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Solutions

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Soft diversity reception

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ABSTRACT

The professional mobile radio system are rapidly moving to digital modulation schema that allows to carry out both audio and data communications efficiently. The possibility to have at the same time and under the same radio system audio and data, open the door for a number of new services and applications. Changing from analog system to a digital one require to keep in account two main physical differences between them.

The first is the abrupt on/off of digital communications. Digital communication, differently from analog, gives an acceptable voice quality in all the coverage area but cuts the communication abruptly on the border area near threshold. The user may not have any advise (as the received noise increment in analog) before the loss of the communication. Therefore it is very important to assure the maximum margin on the RF link near the border of the service area.

Multipath fading is the second main aspect of difference. Digital communication is a stream of bit that carry out at the same time many information like coded voice, users ID, channel management, synchronisms and many others. A short fading event may destroy some critical information in the stream that requests a long time to recover the communication.

To contrast fading and to increase performances near the border threshold, the modern digital communication implements diversity reception. The soft diversity is a receiving technique based on the vector treatment of the incoming signals. The effect of a Soft diversity reception is a real time alignment of the antenna's lobes increasing the gain in the direction of the receiving signal. The main purpose is to assure good reception in the fading environments where a hole in the RF field may destroy a communication for a long time.

With digital modulation, the diversity reception becomes a crucial requirement, as it is also shown by the standardized use by all radio digital systems producers TETRA, GSM, GPRS, UMTS, WiFi, WiMax, ... Now this technique is available in DMR systems also thanks to the Radio Activity implementation in its base station.

Diversity antenna is a technique that gives superior performances in fading channels, increases the coverage of the radio cell and improves the overall grade of service of the system.

DIVERSITY RECEPTION

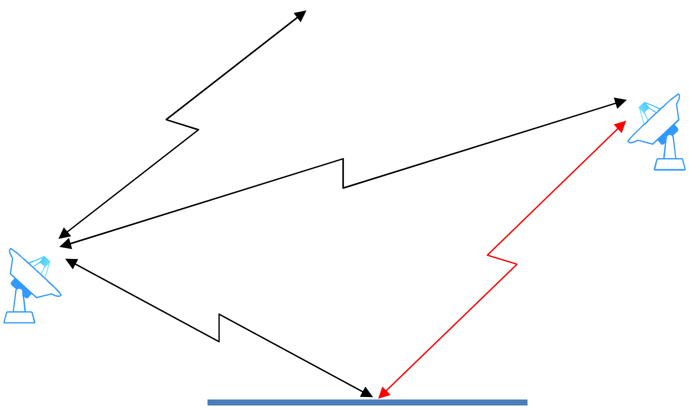
Understand fading effect

A radio communication suffers by the presence of reflectors in the environment surrounding a transmitter and receiver create multiple paths. The received signal is the sum of multiple copies of the transmitted one with different attenuation, delay and phase shift. The result may be destructive (phase opposite rays) or constructive (phased rays) giving attenuation or amplification on the received signal.

The multipath fading can often be so deep to produce a temporary failure of communication, due to a severe drop in the channel signal-to-noise ratio or a due to phase distortion and intersymbol interference in data transmissions.

As a result, it may be necessary to incorporate features within the radio communications system that enables the effects of these problems to be minimized.

To understand fading effect, consider a simple 2 rays model of propagation as described in the figure.

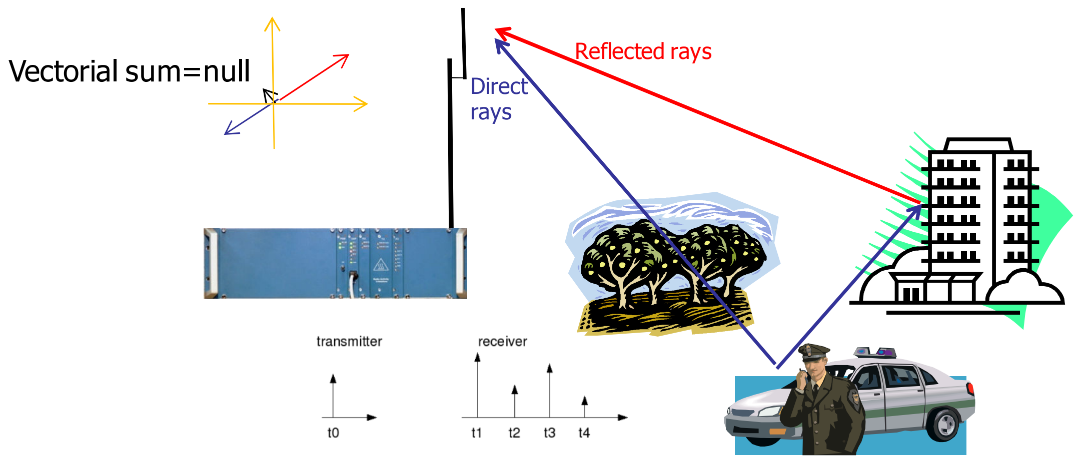


Coming from different paths, signals sum together with different delays (phases) and amplitudes, not predictable in a deterministic way. If reflected paths has a delay equal to half a wavelength (180° signal phase difference) the sum of direct and reflected signals will be affected by disruptive interference and received signal can suffer from a very strong attenuation. Also a carrier cancellation can happen.

