RTT TECHNOLOGY TOPIC
November 2001

CDMA explained

This Hot Topic explains how CDMA works and how processing gains are achieved. The example used is W-CDMA/IMT2000DS/UMTS but the generic benefits apply to all CDMA systems including the CDMA2000/1xEV networks presently deployed in the USA and Korea.

We identify the performance differentiation achievable from a CDMA air interface when compared to existing TDMA (GSM/GPRS, IS136 and/or TETRA/iDEN) air interfaces.

In a small break with tradition, this Hot Topic will also be appearing in a future edition of Land Mobile Magazine, analysing the impact of CDMA on specialist users - police, fire, ambulance and public sector/public safety applications.

If you are interested in benchmarking future specialist user needs in more detail, we recommend the Land Mobile web site www.landmobile.co.uk.

TRADITIONAL PERFORMANCE PARAMETERS

Traditionally, RF engineers have been concerned with three performance parameters: sensitivity (the ability to process a low level signal in the presence of noise); selectivity (the ability to recover wanted signals in the presence of interference); and stability (the ability to stay on a wanted frequency when transmitting and receiving).

A 'good' radio would be a radio with a very carefully designed RF 'front end' with performance being dependent on good LNAs (Low Noise Amplifiers), ceramic and/or SAW (Surface Acoustic Wave) filters and frequency references, oscillators and phase locked loops to deliver short term and long term stability.

THE OBJECTIVE OF CDMA - SIMPLE SENSITIVITY, SELECTIVITY, STABILITY

The objective of using CDMA (Code Division Multiple Access) is to achieve these processes digitally. The benefits in a well designed CDMA transceiver should include better performance (sensitivity, selectivity, stability) and as a consequence, a more efficient use of available RF power.

SOURCE CODING

As with GSM, IS136 and TETRA/iDEN air interfaces, the first step with a CDMA transceiver is to digitise the traffic to be processed. Speech is digitised using a vocoder, imaging and video are digitised by using an M-PEG (Motion Picture Experts Group) encoder or equivalent encoder/decoder.

The result is that all the source 'inputs' to the handset are in the form of binary values represented by noughts (0) and ones (1).

THE CONCEPT OF DISTANCE

Simplistically you might think a '0' is a '0' and a '1' is a '1' but in practice, the noise processes involved in radio transmission and processing introduce uncertainty - is it a 0, is it a 1? This brings the concept of 'coding distance'.

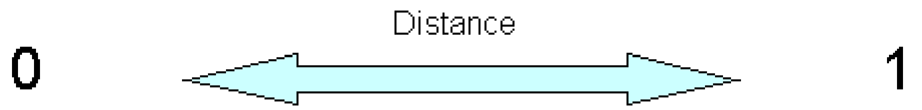

Figure 1

The further in distance apart we can move a 0 and a 1 in terms of certainty (is it a 0, is it a 1), the more sensitivity will be achieved.

ACHIEVING SELECTIVITY

Similarly, if we consider 2 code streams running in parallel with one another the greater the difference or 'distance' between the code streams, the better the selectivity between users.

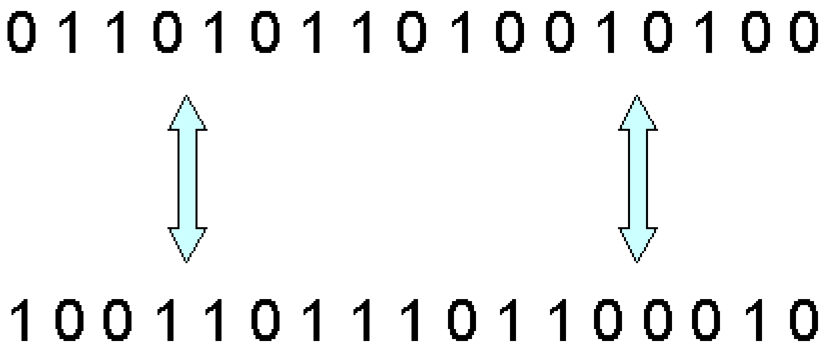

Figure 2

The distance between the two codes above is the number of bits in which the two codes differ (11!!).

TYPES OF CODE

In CDMA, there are two types of codes - spreading codes and scrambling codes. Spreading codes deliver sensitivity and channel selectivity, scrambling codes deliver user selectivity.

