

# **SDR for mobile communication**

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## **Abstract:**

Wireless voice service is one of the new products of modern communication .GSM technology has been at the leading edge of this wireless revolution. In the year 2005 there will be around 1.4 billion wireless mobile subscribers, out of which more than 50% depend on GSM technology . the Internet has been a phenomenal growth simultaneously. The advent of world wide web and web browser which use TCP/IP protocols have been result in widespread use not only in the corporate environment but also in households. The success of mobile communication and Internet result in the idea that integrates them. Although 3G wireless communication concepts aim towards global standardization to break away with multiple standards deployed in particular geographical areas , there is a need for multi-frequency transceivers operating in common hardware platforms . the solution is software radio (SR) and through the application of flexible and programmable transceivers.

## **1- Introduction :**

Broadband wireless multimedia (BWM) is an essential need for today's applications. GSM cannot provide enough bite rate to support this applications. UMTS incorporates all building blocks to provide BWM for users. Different methods using the following strategies:

- High Speed Circuit Switched Data (HSCSD) aggregates symmetrically or asymmetrically several circuit channels.
- General Packet Radio Service (GPRS) enables GSM with Internet access at high spectrum efficiency by sharing time slots between different users which provide data rates over 100 kbps for a single user.
- Enhanced Data Rate for GSM Evolution (EDGE) modifies the radio link modulation scheme from GMSK to 8QPSK and increasing the GSM throughput(three times)
- UMTS utilizes a wide-band CDMA or TD/CDMA transceiver and increasing data rate up to 2 Mbps. (see figure 1)

Although the circuit-switched enhancements such as HSCSD have increased transmission rates, it is packet-switched enhancements which will meet the challenges or demand posed on current wireless networks. after the introduction of R99 , the main innovation took place in the radio side with incorporation of WCDMA ,subsequent release of UMTS will bring evolution in the core by adding all IP features, thereby UMTS will support real-time packet switching to enhance VOIP and streaming and expanding transmission rates up to 20Mbps with High Speed Packet Downlink Access(HSPDA)and intelligent or adaptive antenna(AA).

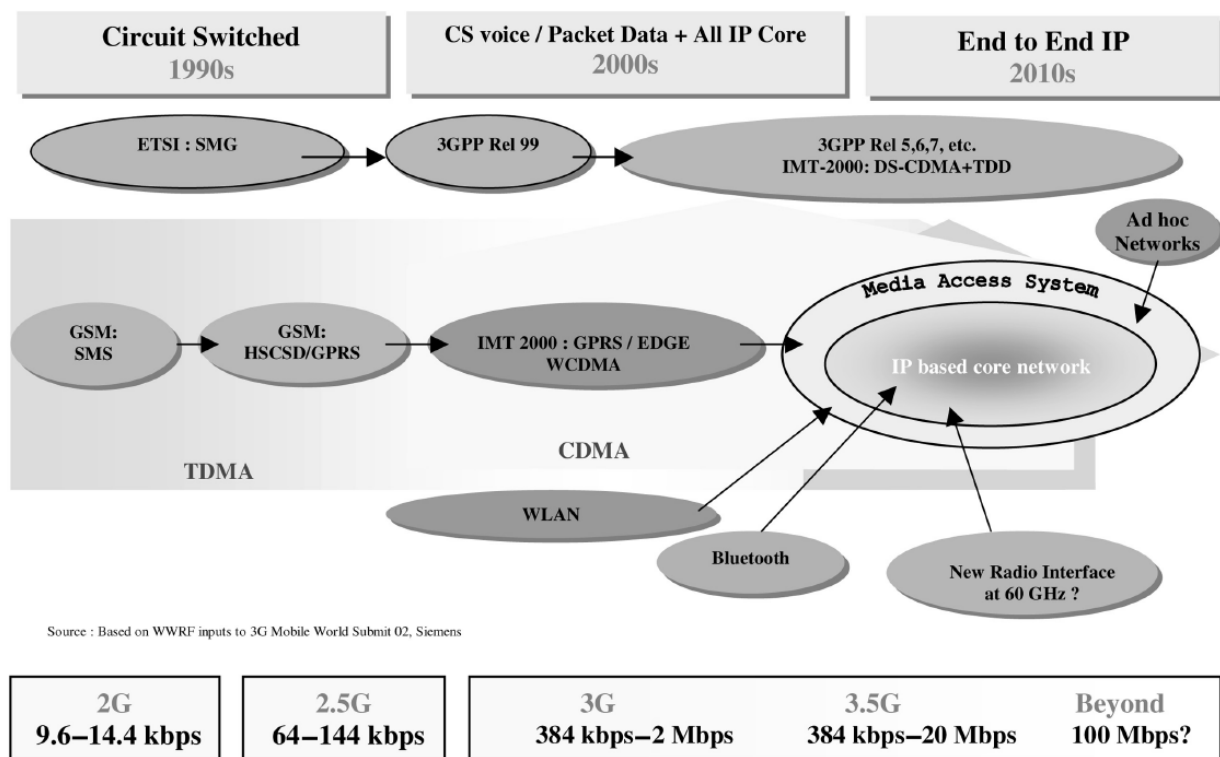


Figure1: evolution for wireless network

## 2- RF system design :

RF engineering is sometimes called the black art. it is important to understand that analog electronics add noise and distortion to the information bandwidth. many of the functions performed by digital electronics and software are designed to limit the effects of the analog processing.

2-1: noise and channel capacity: in analog and RF systems thermal noise is generated when electrons pass through conductors. noise is also contributed by human-generated and

naturally occurring effects. in CDMA systems additional noise is generated by other users who are simultaneously sharing BW by sharing power. Cascading analog devices result in additive nature of noise and careful attention must be paid during the allocation of gain and noise figure to each processing block in a cascade RF system. Shannon-Hartley theorem  $\left\{C = B \log_2\left(1 + \frac{S}{N}\right)\right\}$  introduces minimum channel capacity (C) measuring in bps which B is channel BW(Hz) and S is average signal power and N is the maximum noise power. for UMTS B=5 MHz and N= -107 dBm and for cdma2000 1X B=1.23 MHz and N= -113.1 dBm .