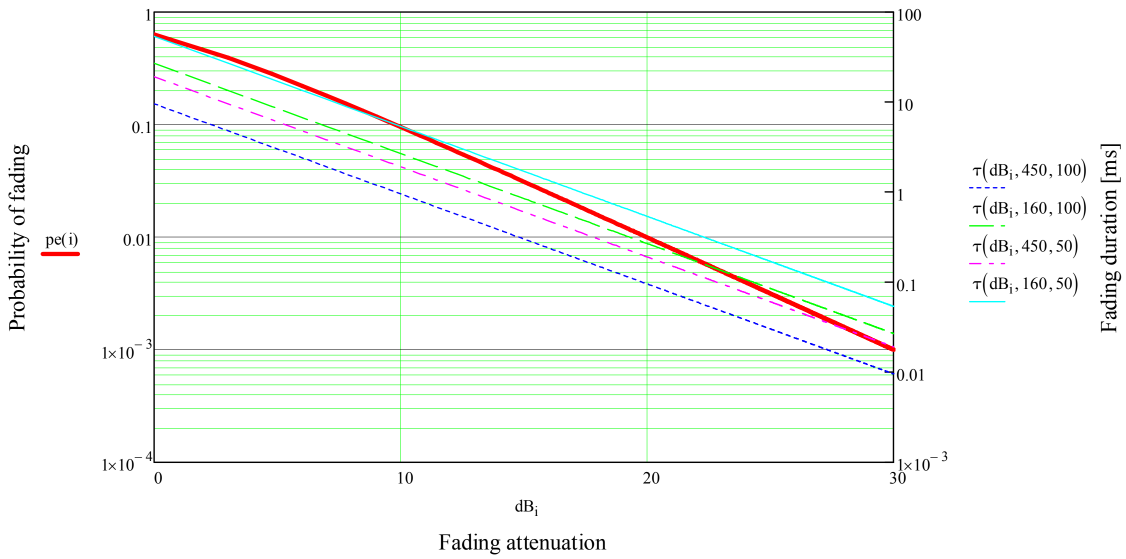
To produce a null in the vector sum it is necessary that the amplitude of the signals must be exactly the same with exactly opposite phase. If the relative amplitude or the phase differ a bit, there will be an attenuation (or an increasing if phase matches) instead of a null of the original signal.

In the real case there are several rays with different amplitude and phase. The relative phase has a uniform distribution from 0 to 360 deg (there isn't a preferable phase) therefore the attenuation follows a statistical law well known as Rayleigh multipath fading. The movement of the transmitter or of the receiver produces modification in the reflection paths and also a Doppler shifting effect that spread in frequency the rays.

The travelling paths from the source to the receiver depend from the radio transmitter or receiver position, or from the elements that give rise to the reflections. As a result, the multipath propagation is an evident experience when there is some movement of elements within the radio communications system, for example a car moving along a motorway.



The DMR is a narrowband radio system in VHF and UHF bands then, at normal speed up to 300Km/h, the fading may be considered stationary respect to the symbol rate.



The figure above indicates:

- in the left Y axis the probability of a fading event that produce an attenuation greater than the value indicated on the X axis; the red line gives the probability
- in the right Y axis the duration in milliseconds of a fading event that produce an attenuation greater than the value indicated on the X axis; the dot-lines represent the durations ad different value of speed and frequency band

In substance high attenuation events have short duration and low probability to happen.

Fading and dynamic sensitivity on DMR

The fading effect reduces the dynamic sensitivity of a system because it increases the probability of error in the communication. The DMR standard specifies many forward error correction techniques (F.E.C) able to mitigate the effect of B.E.R. on the communication.

The voice bit streaming is spread (interleaved) over some bursts to distribute adjacent errors, produced in a fading event, in "like random" errors. Then the F.E.C. processes try to recover the bits lost using the parity bits. In fact the voice is coded at 2450 bit/s and, after adding the F.E.C. redundancy bits, it is send on air at 3600 bit/s. Residual errors after the F.E.C. decoding process produce a smooth degradation of the voice.

The data communication is F.E.C. coded also, but some information are not spread over different burst. A fading event in some signaling bursts could break the communication when the voice suffers a low degradation only. This event is better explained in the following paragraphs.

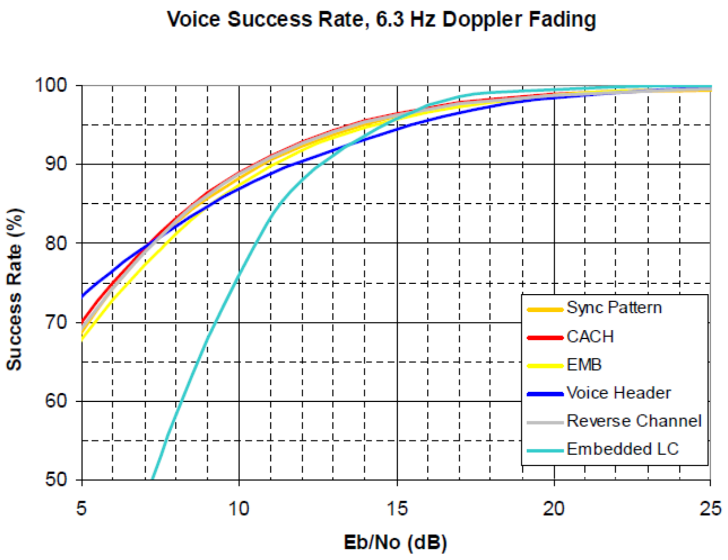


Figure 5.3: The roll-off of performance at coverage boundaries (walking speed)

Excluding for now the case of some signaling blocks not spread in more bursts, thanks to the data interleaving process, we can assume that a fading event will produce a random distribution of the error. It is then reasonable to consider the fading errors like an increasing of the B.E.R. of the channel.