HOW SPREADING CODES WORK

Let us first consider how spreading codes work:

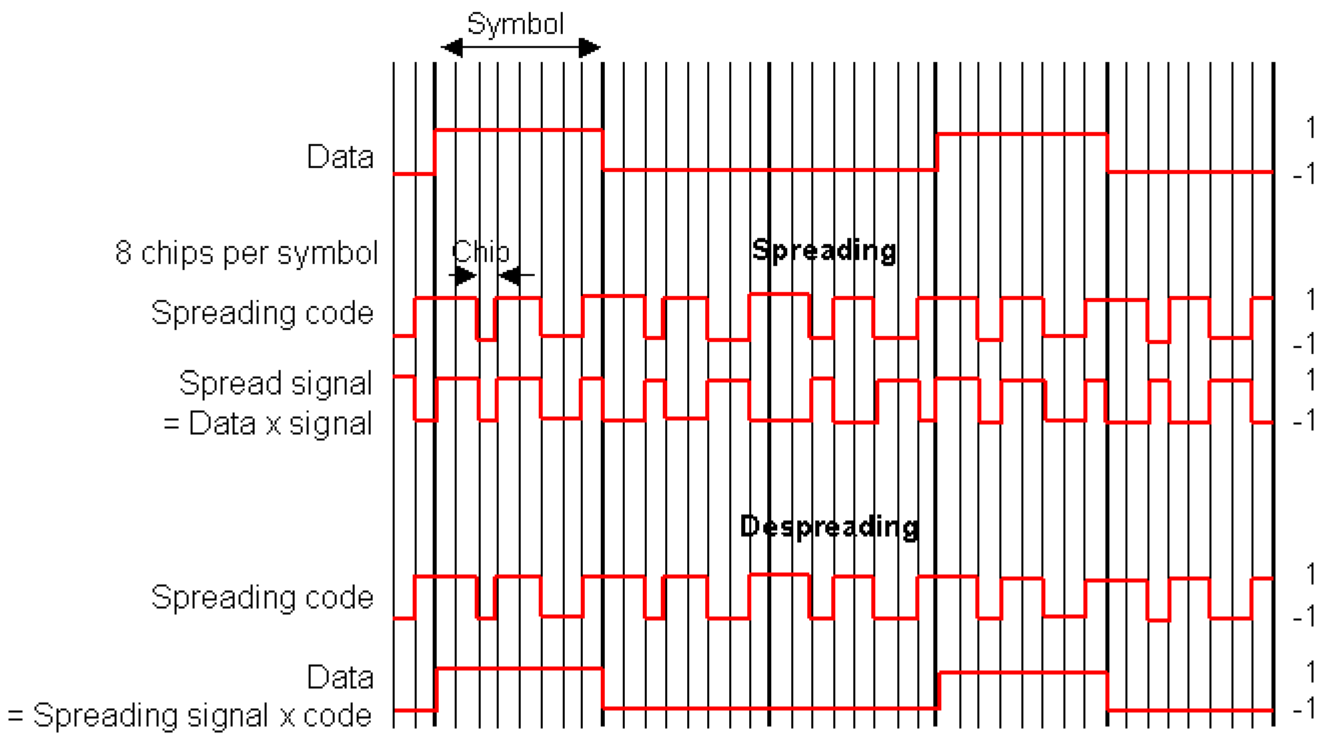

Figure 3 - Spreading and Despreading in IMT2000DS

The 'data' (voice, image, video) comes in as a 0 or a 1 and is described digitally as a +1 or as a -1.

It is then multiplied with whatever the state of the spreading code is at any moment in time using the following 'rule set'.

Data	Spreading Code	Output
-1	-1	+1
+1	-1	-1
-1	+1	-1
+1	+1	+1

Figure 4

In this example, the original data (+1 or -1) is multiplied with the spreading code 8 times before changing state. This is described as the number of chips per symbol. The spreading code runs at a constant rate (3.86 MHz, ie 3.86 Mchips per second) but the input data rate can change. As the input data rate increases, the spreading ratio, also known as 'chip cover' decreases. As the input data rates decrease, the spreading ratio increases. As the spreading ratio increases, the spreading 'gain' increases. It is this spreading gain (from the despreading process) that provides improved sensitivity particularly at lower user data rates.