2-2: link budget: assuming the receive antenna is separated from the transmit antenna by a distance greater than near field distance (greater than ten wavelengths)the free space loss (Lfs) is achieved by  $Lfs(d) = -10 \log \left[ \left( \frac{\lambda}{4\pi d} \right)^2 \right]$  we know that  $c=f\lambda$  and then we have  $Lfs(d) = -147.6 + 20 \log d + 20 \log f$  for example path loss in atypical 3G frequency of 1.9GHz will be 78dB at 100m and 98dB at 1Km.the free space loss model is valid when a line of sight is between transmitter and receiver.

in practice there is obstacles between transmitter and receiver and the loss is modeled by:  $Ll(d) = -159.4 + 20 \log f + 38.4 \log d - 20 \log h_t - 10 \log h_r$  ,  $h_t$  &  $h_r$  respectively is the height of transmitter and receiver antennas.

finally we introduce another loss model namely outdoor to indoor and pedestrian model describe by :  $Loi(d) = Lfs(d) + Lrts(x, \Delta h_m, d) + Lmsd(bs, d)$

Second term in above equation is called diffraction loss and  $\Delta h_m$  is the difference between the mean building height and the mobile antenna height and x is the horizontal distance between the mobile and the diffracting

edge.  $Lrts(x, \Delta h_m, d) = -10 \log \left[ \frac{\lambda}{2\pi^2 r} \left( \frac{1}{\alpha \tan(\frac{|\Delta h_m|}{x})} - \frac{1}{2\pi + \alpha \tan(\frac{|\Delta h_m|}{x})} \right)^2 \right]$  where

$r = \sqrt{(\Delta h_m)^2 + x^2}$  , 3<sup>th</sup> term in above equation is called multiple screen diffracting

loss,  $Lmsd(bs, d) = -10 \log \left[ \left( \frac{bs}{d} \right)^2 \right]$  where bs is the average separation between rows of

buildings. Assuming a frequency of 1.9GHz, x=5m,  $\Delta h_m = 10m$  and bs=20m the path loss at a distance of 100m will be 125.7dB and increase at 40 dB per decade to 165.7dB at d equal to 1 Km. link budget for figure 2 is calculated by :  $P_r = P_t - l_t + G_t - L_p + G_r - l_r$

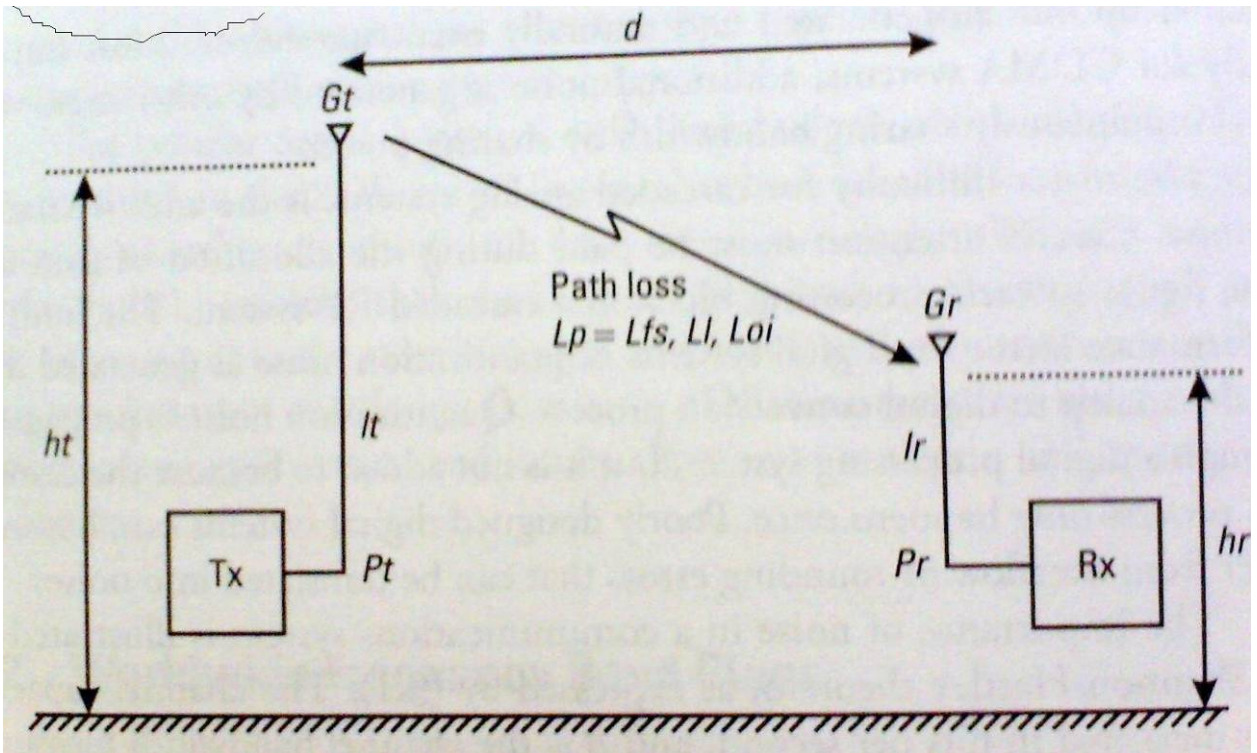


Figure 2:simple system propagation loss block diagram

$P_r$  is the average received power and  $P_t$  is the average transmitted power,  $G_t$  and  $G_r$  is respectively transmitter and receiver antenna gain,  $L_t$  and  $L_r$  is cable loss in transmitter and receiver and  $L_p$  is the propagation loss(all in dB). in figure 3 which is an expanded RF system block diagram power at reference point B and D is :

$$P_t = P_a + G_{tx1} + G_{tx2} + G_{tx3} \quad \text{and} \quad P_d = P_r + G_{rx1} + G_{rx2} + G_{rx3}$$