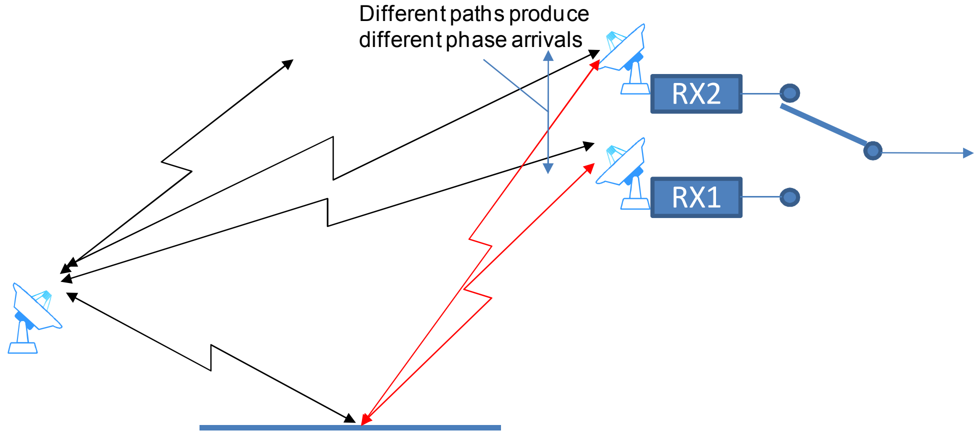
As indicative value we can consider that the DMR protocol works well under 1% of B.E.R. and it presents a threshold at about 5% of B.E.R. The 5% threshold vary depending from the manufacturer and the type of the receiver. For the Radio Activity base station a typical value is -118dBm, but in portable terminals it is more reasonable to consider a typical value around -113dBm.

A right margin respect to fading event may be choice from +20dB, that gives an additional 1% of B.E.R. due to the fading, to a +14dB that gives a 5% of B.E.R. (see the graph in the previous paragraph).

Considering a standard case of a DMR portable terminal, the minimum RF field to assure in the coverage areas may be around -93/-95dBm. Antenna efficiency and other propagation condition (e.g. a portable inside a car) must be keep in account to design the radio system.

Hard diversity reception

Hard diversity is a way to mitigate multipath fading effects often used in fixed point to point radio link. This solution uses two (or sometime more) receivers and antennas. The received signals are compared and when the selected one drops under a certain quality, a voting system commutates to the other receiving path. The concept is easy to understand: if the antennas are placed in different positions, when one antenna suffers destructive fading (phase opposite rays) the other one should have many chances to receive rays with different phases combined in a good signal.

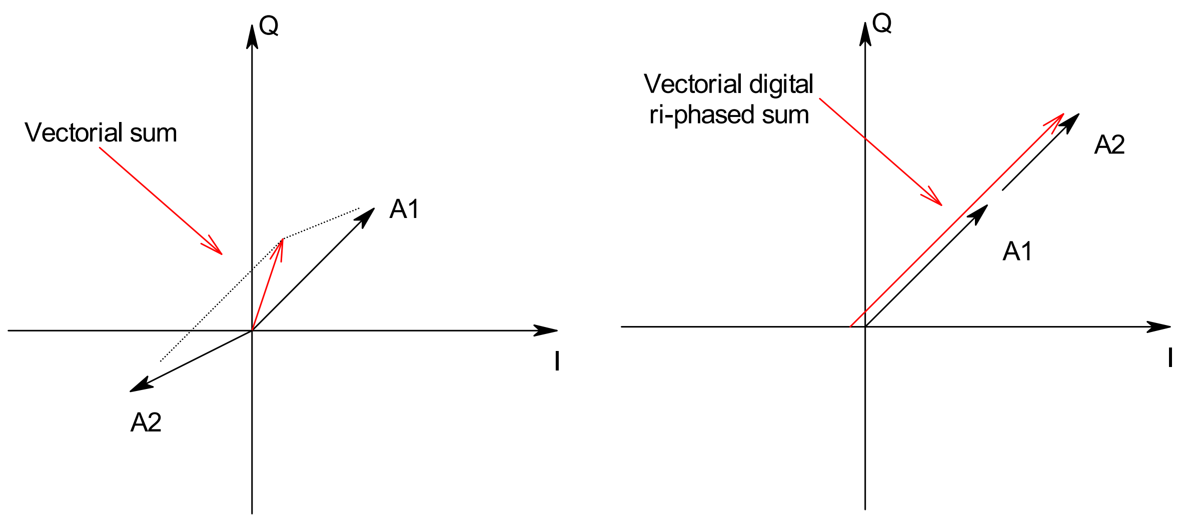


The switch that selects the best signal may introduce or not a loss on the communication during switching. This simple implementation of diversity reception may help in static environment like point to point radio link but it is not the optimum in a mobile one in which the selection must be very frequent and other important effects shell be kept in account.