SPREADING GAIN

The way spreading gain is achieved is shown in the next figure:

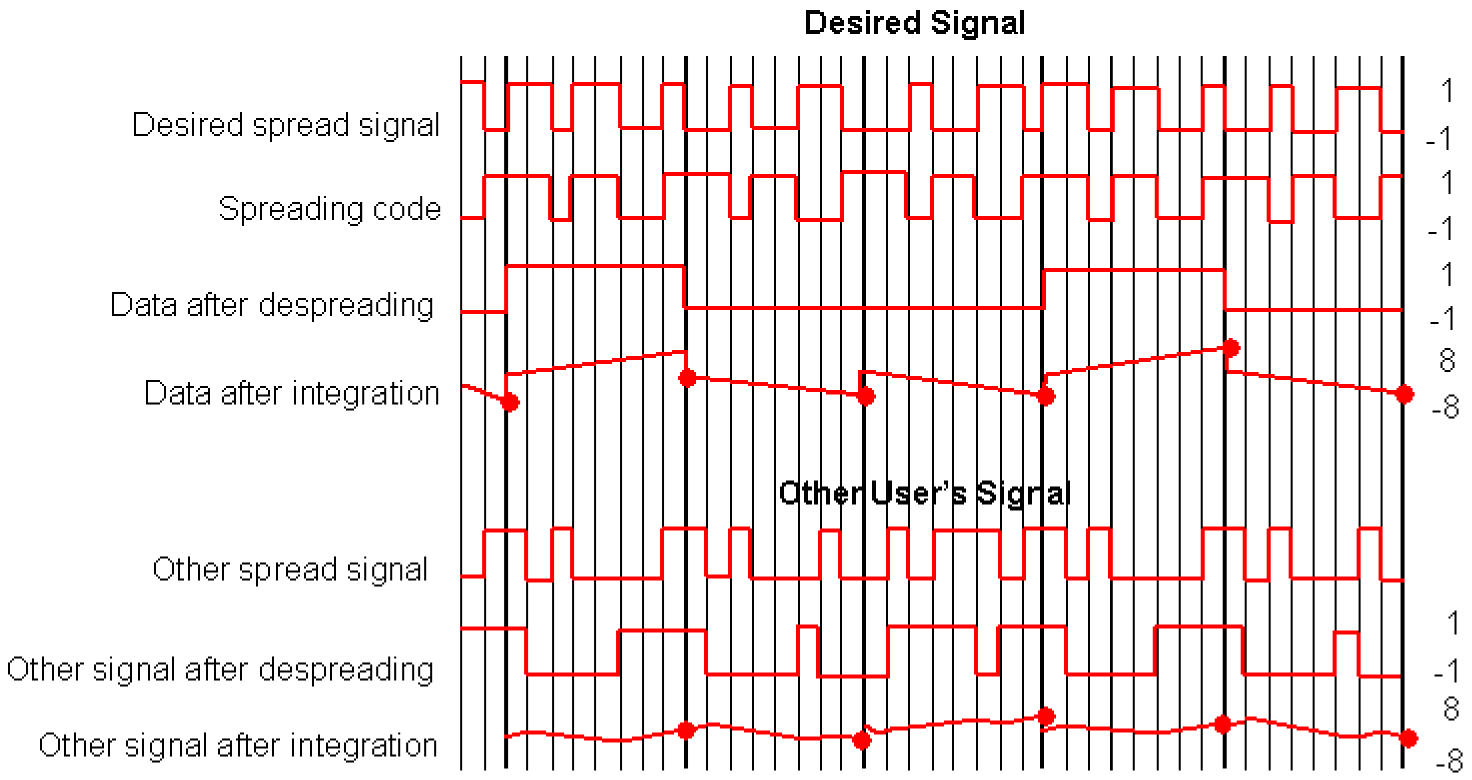

Figure 5 - Orthogonal Variable Spreading Factor Codes

You can see from the example that the wanted signal is despread by running the same spreading code (now a despreading code!) at the same rate in the receiver with the result that the +1 and -1's become +8 and -8's (ie further apart).

The spreading code 'decorrelates' the signal energy of interest and in the process confers spreading gain to the decorrelated signal. Other spreading codes present in the radio bandwidth will not match the despreading code and will remain in the noise floor.