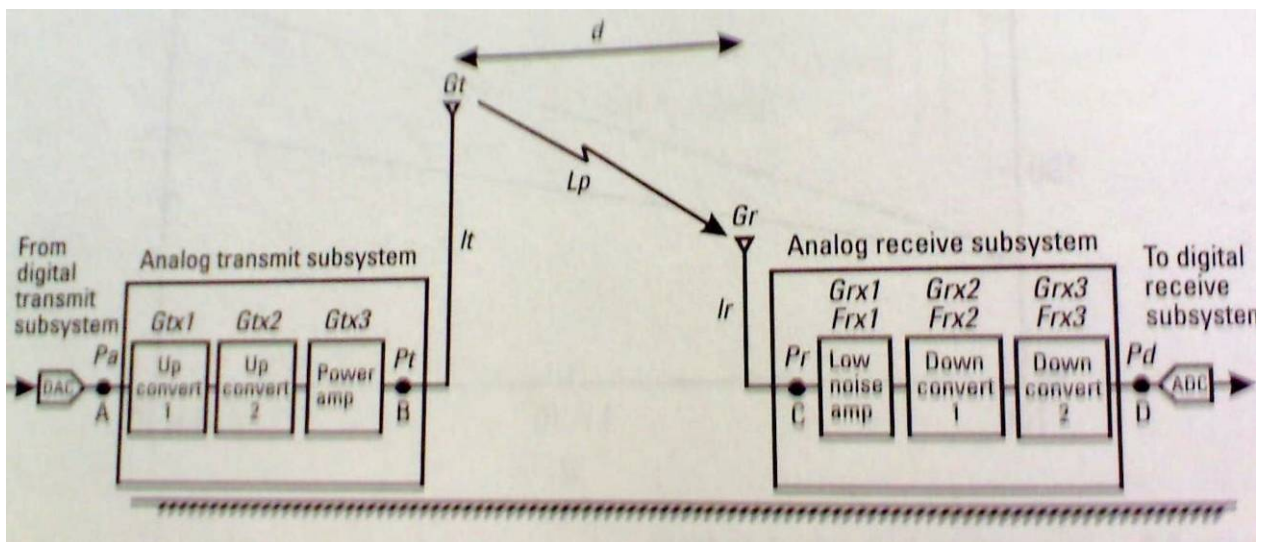


Figure3:expanded RF system block diagram

The noise figure (F) of a device calculated as ratio of input signal to noise ratio to output signal

to noise ratio :

$$F = \frac{(S/N)_{in}}{(S/N)_{out}} \quad F > 1$$

The total noise figure for a cascade system ( $F_T$ ) is calculated by the following formula where

$$F_n, G_n \text{ are the noise figure and gain of } n^{\text{th}} \text{ element: } F_T = F_1 + \frac{F_2 - 1}{G_1} + \frac{F_3 - 1}{G_1 G_2} + \dots + \frac{F_n - 1}{G_1 G_2 \dots G_{n-1}}$$

### 2-3: 3G receiver requirements:

- Sensitivity: the minimum receiver input power measured at the antenna input connector for which the BER does not exceed a specified value. the UMTS BS receiver sensitivity is -121 dBm, given a data rate of 12.2 Kbps and a BER of less than 0.001
- Dynamic range: the ability of the receiver to handle a surge of interference in the channel .a UMTS BS receiver must be able to maintain a BER of less than 0.001 ,while the required signal power is -91 dBm or greater ,and the interfering signal power is -73 dBm.
- Adjacent channel selectivity: receiver's ability to receive a wanted signal on its assigned channel in the presence of an adjacent channel signal .
- Blocking: the receiver's ability to maintain performance for a wanted signal in the presence of an interferer
- Intermodulation: mixing of two interfering RF signals can produce second, third and higher order products in the band of the wanted channel. Intermodulation rejection is a measure of the capability of the receiver to receive a wanted signal on its assigned channel in the presence of two or more interfering signals that have a specific frequency relationship to the wanted signal.

### 2-4: 3G transmitter requirements:

- Occupied BW: it is a span of frequency that contains a specific percentage of the mean emitted power. For UMTS only 0.5% of the mean power is allowed to be radiated outside the occupied BW.
- out of band emissions: these are the unwanted emissions occurring immediately outside the desired channel BW. these exclude spurious emissions and result from the modulation process and nonlinearity in the transmitter.
- Transmitter spurious emissions: these are caused by unwanted transmitter effects, such as harmonic emissions , parasitic emissions ,intermodulation products and frequency conversion products but exclude out of band emissions.
- Transmitter intermodulation:it is a measure of the capability of the transmitter to inhibit the generation of signals in its nonlinear elements caused by the presence of the wanted signals and an interfering signal reaching the transmitter via the antenna.

A significant trade-off for designers is the balance between wideband linear performance and power consumption. Multicarrier combining prior to the power amplifier eliminates the need for high loss transmitter combiners prior the antenna. the SDR design goal should be to use a wideband power amplifier that has better efficiency than the equivalent combination of single channel amplifiers and transmit combiners.

### 3-analog to digital and digital to analog conversion:

The weakest links in the SDR signal processing chain is the process of analog to digital conversion and, to a lesser extent, the process of digital to analog conversion. digital conversion resolution improvements approximately 1.5 bit every 6 years ,however 3G focus have seen SDR -capable converters improve by 2 bits in approximately 2 years.

Common procedures in sampling are first Nyquist rule , bandpass sampling and oversampling.

3-1: antialiasing filter: all signals above  $f_s/2$  are aliased or folded back into the first nyquist

zone, including all unwanted components and any noise. A/D must be preceded by an analog antialiasing filter which has the function of passing only the band of the band of interest and rejecting all other unwanted frequency components. antialiasing filter must exhibit lowpass-band ripple ,good phase linearity and group delay performance with a minimum of insertion loss.in the future as the analog section in the SDR reduces in size,the antialiasing job will become more difficult and we could use a surface acoustic wave(SAW) filter as the prime antialiasing filter because of the design's excellent roll-off in the transition band.

3-2: ADC techniques: common concepts in this area including successive approximation, multipass architecture ,dithering, clock jitter and aperture uncertainty.we explain the last concept. in the basic analysis we assume that the clocks used for sampling and holding are perfect. in practice natural phenomena including BW limitation, skew and noise prevent these clocks from being perfect.these effects cause the time interval between successive clock edges to vary or jitter.this variation in timing is random with a mean and variance.when a narrowband signal source is sampled at frequency  $f_s$  by an ADC with an rms sample clock timing jitter of  $\sigma_T$ the phase modulation introduced in the source by the sampling process limits the SNR to :

$$SNR = \frac{1}{(2\pi f_s \sigma_T)^2}$$

we want to increase sampling frequency to maximize the processable BW of each processing chain and then SNR has been decreasing. because the above equation is the source signal power to error power introduced by clock jitter ,it cannot be directly applied to spread spectrum case. we introduce fractional receiver SNR,  $\Gamma$ , as following:



$\Gamma = \frac{|SNR_J|^2}{|SNR_U|^2}$  where subscripts J and U are expressing jittered case and un jittered case.

expressing the preceding equation in terms of  $f_s$  and chip rate ( $f_c$ ) and  $\sigma_\tau$  (clock jitter in radian)

yielding:  $\Gamma = 1 - \left(\frac{f_s}{f_c}\right)^2 \sigma_\tau^2$

3-3: ADC noise budget: GSM requires a carrier to noise and interference ratio of 9 dB to meet the specified BER. therefore the total spurious and noise power,  $P_{nt}$ , the thermal noise,  $N_{tx}$ , the fractional ADC noise power,  $P_m$  and the worst case spurious component,  $P_s$ , have the following relationship:  $P_{nt} < 10 \log(10^{P_m/10} + 10^{N_{tx}/10} + 10^{P_s/10})$