Soft diversity reception

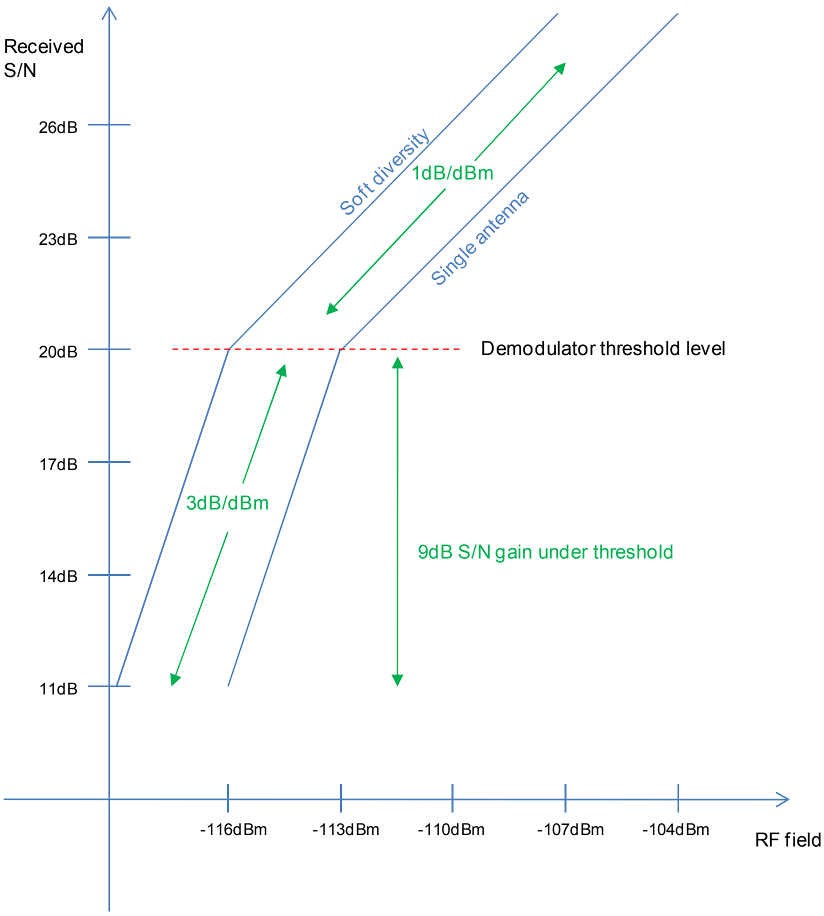
The soft diversity is a receiving technique based on the vector treatment of the incoming signals. A modern radio transceiver uses often a Digital Signal Processing (DSP) unit to demodulate the signals. The demodulation process is done by software algorithms instead than hardware circuitry. For this reason a similar transceiver is called “software defined radio”.

The demodulation process is a mathematical operation over the incoming signals. The signals on the antennas are amplified and filtered by two receivers with the same local oscillators (coherent receivers).
The receivers give the signals in I/Q vector format as shown in the following figure.



The signals are vectors in the I/Q plane with different phase depending on the phase arrival on the antennas. The DSP unit may re-align the signals by a simple real time math process. After the realignment the signals are summed (with some care) to give a stronger vector. After sum the resulting signal is demodulated.

The demodulation is a non linear process over the received signal. It extracts the phase through an arctangent calculation. As any non linear process, it suffer of a threshold respect to the incoming signal to noise ratio. Under the threshold the distortion increase very rapidly (3dB every 1dB of field). Demodulation after summing gives superior performances as displayed in the following figure that represents a simple model of the reception of an analog signal:



The soft diversity reception implements not only a switch from two antennas but is able to extract all the information from both the antennas contemporary. This fact gives many advantages in the real cases respect to the hard diversity (or voted diversity).

The soft diversity reception gives a number of benefits on the receiver capability of the base station:

- it gives 3 dB more of sensitivity
- it contrasts the multipath fading
- it reduces the de-sensitivity effect in the repeater placed at high altitude
- it increases significantly the coverage area of a repeater

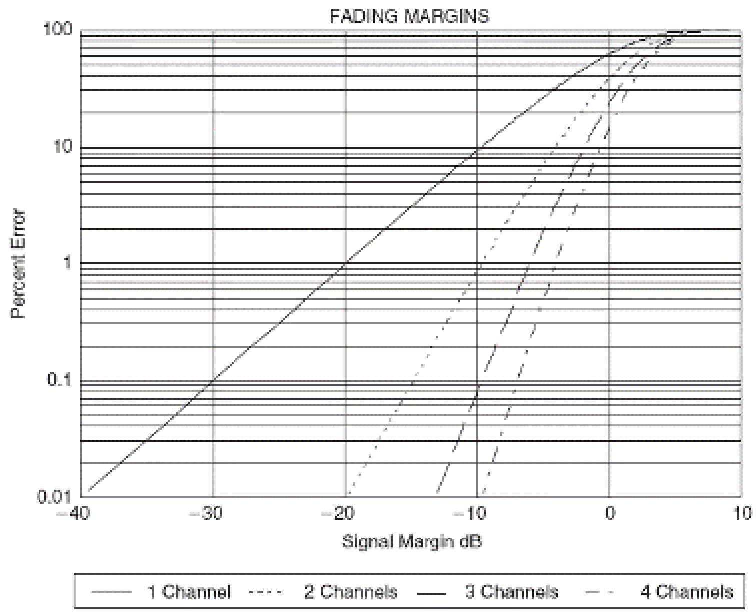
The diversity algorithms work properly in digital and in analog mode. For analog modulations, the obtained benefit by this technology is significant, but non determining, while for systems with digital modulation, it becomes a fundamental requirement.

<u>Soft diversity antenna technique is recommended in every digital communication like DMR. Radio Activity base stations implements a very efficient digital diversity reception</u>.