The chip cover, ie the ratio between the original data rate symbols and the spreading code, can be from 4 chips per symbol to 256 chips per symbol. A 15 kbit data rate on the uplink for example could have a chip cover of 256 chips per symbol and would enjoy maximum spreading gain (maximum sensitivity). A 960 kbit data rate on the uplink would have a chip cover of 4 chips per symbol and would have minimal spreading gain. The difference between the two data rates would typically equate to over 20 dB in terms of link budget sensitivity.

ORTHOGONALITY AND THE CODE TREE

Note the codes in figure 5 are described as orthogonal variable spreading factor codes (OVSF codes).

Orthogonal codes are codes of equal distance (the number of bits by which they differ is the same). The cross correlation (effectively code interference) between orthogonal codes is zero for a perfectly synchronous transmission.

The clever part of the orthogonal variable spreading factor codes is that they preserve the property of orthogonality even though the input data rate may constantly change.

This is achieved by using a code tree:

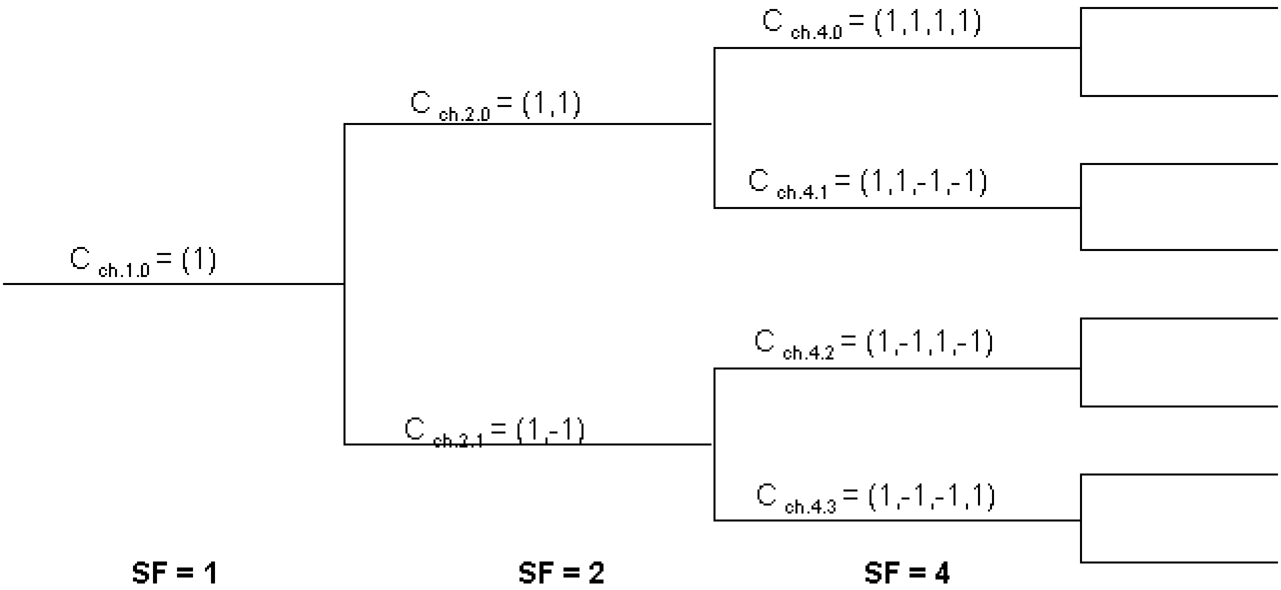

Figure 6 - OVSF Code Tree - Downlink Channel Selectivity

Each branch of the tree uses the same mother code - you just use more of the code as you move to the right of the diagram.

A chip cover of 4 (the minimum allowed in the 'rule set') gives a spreading factor of '4' (SF = 4). As you can see from the diagram, only four codes are available. As you move to the right, so the number of code channels increases but the supportable data rate goes down. Furthest to the right (no room to show it on this diagram) you would have 256 code channels available but each channel could only support 15 kbit.

On a downlink from a base station for example, a single 5 MHz channel could support four high rate users or 256 low rate users or any mix in between.

