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Introduction to TD-SCDMA on the MRC6011 RCF Device

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This application note presents an introduction to the Time Division-Synchronous Code Division Multiple Access (TD-SCDMA) standard and shows how Freescale's first reconfigurable compute fabric (RCF) processor, the MRC6011 device, is ideally suited to perform the complex and computationally intensive tasks associated with TD-SCDMA baseband processing. The discussion focuses on the baseband processing portion of this emerging standard and describes the unique technologies used to implement a TD-SCDMA receiver and transmitter.

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1 The TD-SCDMA Standard

Wireless systems employ a duplexing technique in either the time domain or the frequency domain to allow users to send and receive information (see **Figure 1**):

- *Frequency Division Duplexing (FDD)*. Provides two distinct frequency bands to be used in the system, one for uplink and the other for downlink traffic (see **Figure 2**).
- *Time Division Duplexing (TDD)*. Uses a single frequency band for uplink and downlink, but the uplink and downlink traffic occurs at predetermined time slots (see **Figure 3**).

Thus, given a system with bandwidth W, FDD would use W/2 for uplink and W/2 for downlink, allowing both links to transmit simultaneously. A TDD system would use the same bandwidth W for uplink and downlink, but they would not transmit at the same time.

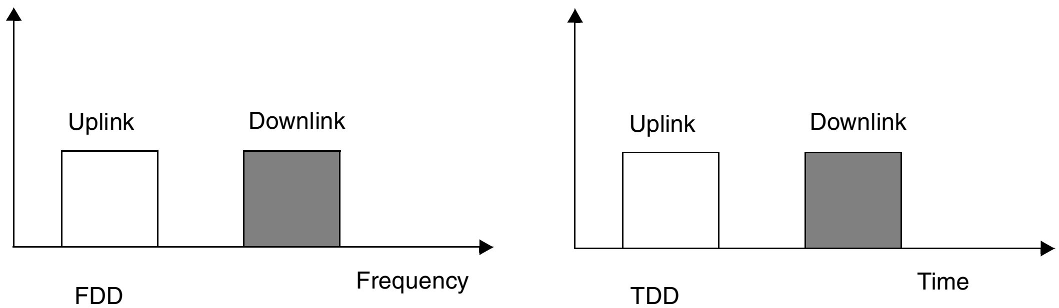

Figure 1. FDD and TDD Compared

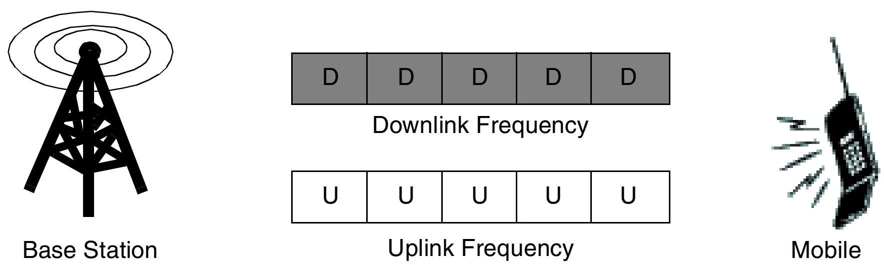

Figure 2. FDD Mode of Operation

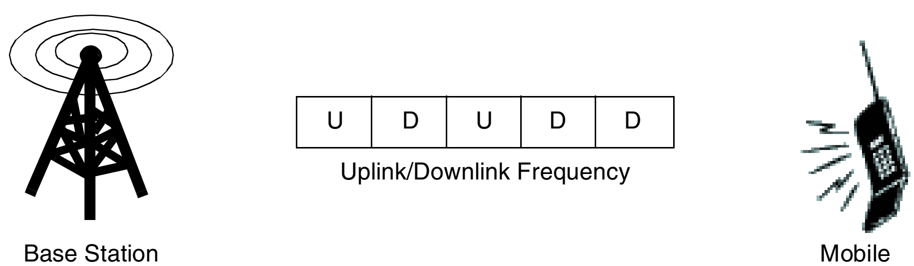

Figure 3. TDD Mode of Operation

Wireless communications systems not only share resources such as time and frequency for uplink and downlink but they also require users to send and receive information in both directions using the same resources. Because the shared spectrum resources are so limited, as many users as possible must access and share the spectrum simultaneously. Resource sharing is achieved via the following multiple access (MA) techniques (see **Figure 4**):

- *Frequency Division Multiple Access (FDMA).* Assigns different frequencies to different users, allowing them to use the channel at the same time.
- *Time Division Multiple Access (TDMA).* Slices a frequency band into multiple slots, allowing various users to use the channels at different points in time.
- *Code Division Multiple Access (CDMA).* All users access the channel at the same time but the users are separated from each other by a unique spreading code.

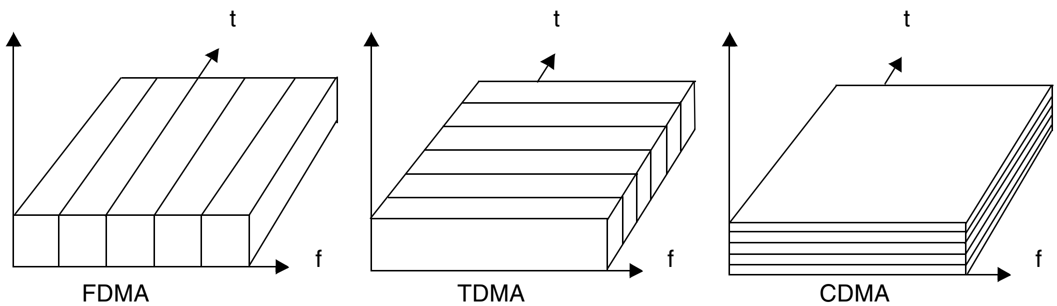

Figure 4. Multiple Access Techniques

The FDD and TDD modes of using the allocated spectrum are specified in the Third-Generation Partnership Project (3GPP) UMTS Terrestrial Radio Access (UTRA) standard. Wideband CDMA (WCDMA) is used for UTRA FDD, and Time Division-CDMA (TD-CDMA) is used for UTRA TDD. The current TD-CDMA standard is actually a combination of TDD and CDMA, and WCDMA is a pure CDMA system with FDD.