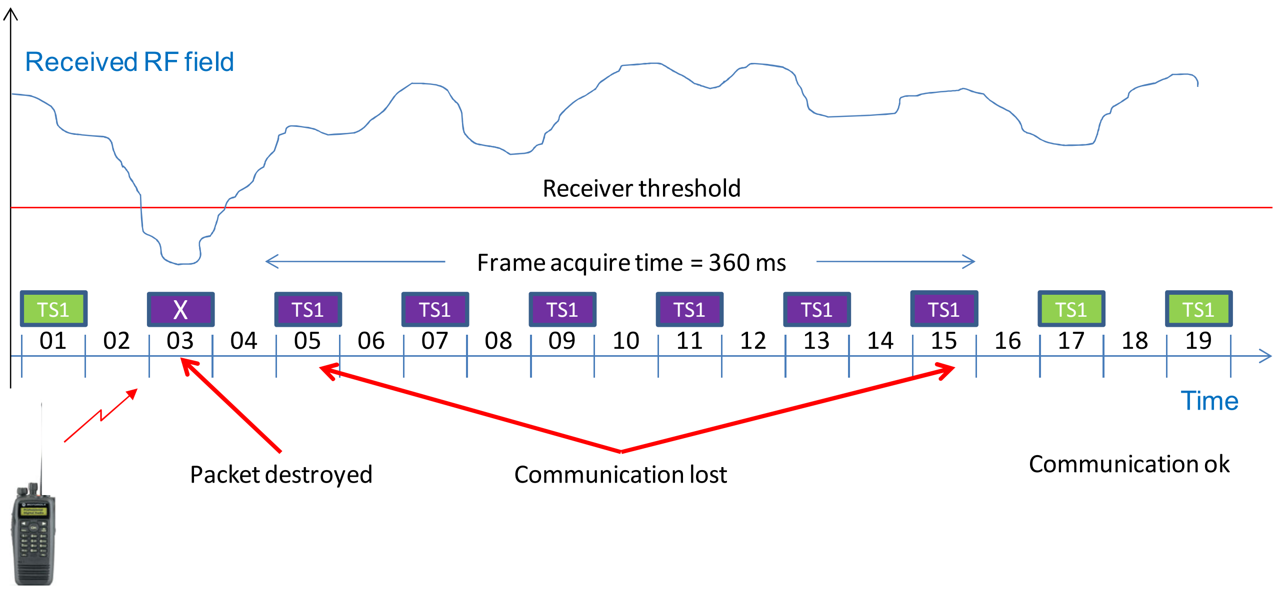
DIVERSITY RECEPTION IN A MULTIPATH FADING ENVIRONMENT

As mentioned before, using more antennas placed in different positions, the probability to have all the antennas under destructive fading is the product of the probabilities of the single antennas.

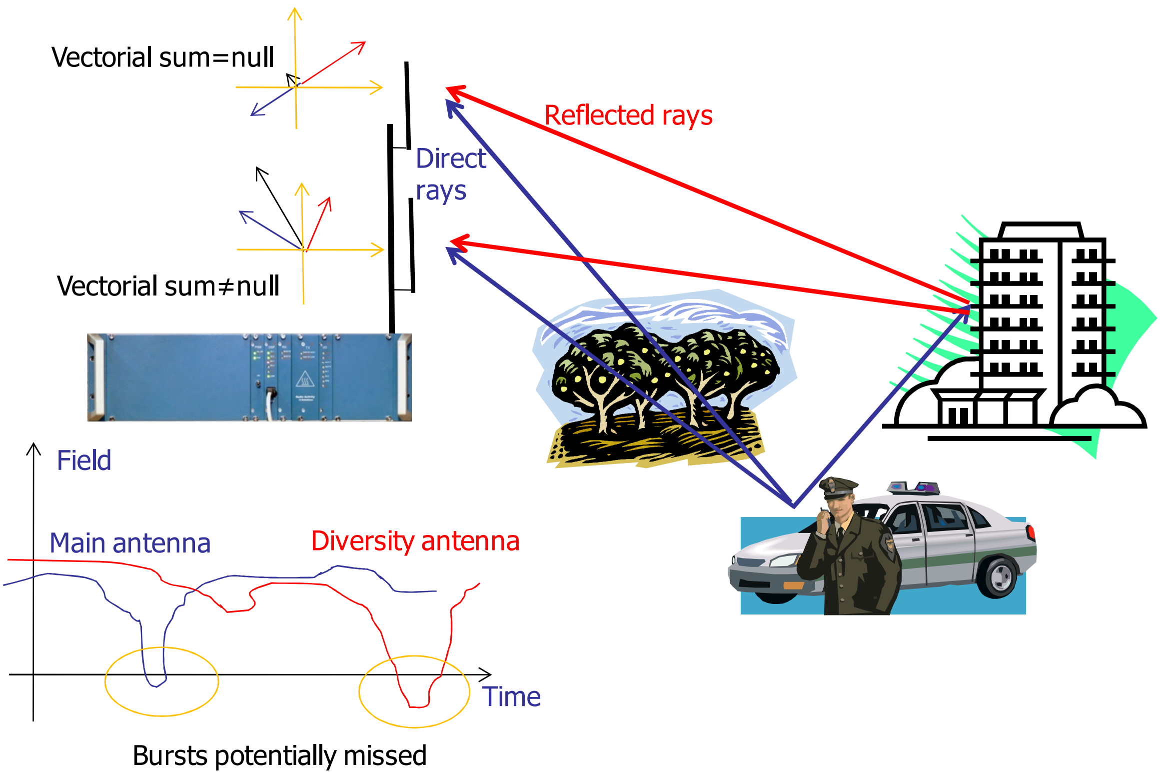
Considering a loss of performance threshold of about 1% of B.E.R (Bit Error Rate) for a DMR communication, the figure below shows that **<u>a system with 2 antennas reduce the B.E.R. of 100 times near the threshold!</u>**



By another point of view, a 2 antennas soft diversity system introduces a gain against fading probability of 13dB near threshold , with great benefit on coverage capability. This phenomena acquires increasing importance with decreasing of the received field, that is while approaching the edge of radio coverage. Although this is also for analog communications, the phenomena is much more significant with digital communications: in the first case in fact nulls of fields worsen the signal quality (it is a common experience to listen a periodic “ciuf-ciuf” noise during an analog communication coming from a car moving on the road), but the content often remains intelligible; in the second case the “ciuf” may destroy an essential data packet of the streaming communication causing the total loss of information for a long time (360 ms in DMR case). This situation is unacceptable, the communication will result continuously interrupted.