3-4: DAC noise budget: for wideband SDR applications the DAC's noise power,  $P_n$ , will be spread over the full nyquist BW. the fractional bandpass measurement BW is  $F_m$ , the fractional noise power,  $P_m$ , is calculated by:  $P_m = P_n - 10 \log\left(\frac{f_s}{2F_m}\right)$  if we consider that the system's

DAC is only followed by analog components that perform the final frequency up conversion and power amplification and this analog section have a noise figure,  $F_{tx}$ , therefore the noise power produced by DAC increased to,  $F_{tx} + P_m$ , if the worst case spurious component power is  $P_s$  then the total noise and spurious power must be less than the specified SFDR and we have the following equation:  $10 \log\left(10^{(P_m+F_{tx})/10} + 10^{P_s/10}\right) < -SFDR_{spec}$

#### 4-DUCs and DDCs:

They are a midway step between fully programmable DSPs and fixed-functions ASICs and sometimes referred to as application-specific standard parts (ASSPs) and sits between digital baseband processing at the network end and digital conversion (ADCs, DACs) at the RF end of system. they can be considered as two ports where wideband IF signals exits at one port and narrowband single carrier baseband signals exit at the other. common concepts in this area are digital NCO, digital mixer, digital filter, halfband filter, decimation, interpolation and multirate processing.

4-1: DDC's requirements in 2G and 3G:

- Filter or isolate a narrow band of frequencies from the wideband source and reject the remainder of the band.
- Translate that isolated carrier down in frequency, usually from an IF to baseband.
- Reduce the data rate to some integer multiple of information rate.

4-2: DUC's requirements in 2G and 3G:

- Translate one or more narrowband signal sources up in frequency, usually from baseband to an IF.
- Combine the baseband sources to create one wideband result.
- Increase the data rate to a digital IF rate.

4-3: digital NCOs : these oscillators generate very precise digital sine and cosine waveforms for use in the digital mixer, which performs the frequency translation function. as the incoming and outgoing information signal is multiplied by the NCO-generated waveform, the NCO performance must be better than the specification for the multiplied result. the SFDR of the NCO must be considerably better than the SFDR of the band-shifted and filtered output of the up or downconverter.

4-4: practical aspects:

- ISL 5217: it is a quad programmable DUC. All four channels can be independently used for narrowband air interface applications such as IS136, GSM, EDGE, IS95, cdma2000-1X. two, three or four channels can be combined together to support widerband applications such as cdma2000-3X-MC, cdma2000-3X-DS, TDSCDMA and UMTS. Device limitations allow the ISL5217 to support three midband carriers (cdma2000-3X-MC) or one wideband carrier (cdma2000-3X-DS or UMTS)
- Data input routing: data can be input through any one of four serial channels (SDA...SDD) or via the device  $\mu$ processor interface. each of the up converter four channels can select any serial input as its source.
- Data modulation: baseband input signals can be vector modulated by using the shaping filter functional block followed by the gain profile block; these can be programmed for QASK for IS136, EDGE, IS95. an FM modulation block is also provided and can be set up either for band-limited mode, as required by AMPS/NMT, or for pulse shaping mode as required by GSM.
- Sample rate NCO: it is a 48 bit programmable oscillator that provides the clock and phase information to data input FIFOs, shaping filters and interpolation filters.
- Shaping filters: this block contains an interpolating FIR filter which could be used for pulse shaping.
- Gain profile block: it provides -0.0026 to -144 dBFS of programmable gain and transmit profile shaping control.
- Halfband filter: it is designed to reduce interpolation image and improve the overall SFDR of the output gain profile block signal.
- Interpolation filter: it provides the channel with its final filtering and resampling.
- Complex mixer and carrier NCO: it provides the resources to perform frequency up conversion where the result is a 20-bit I and Q output signal.
- Gain control: unwanted changes can be compensated by this device.



- Output routing, summing and control: the routing block allows each of the four channels the possibility of being connected to one input on each of the four summer blocks. the 4 input summer has an additional input which is used to put the ISL5217 into a cascade mode.