UPLINK CHANNEL SELECTIVITY

On the uplink, the OVSF codes are used differently:

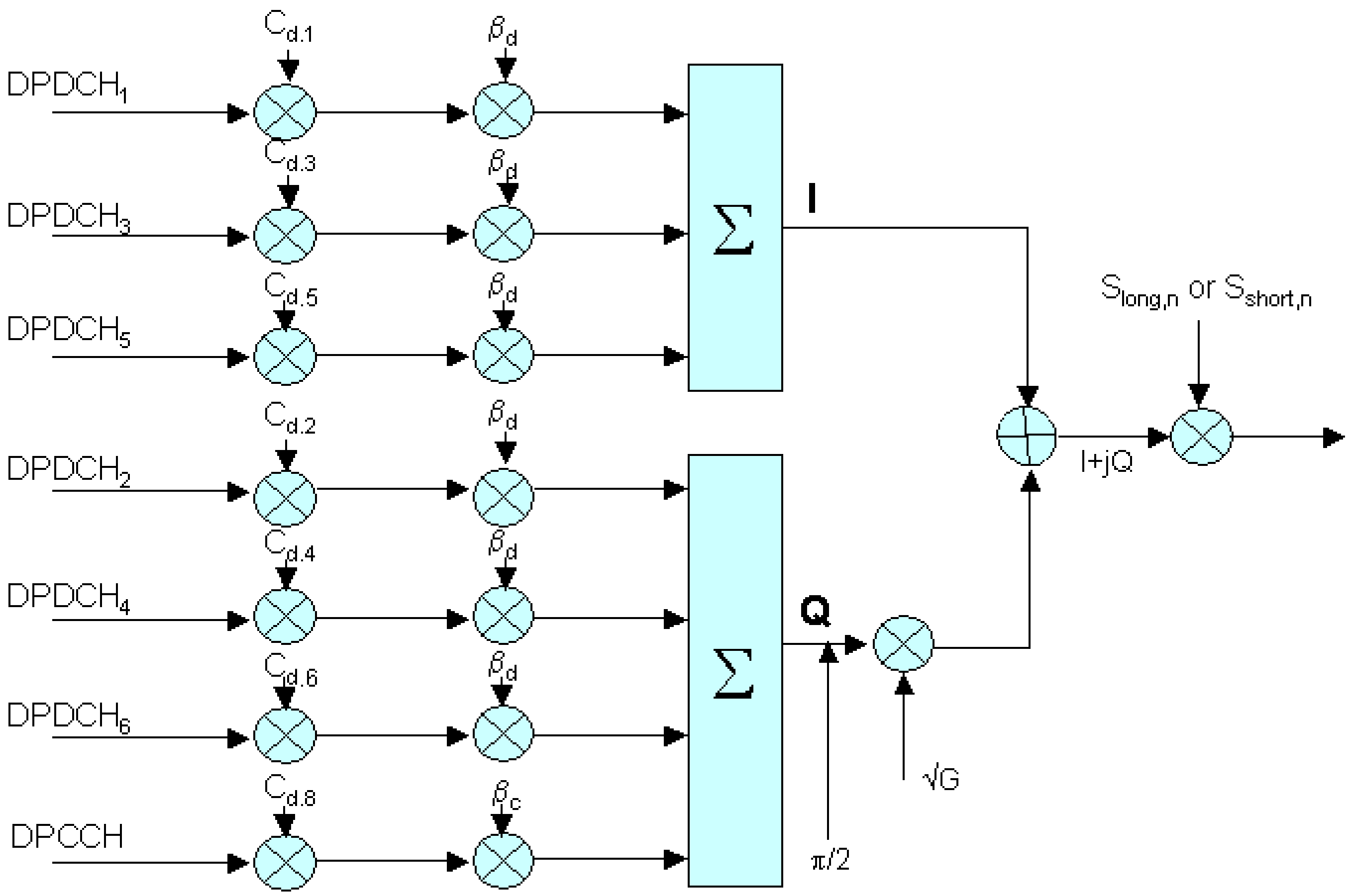

Figure 7 - Uplink Channel Selectivity

There is one control channel (DPCCH) and up to six data channels (DPDCH). The I and Q refer to in-phase and quadrature, in effect the way the code channels are modulated on to the RF channel. The b functions weight the channel energy to balance the code energies, p/2 creates the 90° phase off-set and ÖG balances the I & Q channel energy.

The spreading codes therefore provide a neat way of delivering constantly changing data rates without compromising code performance and provide the ability to deliver multiple per user channel streams on the uplink and downlink, eg a voice channel with simultaneous and parallel encoded image, video and application streaming, ie sensitivity and channel selectivity.