The solution for this problem is fairly simple, effective and very diffused in digital communication world (GSM, GPRS, TETRA, WiMAX, …), especially for microwave. It is sufficient to realize a space diversity receiving system, with 2 coherent independent receivers, connected to two different antennas. The probability to have contemporary fading effects on both the antennas is very low if the antennas are far enough one from the other (typically at least 2 wavelength) to let the signals be considered not correlated. By summing in phase received fields on the two antennas it is possible in case of fading over an antenna to have a good signal over the other one and to obtain a continuous and stable data flux at demodulation output.



The soft diversity reception gives about 13dB of gain over fading near the threshold, then the expected radius of the cell is about doubled, enlarging the effective coverage area by a factor of 4!

SOFT DIVERSITY INCREASES THE EFFECTIVE SENSITIVITY

A first effect of "*soft diversity*" is a static gain of 3dB compared with a single antenna received field. Since the field strength logarithmically decreases with increasing distances, a field increase of 3 dB at coverage boundary gives a significant increase of coverage area.

In the field of digital transmissions, like figure below shows, a static increase of 3dB for received field strength lets the B.E.R. to gain 2 orders of magnitude, from a value near to 10^{-3} (one bit wrong every 1000) to one near 10^{-5} (one bit wrong every 100.000).

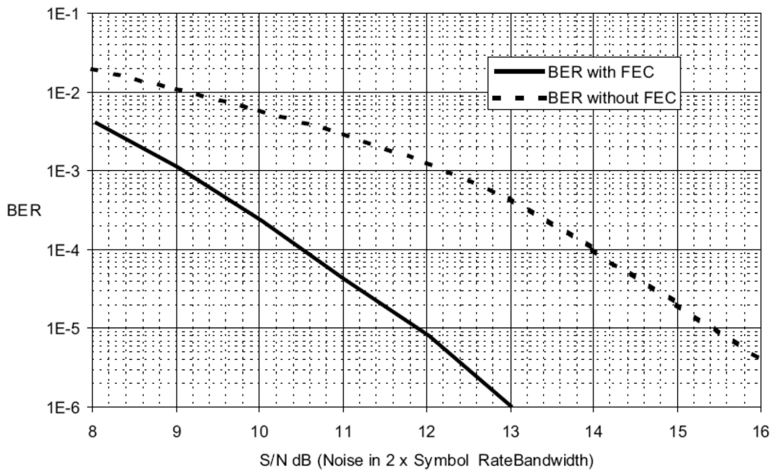


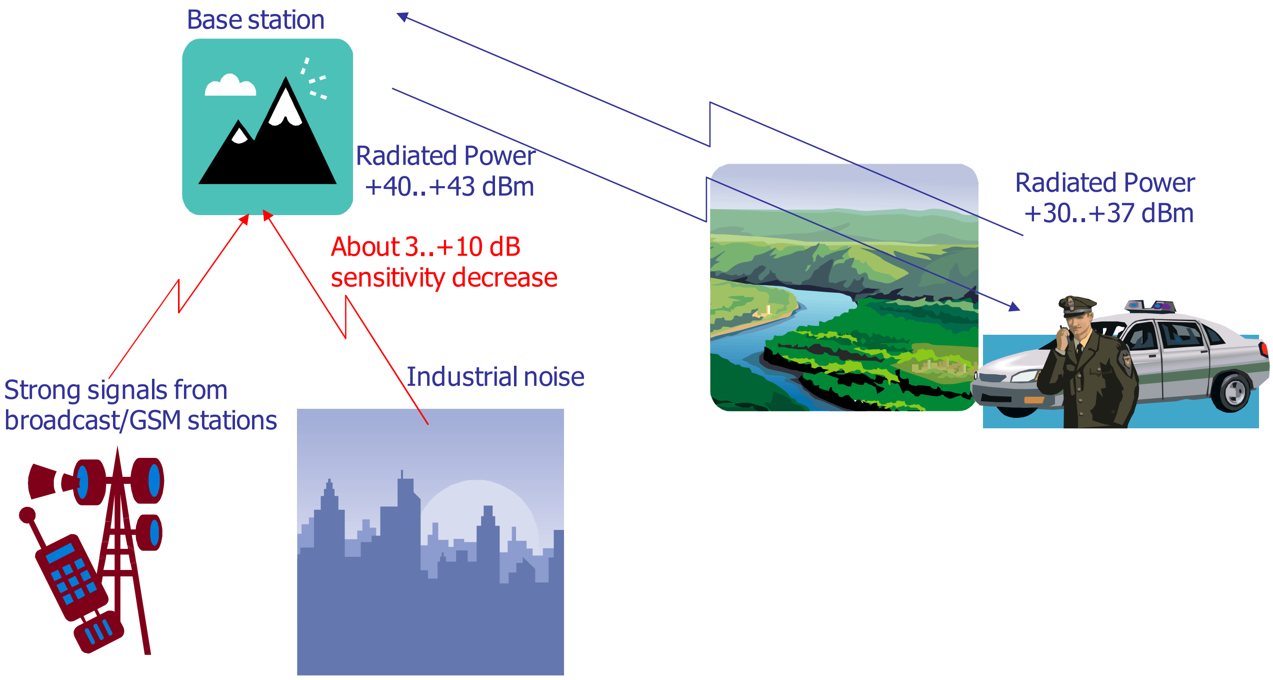
Figure 29: Typical Bit Error Rate With and Without FEC

The automatic antenna phase alignment gives also a greater directivity of radiant system and so it gives a greater rejection of interfering signals as explained in the following.

Generally radio networks suffer from an unbalance between up-link and down-link, due to:

- different transmission power (10-20 W from base station, versus 1-5W from hand-held mobiles)
- bigger radio noise floor received by repeating sites which, being placed at higher altitude, collects noise from a bigger area compared with the mobile terminal
- stronger presences on interfering signals

The base stations of a mobile radio network are normally placed on the top of hill or mountain to serve a wide area. This choice is obvious to maximize the down-link RF budget but it may introduce some troubles in the up-link. In fact a repeater placed at high altitude could receive many signals that reduce the “on air” sensitivity.