In December 1999, 3GPP released the first revision of the UTRA standard, which includes a harmonized concept for all CDMA-based proposals to that date. This standard aligns the radio parameters and defines a common protocol specification for the upper layers. It specifies the following modes of operation:

- CDMA Direct Spread (CDMA-DS) based on UTRA-FDD.
- CDMA Multi-carrier based on CDMA 2000, using FDD.
- TDD (CDMA TDD) based on UTRA TDD.

In 1998 the Chinese Wireless Telecommunications Standards (CWTS, http://www.cwts.org) put forth a proposal to the International Communications Union (ITU) that is based on TDD and Synchronous CDMA technology (TD-SCDMA) for TDD. The ITU approved and adopted this proposal, which became part of 3GPP in March 2001. The TD-SCDMA proposal was incorporated as part of the TDD mode of operation in addition to the existing TDD-CDMA mode of operation. To accommodate both modes, 3GPP now includes a low chip rate mode of 1.28 Mcps that corresponds to the TD-SCDMA specifications. Therefore, TD-SCDMA is sometimes referred to as the low-chip rate mode of UTRA TDD (see **Table 1**).

Table 1. TD-SCDMA in Relation to Other 3G Standards

Standard	Access Mode	Chip Rate
WCDMA	FDD	3.84 Mcps
TDD-CDMA	TDD	3.84 Mcps
TD-SCDMA	TDD	1.28 Mcps

The TD-SCDMA standard has the full support of the Chinese government, which, along with its unique technical advantages, makes TD-SCDMA a formidable contender for mobile communications not only in China but in other parts of the world. Its unique features offer a distinct advantage over existing 2G technologies and even over other parts of the current 3G standard.

2 TD-SCDMA Basics

TD-SCDMA is designed for TDD/TDMA operation with synchronous CDMA technology. Its TDD mode supports a flexible uplink/downlink system with flexible switching points to achieve very high use of the allocated spectrum. TD-SCDMA has distinctive features to support the services required in 3G-based systems. The duplexing mode is TDD, combined with CDMA technology. Time slots and spreading codes separate the users in a cell. **Figure 5** shows a TD-SCDMA frame. Each time slot can contain up to 16 users uniquely separated by their own individual spreading code. A key feature of TD-SCDMA is that the uplink is received synchronously in the base station, allowing better channel separation and the use of truly orthogonal codes.

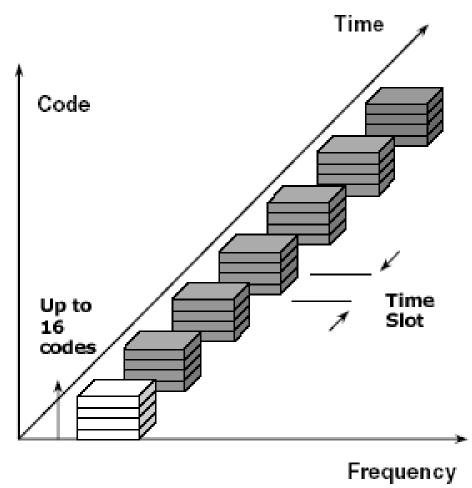

Figure 5. TD-SCDMA Frame Showing Users Separated in Time By Spreading Codes

In addition to TDMA and CDMA, TD-SCDMA includes support for innovative use of key technologies such as smart antennas, joint detection, and dynamic channel allocation to achieve near optimal performance, as follows:

- Eliminate multiple access interference (MAI).
- Minimize intra-cell and inter-cell interference.
- Support high data rates (up to 2 Mb/s).
- Support dynamic traffic and applications with a flexible uplink and downlink design.
- Provide large cell coverage (up to 40 Km in radius).
- Support high mobility users (up to 120 Km/h).
- Achieve high spectrum efficiency.

TDD/TDMA use the spectrum very efficiently because only one frequency band is required for uplink and downlink transmissions. Smart antennas and joint detection are used to eliminate MAI, a primary contributor to intra-cell interference. **Section 3** discusses these technologies in detail.

2.1 Advantages of TD-SCDMA

TD-SCDMA has a number of advantages, which are as follows:

- *Efficient spectrum allocation*. To provide high data rate services, we need large bandwidth allocations. TD-SCDMA systems require only one frequency band for communications between the base station and the mobile.
- *Support for asymmetric traffic and services*. Internet-based applications, media-enabled applications (audio and video), and file transfers have very different bandwidth requirements for uplink and downlink traffic. TD-SCDMA does not dictate fixed usage of the frequency band. Instead, uplink and downlink resources are assigned according to traffic needs. The flexible frame structure allows the channel uplink/downlink allocations to change dynamically during the same call, as required by the applications (see **Figure 6**).

  TD-SCDMA uses the available spectrum more efficiently than IS-95, WCDMA, CDMA2000, or GSM systems. As a TDD system, it requires only a single unpaired frequency band for both uplink and downlink traffic instead of the two separate frequency bands needed by FDD systems.