UPLINK USER SELECTIVITY - SCRAMBLING CODES (LONG AND SHORT)

Note also in the diagram the addition of long and short scrambling codes. The job of the scrambling codes is to deliver user to user selectivity. This job is much harder on the uplink than the downlink. For instance you might have six base stations 'in view' from a handset but a base station might be 'seeing' thousands of mobiles.

On the uplink, a long code (38,400 chips truncated to fit into a 10 millisecond frame) is used so that the base station can separate out different users (remember each user could potentially be delivering up to 6 channel streams). A short (256 chip) code is also optionally added to allow the base station to do additional digital filtering of unwanted (ie other users) signal energy.

STABILITY

The final parameter we discussed was stability. The diagram shows how the spreading codes (OVSF codes) and scrambling codes are generated in a phone and managed (in time) by a numerically controlled oscillator (NCO).

An NCO is a digital clock generation process allowing for very fine phase adjustments.

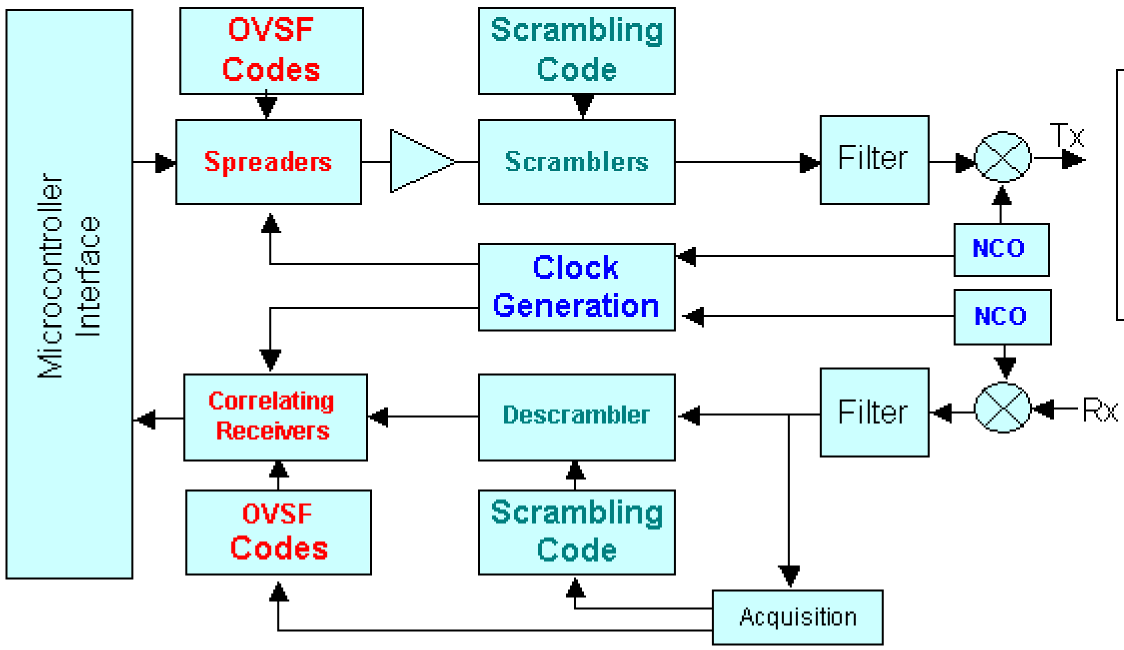

Figure 8 - W-CDMA/IMT2000DS/UMTS transceiver

Note also that the use of a 5 MHz channel relaxes the frequency stability required when compared to a narrow band (12½ or 25 kHz or 200 kHz) transceiver so the main parameter to control is time stability, eg code synchronicity - an easier (less component intensive) task.

REDUCING RF COMPONENT COSTS

The other benefit of moving to a 5 MHz RF channel is that there are less channels to process in a 3G CDMA phone.

		Spectrum	ChannelSpacing	No of RFChannels
1G	E-TACS	33 MHz	25 kHz	1321
	AMPS	25 MHz	30 kHz	833
2G	GSM 900(E-GSM/GSM-R)	39 MHz	200 kHz	195
	GSM 1800	75 MHz	200 kHz	375
3G	IMT2000	60 MHz	5 MHz	12

Figure 9

Figure 9 shows how the job of RF channel selectivity has become easier with each successive generation of cellular technologies - from 1321 x 25 kHz ETACS channels in a 1G cellular handset to 12 x 5 MHz channels in a 3G CDMA handset. The result should be lower RF handset component costs and simpler (and in the longer term smaller and lower cost) base stations.