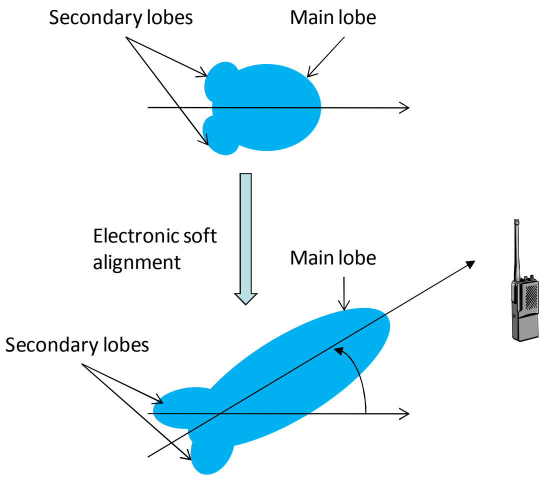
The strong signals sourced from near GSM cellular base stations or from broadcast stations create an elettromagnetic pollution in the receiving band of the repeater. So it collects noise from a big area that reduce the effective sensitivity. A band-pass filter placed before the RX input port may help for the blocking problems (“out of band” signals too strong that saturate the receiver) but it doesn’t produce any effect for the “in band” noise. The “in band” noise is “on air”, therefore there isn’t a way to filter it. An effective sensitivity decrease of -3 to -10dB is a common value in most repeater sites, more palpable in VHF band than in UHF one.

At the opposite, a user calling with a portable device placed in a quiet land may receive a very low ambient noise. He will receive very well the base station signal. Unfortunately when he try to transmit a signal to the base station the lower RF power (1-5W), in conjunction with the lower effective sensitivity of the repeater, penalizes the RF up-link budget. In some area a user may receive a good signal from the network but he may not be able to communicate through the network.

This situation may produce unpleasant effects. A user, listening very well the base station without receive answer from the Operative Center, will imagine that in the Operative Center all people are sleeping! In fact none had received his communication.

The RF budged link may be 5 to 15 dB more favourable in the broadcasting than in network access. “*Soft diversity*” function significantly increases radio system receiving performances in both analog and digital working.

The receivers of the RA-XXX base station gives to the DSP input the electromagnetic field vector in I/Q format, as received from antennas, without performing any demodulation. By this way the DSP can sum with the appropriate phases the received signals to obtain a "soft diversity" reception. This corresponds to an electronic antennas alignment in order to receive the maximum available information along the incoming signal direction.



The figure gives an idea about the effect on the gain in the xy plane operating a phase re-alignment on two antennas.
It produces two main effects:

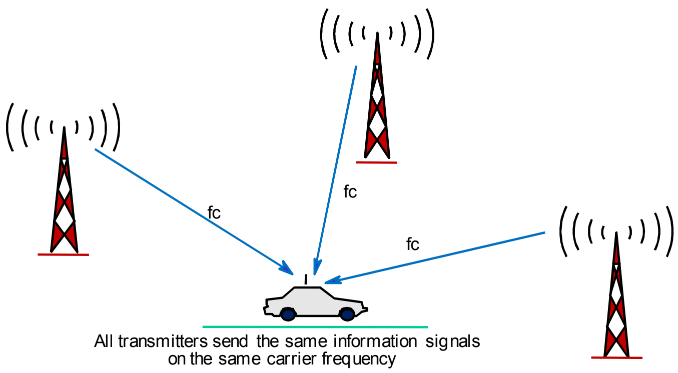
- it increases the received field (antenna gain)
- it produces a soft automatic alignment of the antennas through the direction of the radio source
- it introduces a relative more attenuation in the other directions

The global effect is a "soft directivity" of the antenna system with many advantages for the "de-sensitivity" problem.

SIMULCAST VOTER AS MACRO-DIVERSITY

Simulcast networks operate on the same radio channel (one frequency for access and one frequency for broadcast) on the whole coverage area. The network will make the automatic selection of accessing terminals and will broadcast the signal on the same frequency throughout the coverage area. The terminals are served regardless of their position as if they were covered by a single repeater.

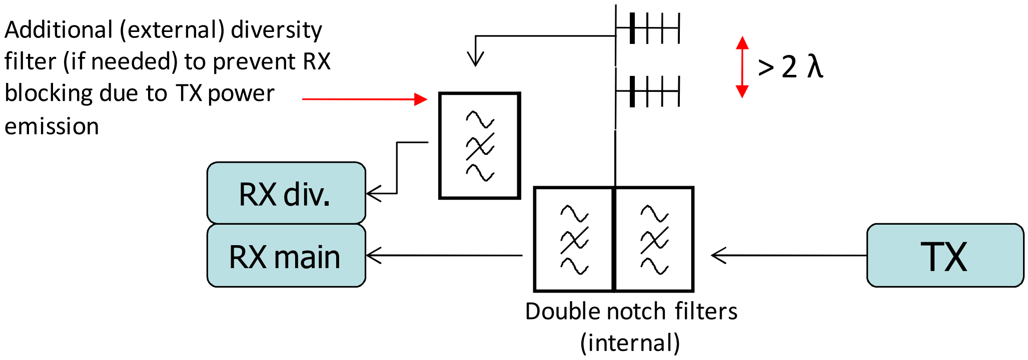
The incoming signal from a terminal equipment may be received from one or more base stations. All base stations receiving a valid signal send it to the master station via the Ethernet interface through the LAN backbone. The master station waits the arrival of all signals and then performs the selection of the best signal. The master selects the incoming signals continuously (burst by burst) on the basis of signal/noise (analog) or maximum likelihood (digital DMR).
The master station sends back the best signal to all the slaves via the Ethernet interface through the LAN backbone utilizing a multicast IP protocol.