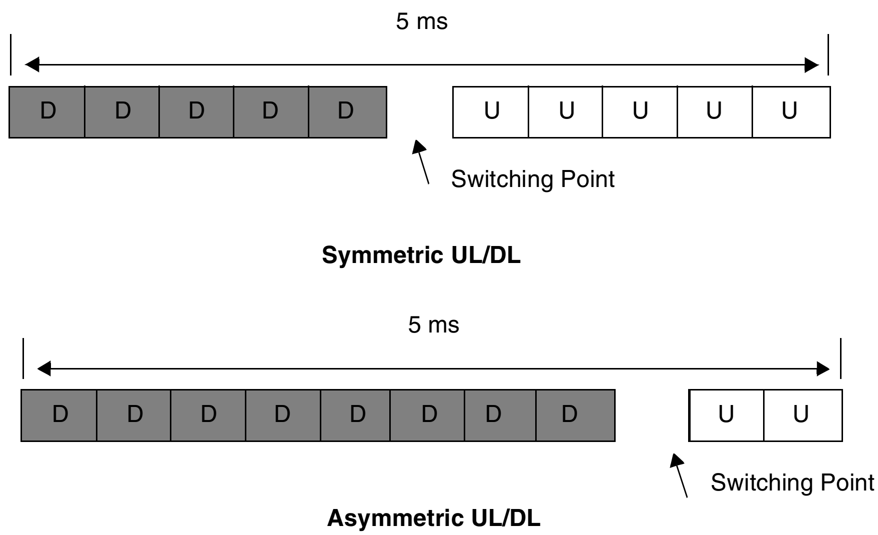

Figure 6. TD-SCDMA Frames for Symmetric and Asymmetric Services

- *Equivalent Channel in the Uplink and Downlink*. Fading and multi-path impairments at the mobile receiver are caused by the disjoint arrival of multiple signals from the base station. This multiplicity of signals occurs because the signal from the base station bounces from geographical features or other objects. All signal trajectories in the forward direction have corresponding reverse trajectories. A signal transmitted from the mobile reaches the base station receiver with the same fading characteristics because the same antennas are used for transmission and reception in TD-SCDMA systems. This is true only because TD-SCDMA is a TDD rather than an FDD-based system. Fast fading and multi-path channel impairments depend on frequency. In FDD-based systems, the UL and DL multi-path impairments are not related to one another because separate frequencies are used. In TDD systems, since the same frequency is used for both the UL and the DL, the transmitter can make assumptions about the forward channel based on the received information. Therefore, smart antennas and open-loop power control can be implemented.
- *Elimination of intra-cell and inter-cell interference*. Interference is eliminated through the use of joint detection and smart antennas. In TD-SCDMA, the uplink is received synchronously in the base station, improving channel separation, which can be even further improved by the use of joint detection and smart antennas.

- *Low power consumption*. Employing smart antenna technology, the base station can direct power to active mobiles instead of sending it to the entire cell. In TD-SCDMA systems, the users are active only at predetermined slots in time (see **Figure 5**)
- *Baton handover*. In TD-SCDMA systems, soft handover is unnecessary. Smart antennas enable the base station to acquire very accurate position of the mobile. Once the system has the position of the mobile, it locates the target cell for the handover and gives the mobile the information on the new cell. The mobile synchronizes to the new cell and switches to it.
- *Low cost for the RF front end*. As a TDD system, TD-SCDMA uses a single frequency band for transmission and reception, so it needs only one RF section, unlike FDD systems that require two nearly identical RF sections for the uplink and downlink frequencies.

2.2 Disadvantages of TD-SCDMA

Disadvantages of TD-SCDMA are as follows:

- *Requires accurate synchronization*. In the uplink and the downlink, transmission occurs synchronously. In the uplink, synchronization is achieved as the base station monitors signals from the mobiles and timing adjustments are made in the transmission. This synchronization between base station and the mobile must be very accurate. All base stations must be time synchronized to minimize inter-cell interference, especially in handover situations. This requires sophisticated network synchronization procedures, such as the use of global positioning systems (GPS).
- *Limited support for high speed/mobility users*. TDD systems are inherently limited in their ability to support fast fading and Doppler effects. While these limitations can be mitigated by smart antenna beam forming and joint detection, TDD systems still cannot attain the performance of comparable WCDMA systems.
- *Complex and expensive technologies*. Baton handover in TD-SCDMA systems demands extremely accurate position information on the mobile users. Smart antennas can meet these demands, but the system is dependent on these complex and expensive technologies.

3 TD-SCDMA Functional Blocks and Parameters

This section examines the functional blocks of TD-SCDMA and how the system parameters shown in **Table 2** are used in the context of a receiver and transmitter.

Table 2. TD-SCDMA System Parameters [7]

Parameter	Value
Carrier bandwidth	1.6 MHz
Carrier spacing	1.6 MHz
Chip rate	1.28 Mcps
Duplex type	TDD
Multiple access scheme	TDMA, CDMA, FDMA
Frame length	10 ms
Number of slots/frames	7
Radio frame length	10 ms
Radio sub-frame length	5 ms
Data modulation	QPSK or 8 PSK

Table 2. TD-SCDMA System Parameters [7] (Continued)

Parameter	Value
Voice data rate	8 Kbit/s
Receiver	Joint detector
Spreading factors	1,2,4,8 and 16
Max data rate per user (theoretical)	2 Mbps
Synchronization	Downlink and uplink
Antenna processing	Smart antenna with beam forming

3.1 TDD/TDMA

TD-SCDMA uses TDD in combination with multiple access techniques to support both symmetrical and asymmetrical traffic. The variable allocation of the time slots for uplink or downlink traffic allows TD-SCDMA to meet asymmetric traffic requirements and support a variety of users. As **Figure 7** shows, the time slots are equally split for symmetric traffic, but for asymmetric traffic, the DL can use more time slots.

Figure 7. Variable Allocation of Time Slots for Different Traffic Needs

In TD-SCDMA systems, multiple access techniques employ both unique codes and time signatures to separate the users in a given cell. As shown in **Figure 8**, the TD-SCDMA standard defines a very specific frame structure with three layers: the radio frame, the subframe, and the time slot. Resource allocation affects the configuration of the radio frames. All physical channels require a guard symbol in every time slot [6]. The radio frame is 10 ms. The subframe is 5 ms long and is divided into 7 slots. The standard also specifies various ratios for the number of slots between these two groups to meet specific traffic requirements. There is a time slot that fits into exactly one burst. It consists of two data parts separated by a section called the *midamble*. The receiver uses this midamble to perform the channel estimation tasks.

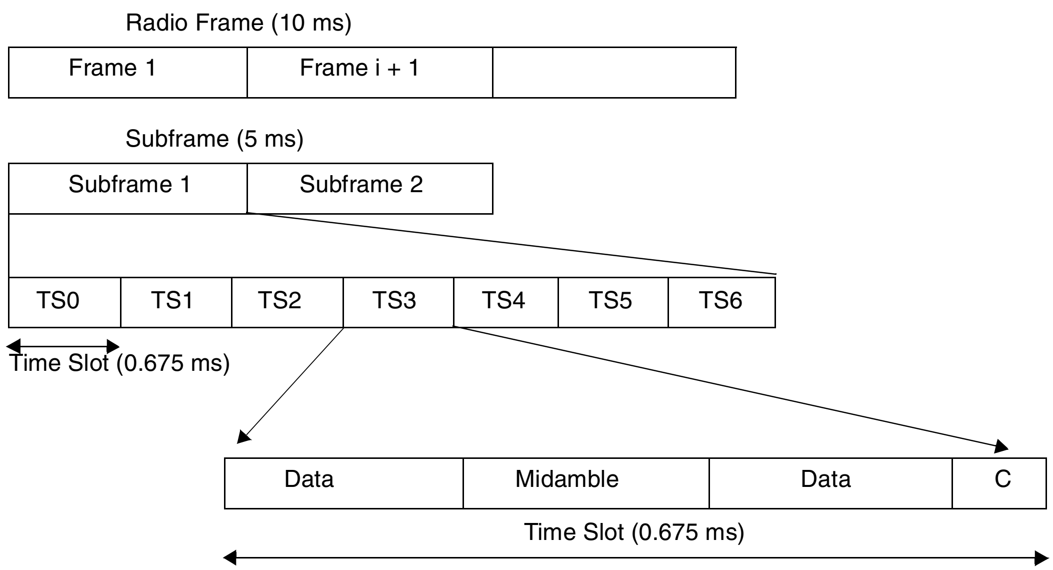

Figure 8. TD-SCDMA Physical Channel Frame Structure [6]

As **Figure 9** shows, a time slot consists of four parts: a midamble with a duration of 144 chips, two identical data fields with a duration of 352 chips on each side of the midamble, and a 16-chip guard period. The time slot fits into exactly one burst. The receiver uses the midamble to perform the channel estimation tasks.