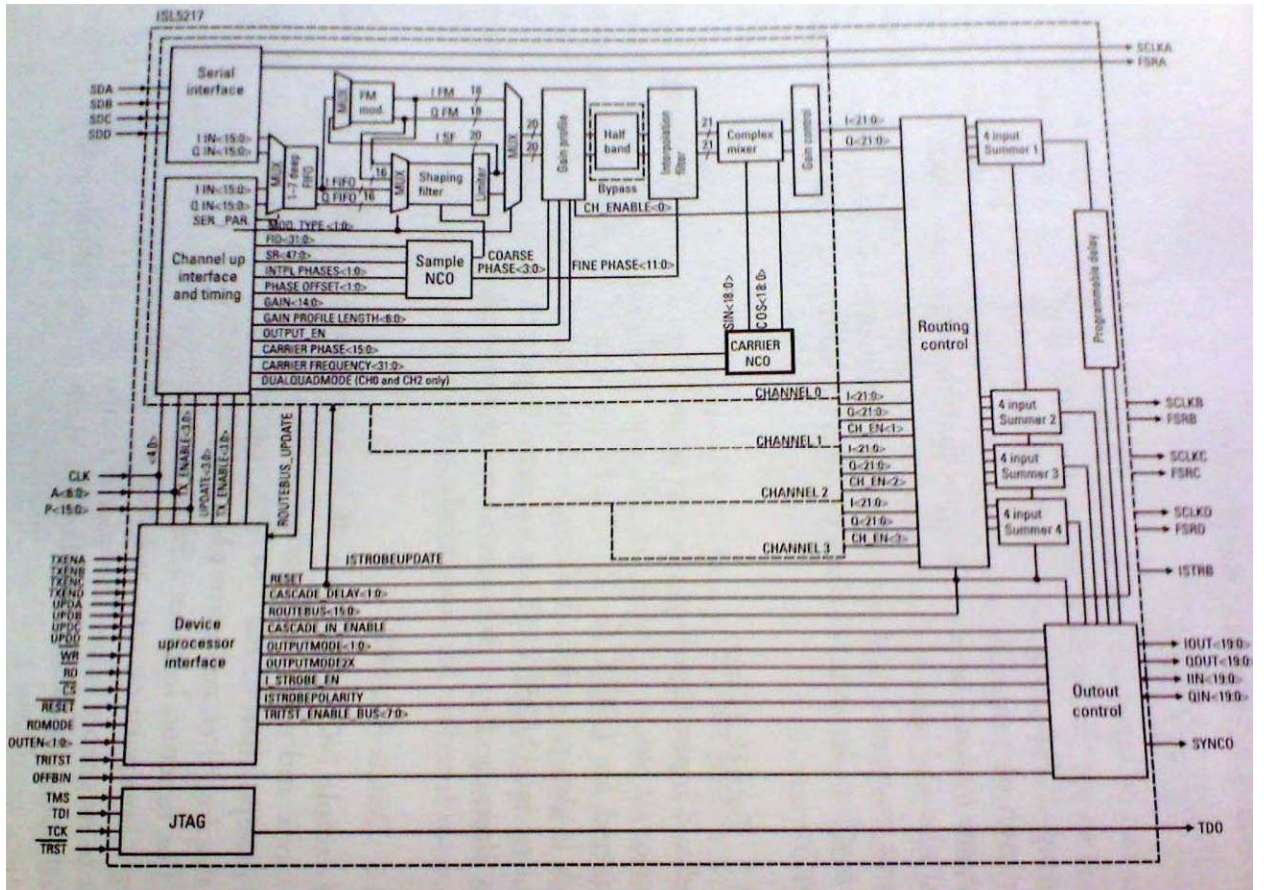


Figure 4: ISL 5217

- ISL 5216: the maximum output BW for each channel of this quad DDC is 1MHz. higher output BWs are achievable by cascading filters and polyphasing the outputs.
- CIC filter: it can be configured between one and five stages. a barrel shifter is included prior to the CIC filter to provide gain control and keep the overall gain between 0.5 and 1.
- Filter compute engine: the FIR filter, AGC, Cartesian-to-polar coordinate converter processing block includes a flexible filter compute engine which is programmed in a way similar to a  $\mu$ processor.

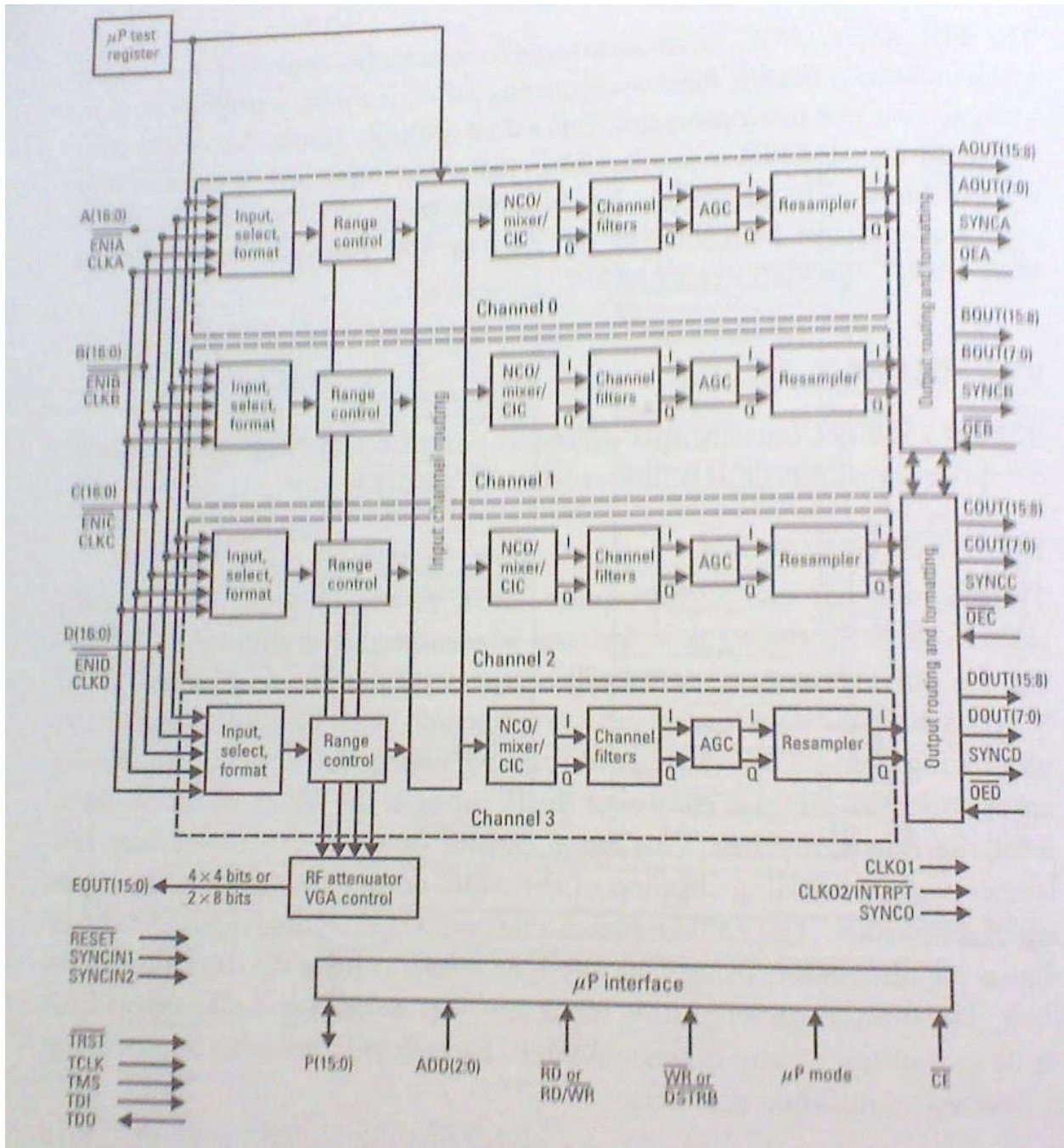


Figure 5 : ISL5216

- ISL5416: it is a four channel wideband programmable 3G-capable DDC.
- input functions: this device has four 17-bit input (A,B,C,D) each with its own clock to allow for timing skew for cases where there are multiple ADCs feeding the DDC. input will accept a maximum sample rate of 80 MSPS, where the data format can be represented as 16-bit fixed point or 17-bit floating point.



- Mixing and filtering: each of four channels contains an NCO/mixer to perform the frequency down conversion to baseband followed by CIC filtering, channel filters, AGC, and a resampling filter.
- Output routing and formatting: they are provided between the resampling filter block and the eight 8-bit parallel output buses. The output buses can be configured as eight 8-bit outputs, four 16-bit outputs, or two 32-bit outputs.