THE (USER) BENEFITS OF A WIDE BAND CHANNEL

The radio channel between a mobile and a base station is affected by a number of factors that contribute to signal fading.

This fading effect is shallower in a wide band channel due to an averaging effect across the available bandwidth.

By careful design, both the slow fading and fast fading in the channel can be 'hidden' by decreasing and increasing the RF power of the handset. IN GSM, power control is done twice a second. In CDMA, it is done 1500 times a second - the result should be a more consistent user experience, ie a 'constant quality' channel.

DYNAMIC RANGE

We said that the job of the OVSF codes is to support variable data rates. User data is mapped on to the 15 slot 10 millisecond frame and the number of bits per slot can vary from 10 to 640 bits on the uplink (15 kbits to 960 kbits) and 10 to 1280 bits on the downlink (15 kbits to 1920 kbits).

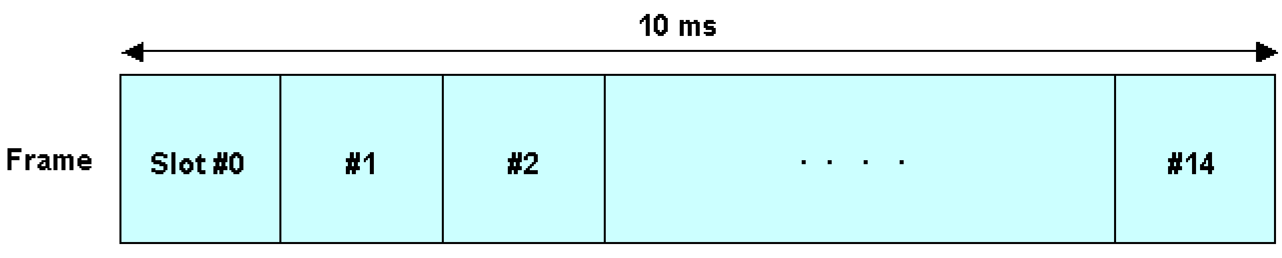

Figure 10 - Slot and Frame Structure in IMT2000DS

The channel rate can be set either when a coded channel is allocated (static rate matching) or dynamically every 10 milliseconds (dynamic rate matching).

In theory (and in the longer term in practice) this will mean that the data rate could be 15 kbits in one 10 millisecond frame, 960 kbits in the next frame and 15 kbits in the next frame.

Ratio	1		64		1
Data Rate	15 kbits		960 kbits		15 kbits
Frame	10 ms	-	10 ms		10 ms

Figure 11 - Dynamic Range - The Data Rate 'Excursion' Limits from Frame to Frame

This is a ratio of 64 to 1 or in technical terms a dynamic range of 18 dB. It is far greater than TETRA (4 to 1) or GSM (8 to 1) where in both cases the dynamic range is limited by the legacy slot and frame structure and limited baseband coding.

It will be very difficult to support highly bursty 'rich media' traffic, ie a simultaneous mix of voice and non-voice products, on a TETRA or GSM/GPRS air interface due to these dynamic range limitations.

THE SHIFT IN USER EXPECTATIONS

Which brings us to how user expectations will change over the next few years. Present 2G technologies, including TETRA and GSM were designed to support (more or less) constant rate channels. Later iterations of GSM (GPRS and EDGE) and TETRA (TETRA multislot proposals) can only offer limited 'bandwidth on demand' and are effectively constrained by their legacy slot and frame structures.

The simultaneous source encoding of voice and non-voice products (image, video and application streaming) implies highly bursty 'asynchronous' traffic and parallel encoding and decoding of multiple per user data streams.

Such traffic is essentially ill suited to the legacy air interfaces presently used in our public and private networks.

CDMA offers a way forward towards a more flexible and future-friendly radio network for public, private and specialist user communities and allows us to move from the constant rate variable quality channels that we have today to variable rate constant quality channels - bandwidth quantity and quality.

Contact RTT

RTT, the Shosteck Group and The Mobile World are presently working on a number of research and forecasting projects in the cellular, two way radio, satellite and broadcasting industry.

If you would like more information on this work then please contact

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