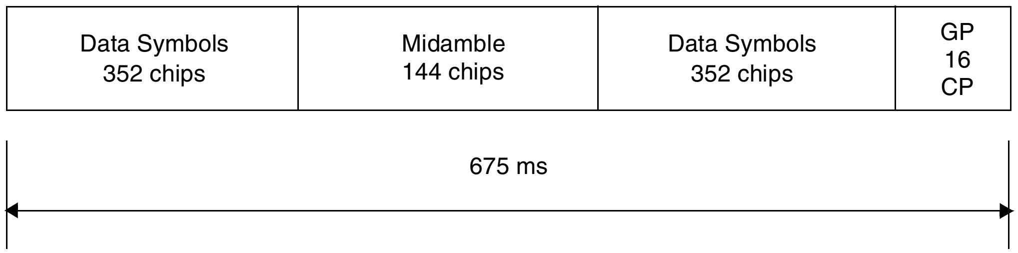

Figure 9. TD-SCDMA Slot Structure [6]

3.2 CDMA

TD-SCDMA uses CDMA differently than UMTS, CDMA 2000, or other conventional CDMA-based systems. In CDMA systems, many users access the same channel simultaneously. Each user is separated from the others by a special code (spreading code). However, each new user added to the system is an interference to all the other users. In CDMA systems, this multiple access interference (MAI) is the limiting factor in system capacity. However, TD-SCDMA limits the number of codes for each time slot to a maximum of 16 (see **Figure 10**), thus reducing the MAI, which is further reduced by the joint detector and smart antenna systems.

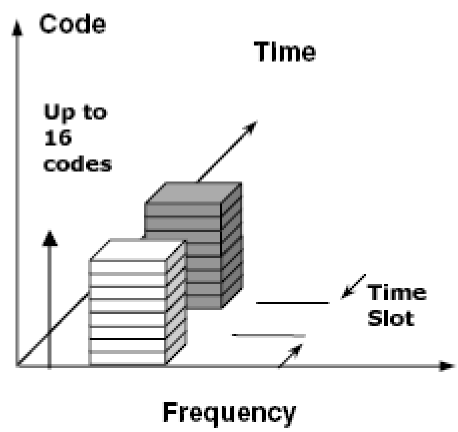

Figure 10. Combined Use of CDMA and TDMA and a TD-SCDMA System

3.3 FDMA

The chip rate of 1.28 Mcps gives a bandwidth of 1.6 MHz. Current TDD licenses are 5 MHz, allowing deployment of up to three full TD-SCDMA carriers. In a TD-SCDMA system a time slot, a spreading code, and the carrier frequency uniquely identify a radio resource unit.

3.4 Joint Detection (JD)

MAI equally affects all users in a CDMA system. Under certain conditions, a detected user is barely discernible above the noise represented by the other users in the system. To deal with this, other 3G systems use detection schemes such as the rake receiver. However, rake receivers are sub-optimal because they consider only the user's signal information in the detection process, with no attempt to characterize the interference from all the other users.

In contrast, joint detection algorithms process all users in parallel and thus include the interference information from the other users. **Figure 11** shows the block diagram of a joint detector as used in the TD-SCDMA receiver. Joint detection schemes are complex and computationally intensive. Complexity grows exponentially as the number of codes increases. Therefore, joint detectors are not suitable for use in other CDMA systems because of the high number of codes used in those systems. In **Figure 11**, most of the operations are matrix and vector operations. As the size of the matrices and vectors increases, so does the complexity of the system and the computational power that is required to separate the users.

Joint detection is well suited to TD-SCDMA systems because they limit the number of users in a time slot to 16, a very manageable number of users to process in parallel. These users are also synchronized. The result is a joint detector of reasonable complexity that can easily be implemented in today's parallel computational architectures.