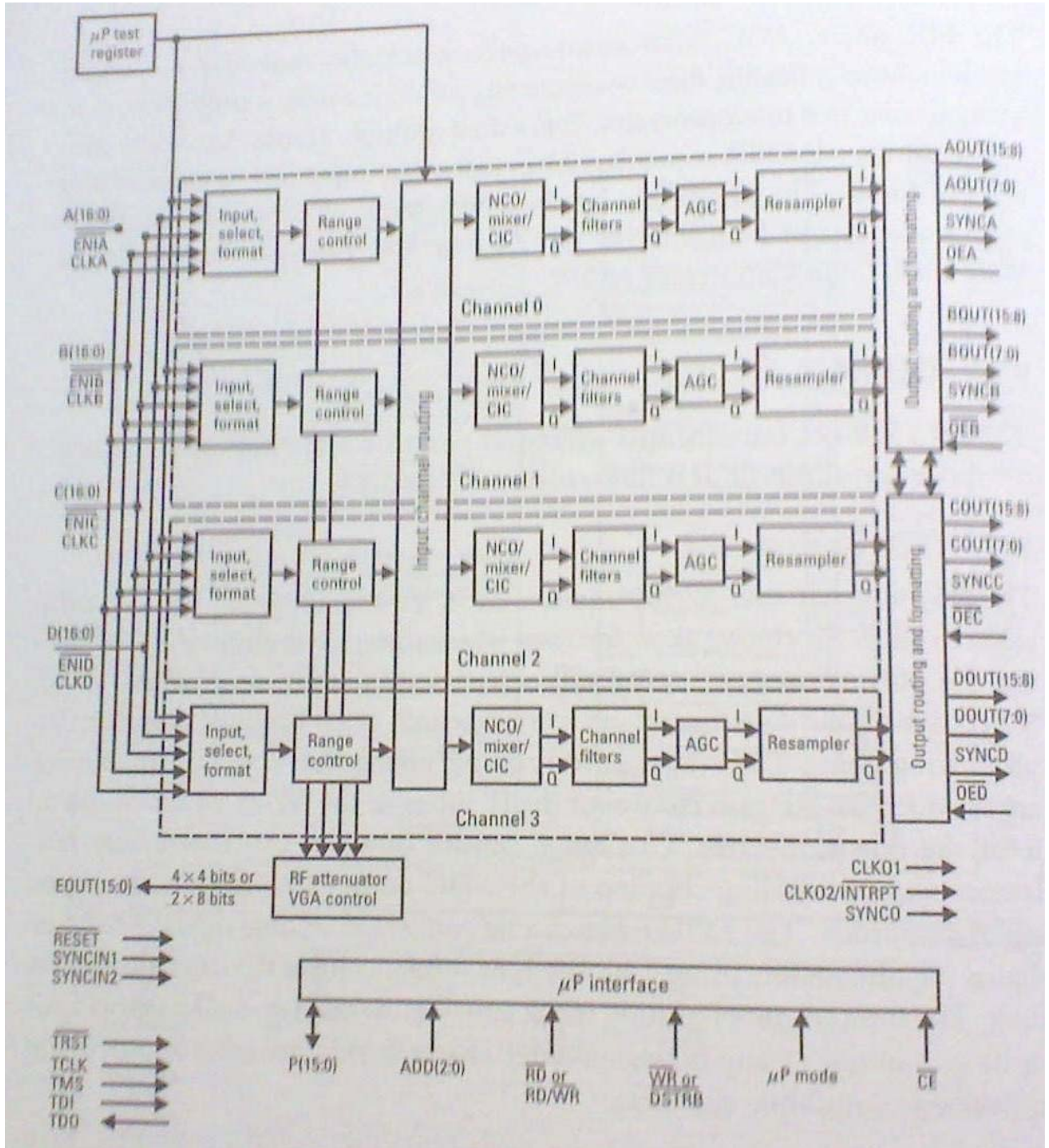


Figure6 : ISL 5416

## 5- CDMA fundamentals:

5-1: spreading: WCDMA and cdma2000 use direct sequence spread spectrum to transmit and receive digital information. the on-air (spread)signal is produced by multiplying the symbol signal by the spreading signal and then modulated onto an RF carrier for transmission. after demodulation in the receiver and synchronization with the spreading code, the on-air bits are multiplied and integrated to recover the transmitted symbols.

5-2: multiple access: spreading codes are also used to implement the multiple access by choosing groups of codes that orthogonal to each other. Orthogonality allows different information streams to be multiplexed together for transmission through a single physical pipe and demultiplexed without loss at the other end.

5-3: RAKE receiver: with considering the transmission between a mobile and a BTS each of the multipath signals arrive at the receiver with different time offsets. multipath is a significant problem in TDMA systems such as GSM and it causes ISI which usually minimized by using an equalizer. one of the great advantage of using DSSS is that multipath could be improve the system performance. figure illustrate a four finger rake receiver as typically deployed in BTS. each finger oversampled baseband in-phase and quadrature digital data from a DDC, this time series is also fed to path searcher which despreads the DDC output data and completes this operation many times using different time delays and the range of searching equates to the cell radius plus an allowance for delay spread. strong multipath signals appears as peaks in in the figure. timing information received by the code generation function is used to synchronize the despreading code and allow to finger to lock onto an individual multipath. the correlator multiplies the incoming data by the despreading code and integrates it to produce symbols. resultant symbol data can still have some phase rotation and removed by the phase rotation function, it uses phase data from the channel estimator which in turn uses the pilot symbols for estimating the channel state. the final step in the process is for the combiner to add the active output with the aim of producing a larger SNR when compared with that of a single finger. with using maximal ratio combiner and weights the contribution of each finger to maximizes the SNR.

5-4: soft handoff: this feature in CDMA systems reduces the dropped call rate during a mobile's transition between cells or sectors, for this reason the mobile periodically searches for candidate BS and relays their power strength measurements back to the current BS. BSC first allocate resource in new cell and then transfer the call.

5-5: power control: all multiple access spread spectrum systems must use some form of power control mechanism to ensure adequate capacity. Different channels must be closely matched in amplitude to maintain the degree of orthogonality and limit the degree of interference. WCDMA and cdma2000 control the power of the up and downlink transmission at a rate that balance increased system capacity with increased complexity.