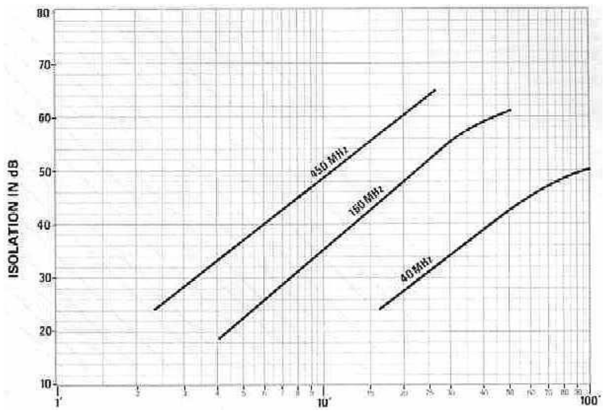
The access schema of a simulcast network operate as a "macro-diversity" antenna system giving an exceptional protection over fading effects in digital (DMR) communications.

SUGGESTED ANTENNA SYSTEM

The insertion of a diversity antenna is a simple operation. The typical branching schema is explained in the following figure.

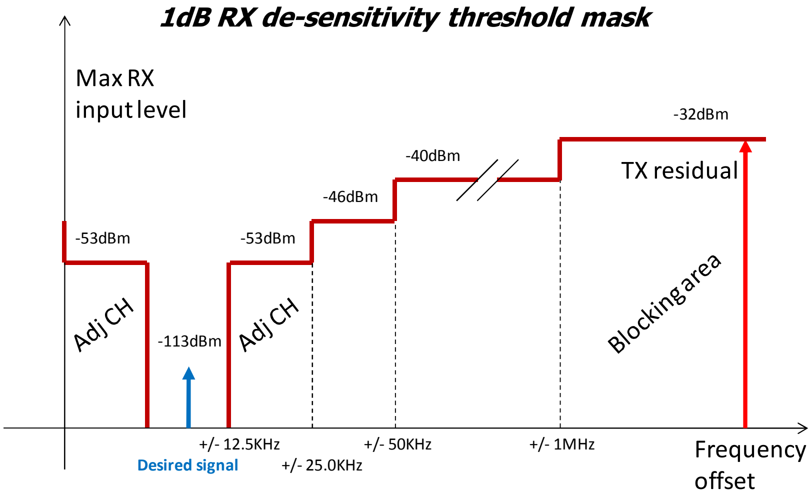


The antenna space separation should be more than twice the wavelength (e.g. >4m in VHF band). In this condition the coupling factor of two vertical dipole antenna placed on the same vertical axe is about -40dB as displayed in the following graph:

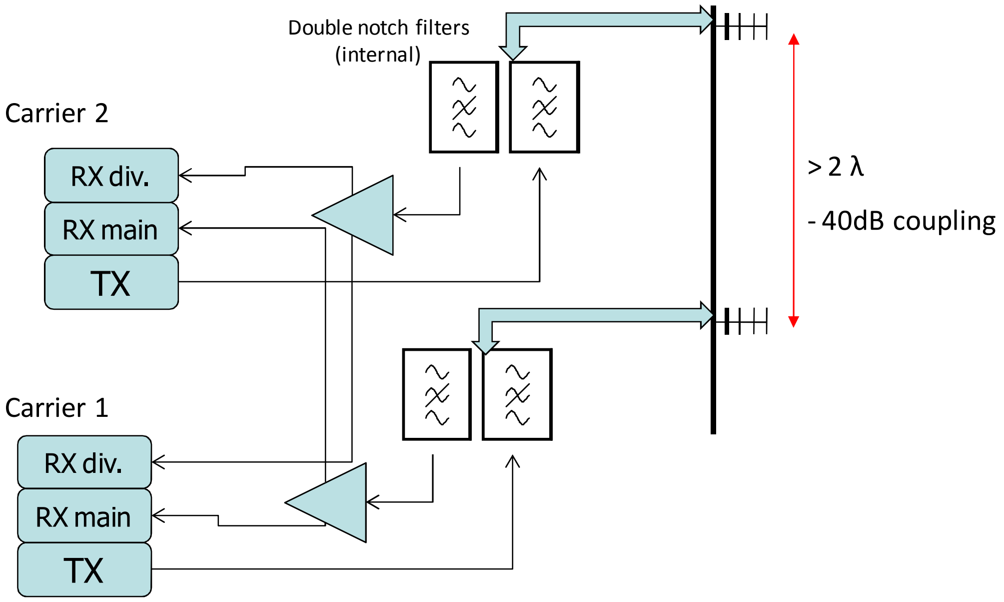


No special need is request for the diversity antenna, it works in reception only. A simple dipole should be enough.
The main antenna is connected through the duplexer filter to the main receiver and to the transmitter.

The diversity antenna is connected to the diversity receiver through a (notch) filter that suppresses the residual TX signal to avoid blocking effect on the diversity reception path. A reasonable (and easy to obtain) attenuation at the TX frequency may be 40dB or more. See the maximum blocking rejection of the receiver below to decide if insert or not a filter on the diversity receiver:



In the case of multicarrier branching system, a good implementation may be suggested by the following figure (RF insulators are not drawn) :



The approach above maximizes the available RF power on the antennas and, at the same time, optimizes the receiving performance.

A similar approach may be used to built multi carrier realizations combining the TX and the RX to take advantage of diversity antenna schema. The drawing below suggest a very compact and effective branching system with diversity antenna for 4 carriers giving an 8 channels system.