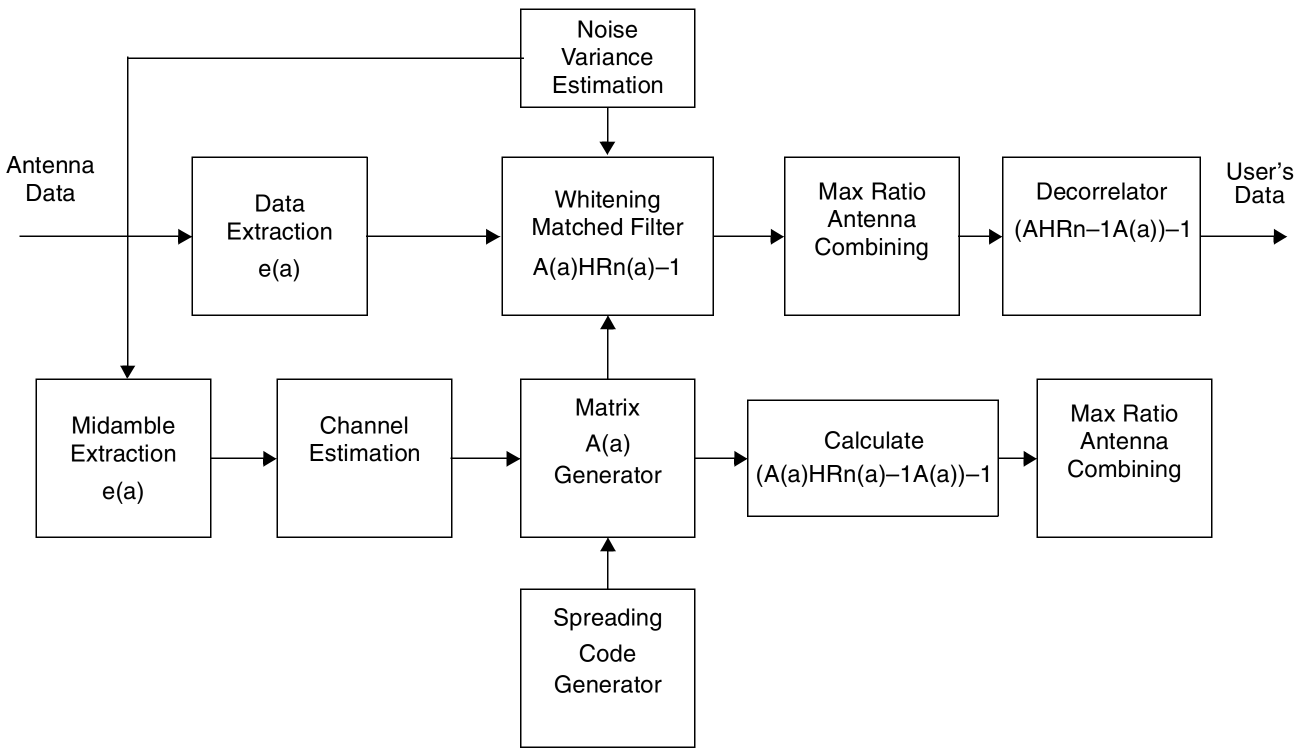

Figure 11. Joint Detector for the TD-SCDMA Receiver

3.5 Smart Antennas

Smart antennas are antenna arrays installed at base station sites. In a typical TD-SCDMA configuration, the antenna array is a circular array composed of 8 antenna elements. The TD-SCDMA smart antenna system combines the multiple antenna elements from the antenna array using beam forming concepts and other sophisticated signal processing algorithms to transmit and receive adaptively. **Figure 12** illustrates this concept. Instead of illuminating the entire cell with radio power, the base station sends power only to the terminals that are active in the cell. This illumination has the immediate benefit of increasing the power received by the terminals in the cell while reducing mobile-to-mobile interference in the cell and interference in nearby cells. Smart antenna systems in TD-SCDMA and TDD-based systems can be very effective because these systems use the same frequency for both the uplink and the downlink and therefore can assume a nearly identical channel in both directions.

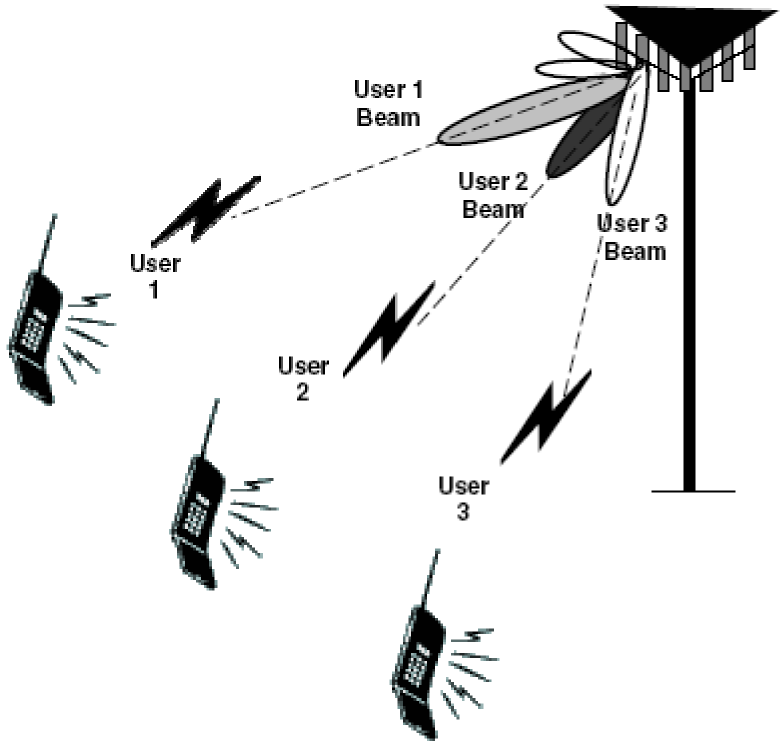

Figure 12. Base Station Equipped With a Smart Antenna System

3.6 Dynamic Channel Allocation

TD-SCDMA uses the following multiple access techniques to allocate the traffic to the codes with least interference (subject to the limitation of 16 codes per time slot per carrier) or to the carrier with the least interference or by using smart antennas to near optimum transmission paths:

- TDMA
- FDMA
- CDMA
- Space Division Multiple Access (SDMA)

3.7 Terminal Synchronization

In a TD-SCDMA system, synchronization between the base station and the mobile is critical because the bursts must be transmitted and received within the allocated real-time slots. The longer the distance between the mobile and the base station, the longer the time before the bursts reach their destination. Highly mobile users present a special challenge because their distance to the base station is not fixed. TD-SCDMA resolves these problems by having the base station direct the mobile units to advance their timing (that is, transmit earlier) to compensate for changes in propagation delay. In **Figure 13**, mobile (a) transmits and receives in the correct time slot, but the base station instructs mobile (b) to advance its timing so that when it transmits back to the base station, its signal arrives aligned at its allocated time slot.