## 6-macro and micro cell specifications:

Macro cells have radius equal to  $r$  where  $1Km < r < 35Km$ . they need to provide higher reliability and umbrella coverage, therefore should have bigger power amplifiers and higher antenna system and providing fall-back capacity when a micro cell fails or is required to be taken off-line for a period of maintenance or upgrade. if the density of users increases, these macro cells start to become overloaded and network capacity is usually improved by adding micro and Pico cells in hot spots. in figure 7 we see an architecture for macro cells. we see three key component: hardware platform, operating software, application software. the hardware is partitioned into three functional blocks: analog RF, digital IF, digital signal processing(SP).each RF block represents a complete wideband receive or transmit chain capable of processing up to 20MHz of spectrum. the RF chain is responsible for A/D,D/A, analog up and down conversion to a common digital IF, low noise receive amplification and power amplification. RF chains are connected by a flexible switching matrix to the digital IF section. On the receiving side for a given instance, IF processing includes selection of a carrier at the common digital IF frequency as well as filtering, decimation and frequency down conversion to baseband. On the transmit side, IF processing includes digital frequency up conversion from baseband, rate matching and carrier combination to present a single wideband multicarrier source to a D/A converter. the SP blocks represent high capacity generic digital signal processing cards. they are the prime layer one resource in BTS, being responsible for source traffic and control channels from the BSC and encoding and modulating them as per the resident layer one air interface applications.

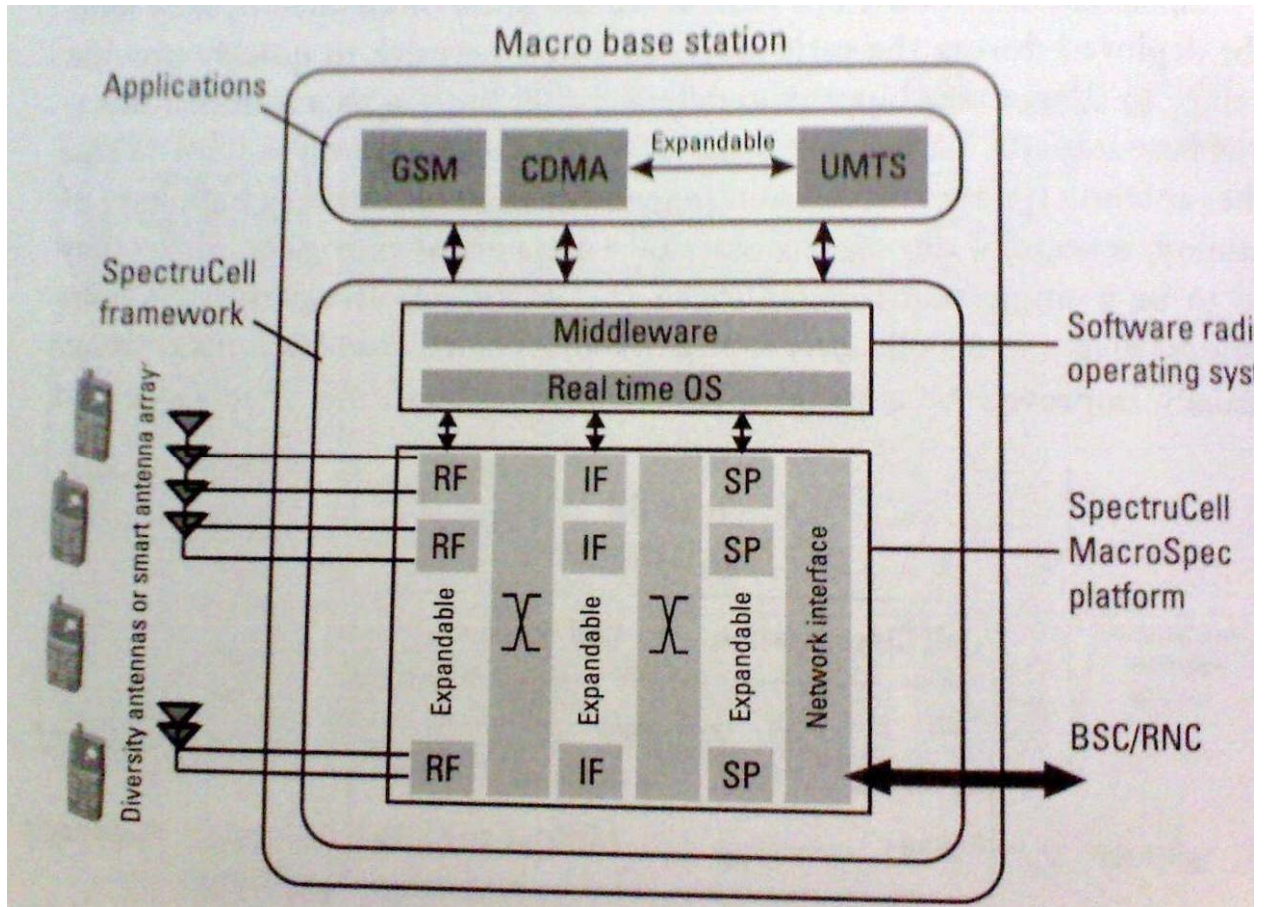


Figure 7 : macro cell BS

The micro cell specification is illustrated in figure .it is designed for high user density and small cell area traffic scenarios requiring lower power RF power amplifiers. the SDDP card includes IF, SP, system controller and network interface functionality. more capacity can be added with additional SDDP cards and extra RF hardware is usually not necessary.



