IP network solution: new 3G technology + IP core network. Hopefully, a CDD system will be the system of choice for future 3G networks.

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