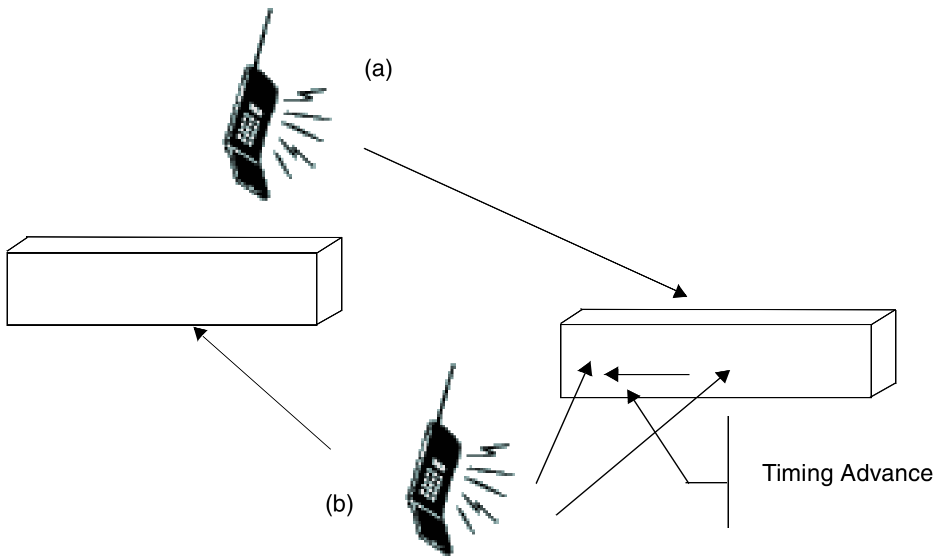

Figure 13. Terminal Synchronization

4 TD-SCDMA System Model

Figure 14 shows a simplified block diagram of a TD-SCDMA receiver. All signals from the various users and antennas are processed in the analog front end, where they are filtered and amplified and then sent to the analog-to-digital (A/D) converter. The burst split block de-multiplexes the input data stream and sends it to the channel estimation block, which processes the data in the midamble and also to the joint detector. The joint detector separates the stream into data for all *k* users in the system. The output of the joint detector is forwarded to the symbol rate processor, which deinterleaves and convolutionally decodes the data into the user data.

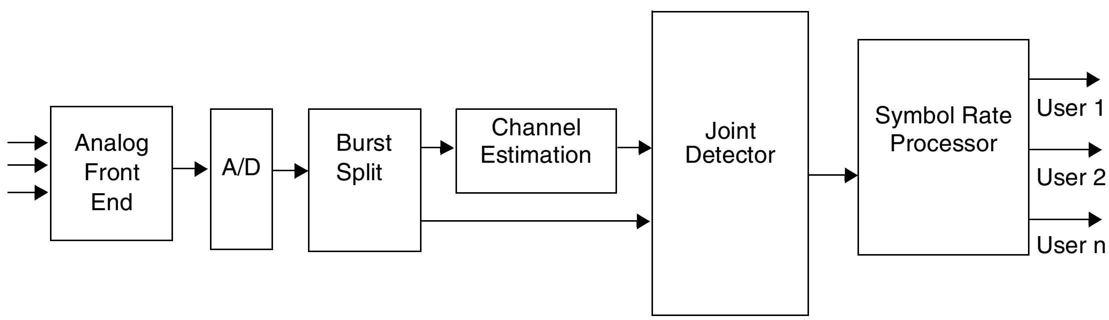

Figure 14. TD-SCDMA Receiver

The TD-SCDMA transmitter is much simpler than the corresponding receiver (see **Figure 15**). The bit stream from the users is passed to a symbol rate processor where it is convolutionally encoded and interleaved. It is then modulated and sent to the spreading block, where each user is spread by a unique user-specific sequence. Finally, the data is multiplexed in the burst generator before it is sent to the D/A converter and RF section for transmission over the air.

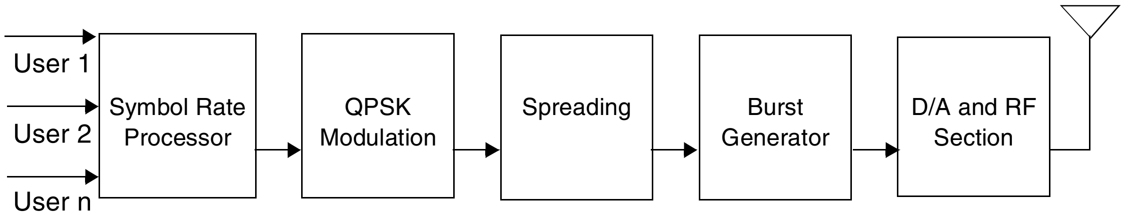

Figure 15. TD-SCDMA Transmitter

5 Freescale Solutions for TD-SCDMA

The Freescale reconfigurable compute fabric (RCF) technology is designed to meet the processing needs of the physical layer in 3G systems and is targeted to replace ASIC and FGPAs in these systems. RCF will become a key element in the design of future 3G systems. The MRC6011, which is the first commercial device deploying the RCF technology, is designed to meet the processing needs of the TD-SCDMA layer. It is a highly effective device on which to implement the key functional blocks of the TD-SCDMA receiver and transmitter. The RCF core technology is based on an array of processing elements that combines efficient parallel computing with fast and flexible reconfiguration and data routing operation. RCF parallel processing is very close to the Single Instruction Multiple Data (SIMD) approach. In addition, the very flexible organization of the computing arrays allows the array to be used in a multiple instruction multiple data (MIMD) mode. **Figure 16** shows a diagram of the RCF core.