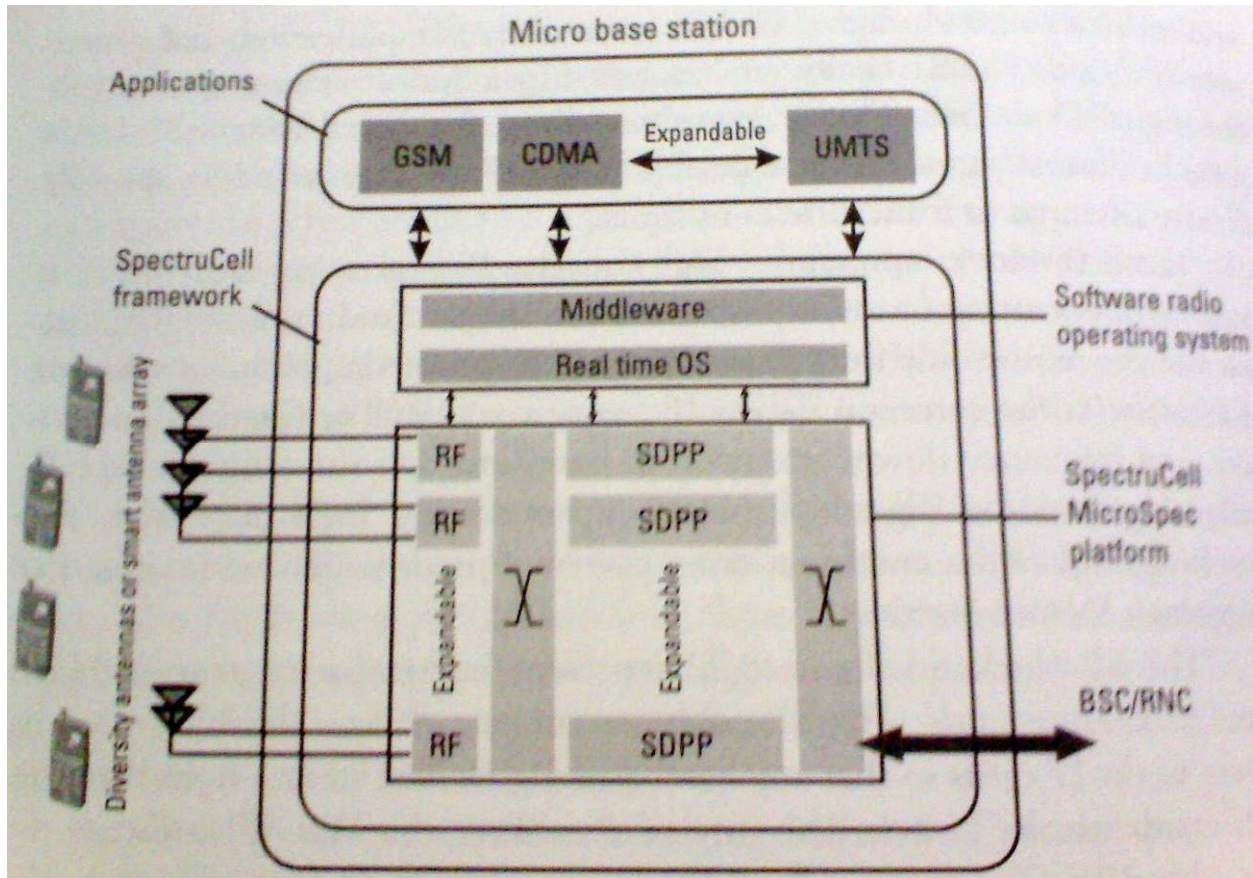


Figure 8 : micro cell BS

### 7-multi user detection techniques:

Multi user detection techniques can be applied both the uplink and downlink. but due to processing power constraints in the MS, MUD exploited first in BS. the two UTRA modes i.e. FDD and TDD can benefit from MUD techniques. in fact the joint detection algorithm is already an inherent part of TDD mode. studies on MUD techniques for WCDMA BS receiver indicate that a multi stage parallel interference cancellation(PIC) may suit well WCDMA systems with a single spreading factor. The parallel interference cancellation implies that interference get cancelled from all users concurrently. MUD techniques for multi service WCDMA with a variable spreading factor have been handled by group-wise serial interference cancellation(GSIC) receiver designs. in this techniques users with a given spreading factor are also detected concurrently after which the MAI originated by them gets suppressed by the users having different spreading factor.



## 8-packet oriented architecture:

The introduction of UMTS benefited from the established GSM building blocks and architecture. It has even added further IP subsystems, e.g. IP Radio-Access Network (RAN) transport and IP-Multimedia Subsystem (IMS). If we look at the Network Elements (NE) of the established mobile infrastructure illustrated in Figure (left), we shall notice that Node B's have limited functions, which make the channel quality feedback slow. This architecture has:

- circuit-oriented design inappropriate and inefficient for bursty traffic
- scheduler at RNC—slow resource allocation
- slow updates for SHO during cell selection

A packet oriented MAC model illustrated also in Figure 1.9 (right after [17]) would allow a more dynamic interaction of core and Mobile Station (MS), resulting in :

- a spectrum efficient packet-by-packet fast scheduling
- Fast Resource Allocation (i.e. code, modulation and bandwidth) with the scheduler at the BTS
- Fast Cell Switching (FCS) due to the optimization for packet data delivery, capacity coverage and high data rate at the cell edge

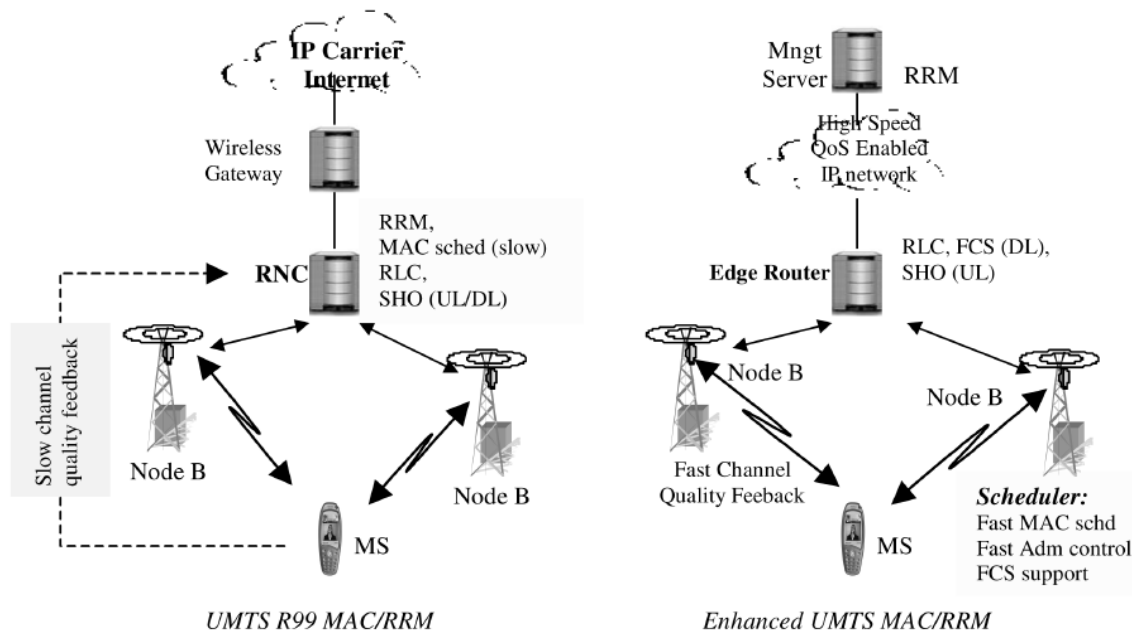


Figure 9 : MAC/RRM in R99 and enhanced UMTS

## 9-conclusion:

This paper discussed about common methods in mobile communications which using SDR concepts to have handheld and base stations which support more than one air interface and could be switches between them.

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