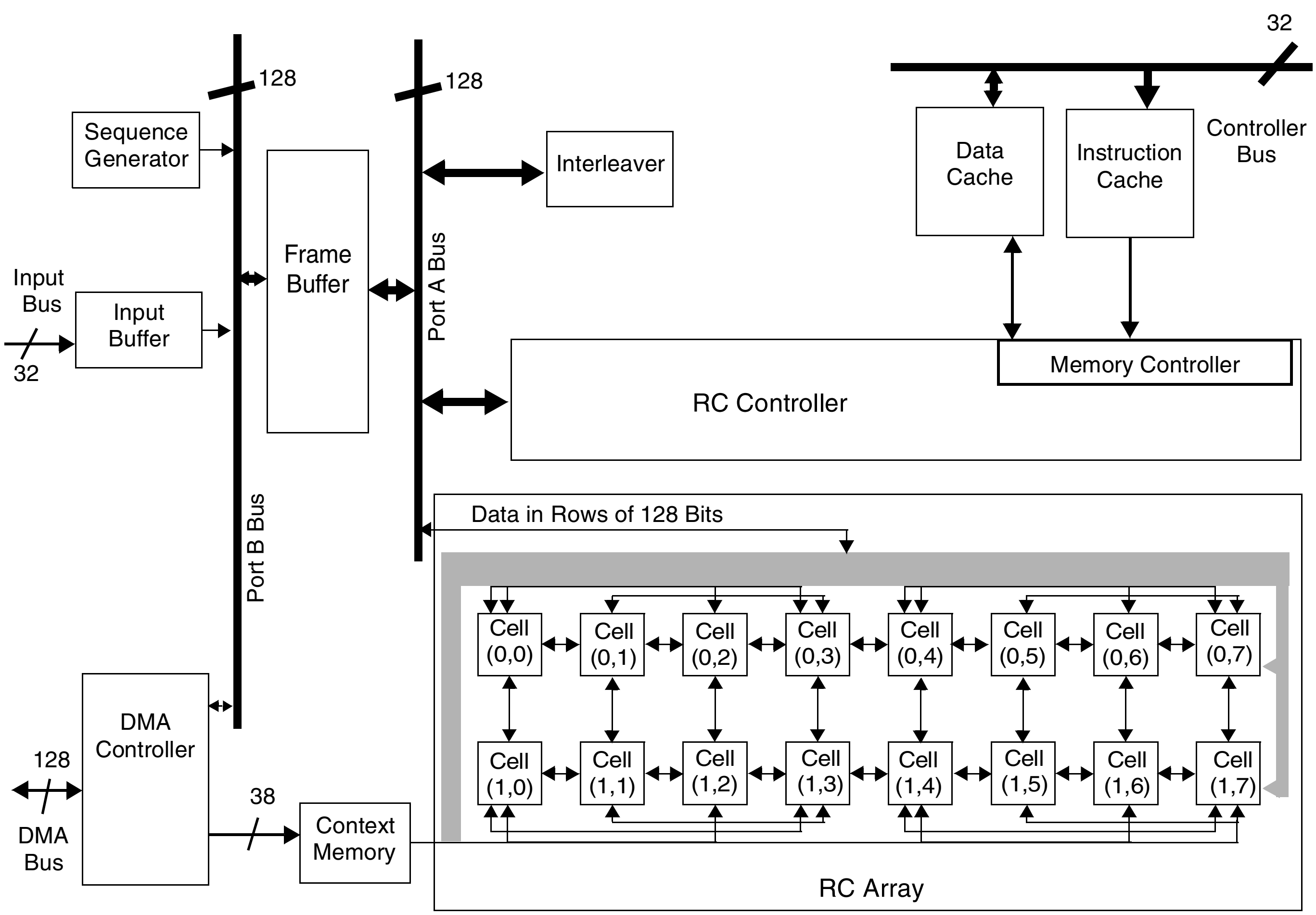

Figure 16. RCF Core

The RC controller executes the main control process of an application and also schedules every execution cycle of the processing array. The actual array instructions reside in the context memory. The wide interconnect path between context memory and the RC array allows single-cycle reconfiguration of the processing units. Peripherals such as the interleaver and sequence generator accelerate the CDMA-related applications such as turbo decoding and scrambling/descrambling. The DMA controller is the interface to the main system bus. The input buffer connects to the antenna input ports and is responsible for appropriate data interleaving and combining for efficient writes into the frame buffer.

The Freescale MRC6011 processor is the first Freescale device to be based on the RCF core. It is a highly integrated System-on-a-Chip (SoC) that combines six reconfigurable RCF cores into a homogeneous compute node. The six RCF cores reside in two RC modules containing three RCF cores each. The RCF cores on the MRC6011 instantiate the 2×8 processing array (see **Figure 17**). Both RC modules are accessible via an antenna slave interfaces and two slave I/O Interfaces. Each antenna interface can interface with up to 16 antennas, and each RCF core can manipulate the data from two antennas. The processed data goes either to one of the two Slave I/O bus interfaces (industry-wide DSP device compatible) or to another RCF core in the same or the adjacent module.

At 250 MHz, the six-core MRC6011 device delivers a peak performance of 24 Giga complex correlations per second with a sample resolution of 8 bits for I and Q inputs each, or even 48 Giga complex correlations per second at a resolution of 4 bits.

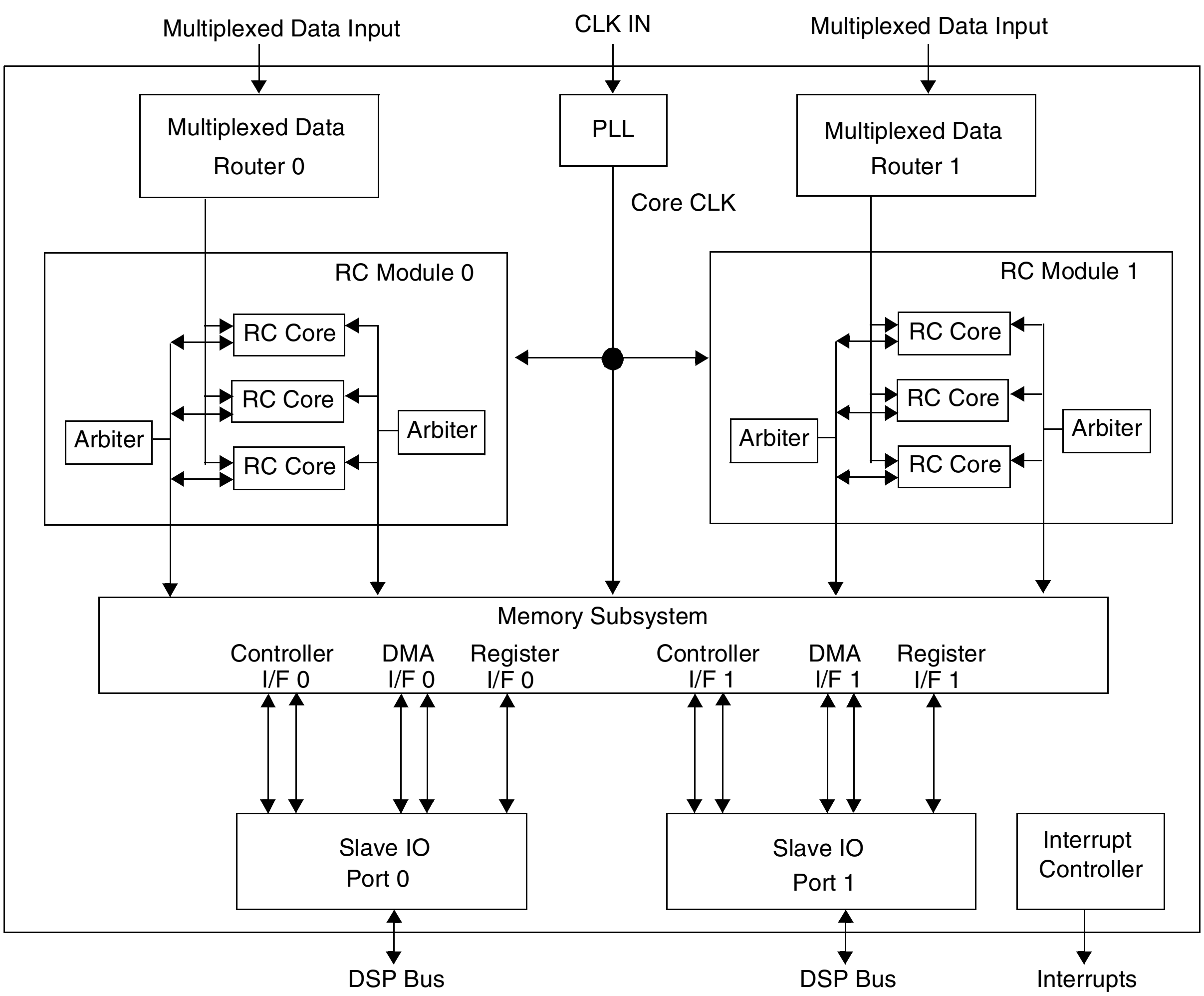

Figure 17. MRC6011 Block Diagram

The joint detector is the most complex and computationally intensive section in a TD-SCDMA receiver. It makes heavy use of matrix and vector operations (see **Figure 11**). The inherent parallelism of the joint detector is an ideal fit to the architecture and instruction set of the MRC6011. The multi-core architecture of the MRC6011 device provides a very high degree of flexibility and scalability and helps to integrate the joint detector operation with other receiver components, such as the channel estimation processor. **Figure 18** shows a high-level view of how the receiver functions are mapped to the MRC6011 device, in conjunction with Freescale's advanced DSP to handle the symbol rate processing tasks.

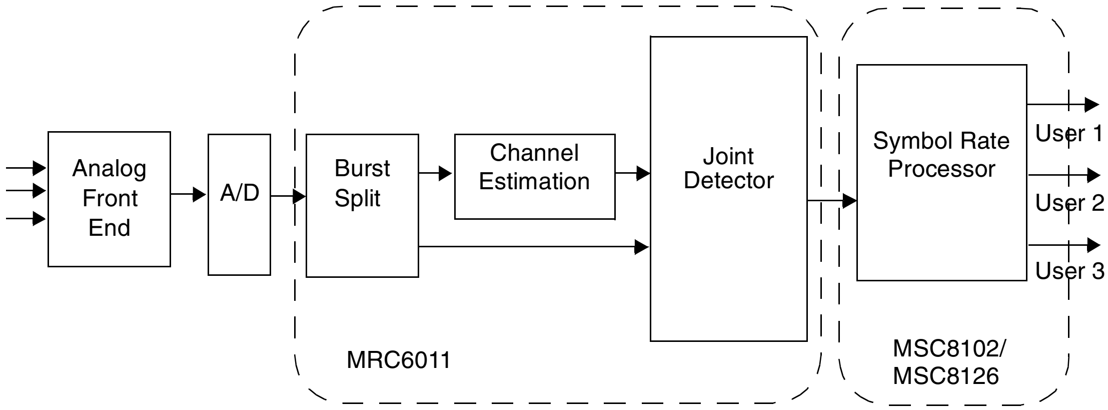

Figure 18. TS-SCDMA MRC6011-Based Receiver

For the TD-SCDMA transmitter, the symbol rate processing can easily be mapped to one of Freescale's advanced DSPs. The modulation and spreading tasks are the most computationally intensive tasks in the downlink, and they are mapped to the MRC6011 device, as shown in **Figure 19**.

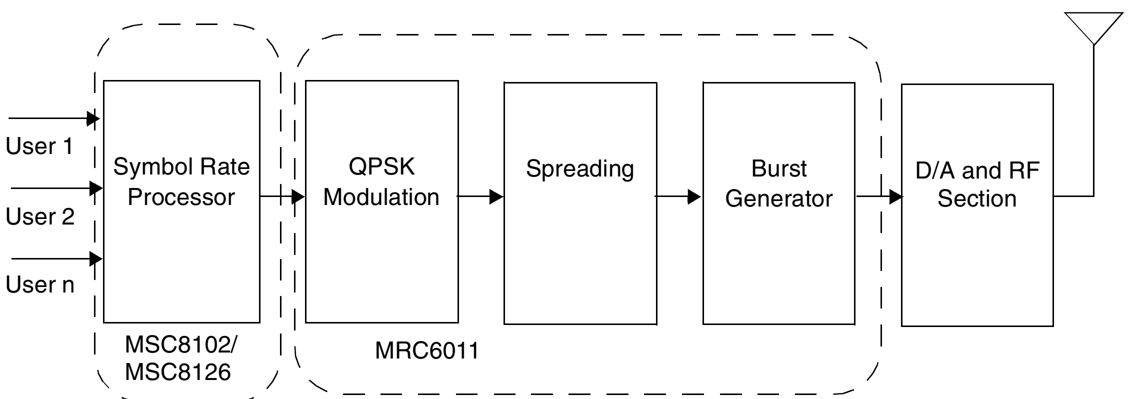

Figure 19. TD-SCDMA MRC6011-Based Transmitter

6 TD-SCDMA and RCF, A Winning Combination

TD-SCDMA is a formidable contender for mobile communications in China and in other parts of the world. Its unique features offer a distinct advantage over existing 2G technologies and even over other parts of the current 3G standard. Freescale's MRC60ll implementation of RCF technology offers several distinct advantages over other TD-SCDMA baseband processing solutions, as follows:

- A TD-SCDMA receiver/transmitter system incorporating the MRC6011 device and a high-end DSP such as the MSC8102 or the MSC8126 provides the optimal solution to address the computation requirements of the receiver's joint detector and the smart antenna components (uplink and downlink).
- The parallel architecture of RCF matches the inherent parallelism of the joint detection and smart antenna tasks of the TD-SCDMA receiver.
- The entire system can be programmed in C and Assembly. No HDL coding is required.
- The system offers a high degree of flexibility and programmability.
- A combination of DSP and RCF supports an aggressive cost reduction road map:
  - Faster development cycle time, lower design effort, software-based upgrades as standards evolve, and support for field upgrade ability result in significant savings in development expenses, compared to the cost of a traditional ASIC and DSP solution.
  - The software-programmable RCF solution can be modified remotely and instantly without the physical respin and replacement required by an ASIC on a board.
  - A software-programmable solution allows both shorter time to market and longer time in market.

The TD-SCDMA MRC6011-based communications system is a powerful baseband processing solution that promises unparalleled flexibility, programmability, convenience, and cost-effectiveness.

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