WHITEPAPER

Improving recovered signal quality in TETRA Systems

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To ensure the reliable recovery of transmitted digital signals, modern communication systems must overcome a number of factors affecting the signal's propagation through space, causing the signal to noise ratio (SNR) to degrade and, consequently, compromising the radio's ability to decode a voice or a data message.

A number of techniques exist that help overcome these distortions. The first approach advocates use of a triple diversity receiver design, while the second argues for dual diversity in tandem with equalization techniques.

FACTORS AFFECTING SIGNAL PROPAGATION AND QUALITY: FADING

Industry literature summarises three fading types that are important in radio network planning: slow fading, fast fading and direct wave versus reflected wave.

SLOW FADING

Slow fading is the attenuation of the radio signal due to propagation loss and shadowing, where the changes in signal strength are relatively slow. Slow fading or long-term fading is caused by amplitude variations due to diffraction or shadowing.

When the receiving antenna moves into the shadow of a large object, or moves under the horizon of the transmitting antenna, the radio signal will fluctuate and fade away relatively slowly. In real life, slow fading is caused by hills, buildings, tunnels, trees and other large objects that attenuate or block the radio signal.

Slow fading can be reduced by:

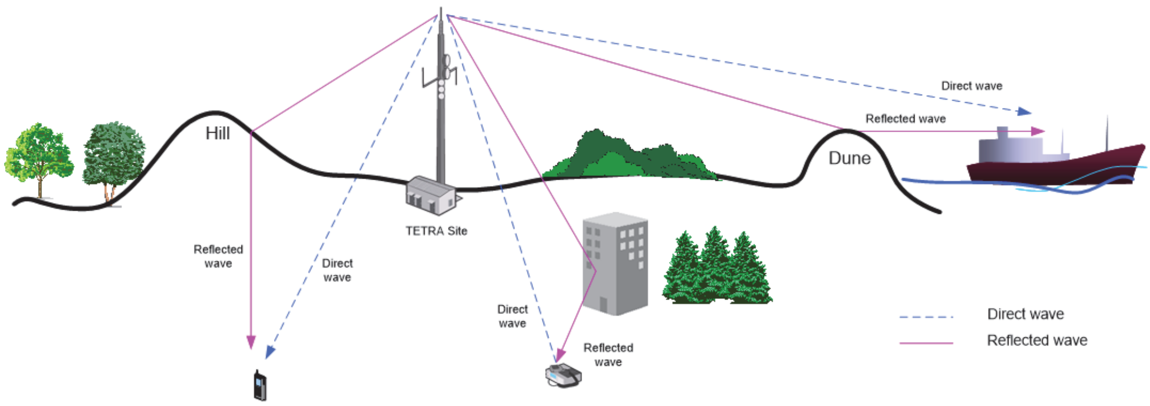
- careful positioning of sites to minimise shadowing effects
- power control, according to TETRA standard 300 392-2
- power of the radio terminal, controlled by the radio terminal
- power of the radio terminal, controlled by the system

Slow fading can be modelled mathematically by a log-normal (Gaussian) distribution.

FAST FADING

Fast fading – also known as short-term fading, Rayleigh fading or delay spread – is the attenuation caused by multi-path propagation of the signal.

The receiver hears the wave on the direct path, plus one or more reflected waves. Signals with the same amplitude and opposite phase shifts when superimposed will destructively interfere with each other. This creates characteristic fading dips within a distance of fractional wavelengths (e.g. ~10 cm). Fast fading is applicable to obstructed propagation paths (non-line-of-sight conditions) and can be mathematically described by the Rayleigh distribution. Multi-path propagation from nearby objects behaves differently to multi-path propagation from distant objects.



Fast fading

Fast fading can be divided into:

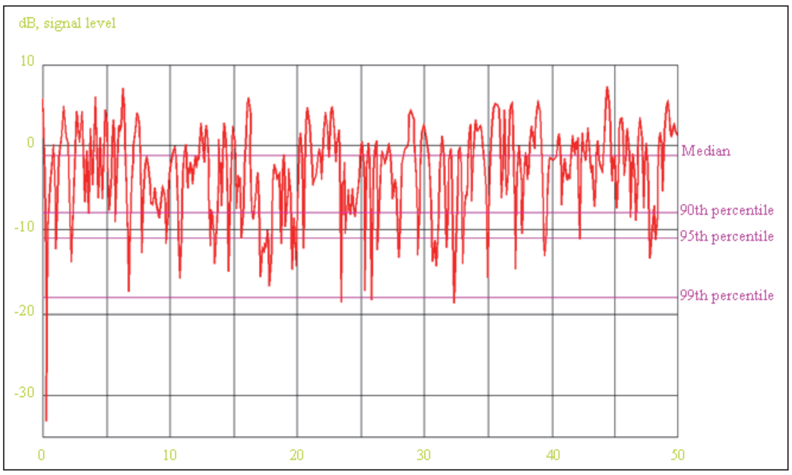
- frequency-selective fading (not relevant for TETRA systems as they use 25 kHz channels)
- destructive interference of partial waves

Fast fading behaviour is included in the 'dynamic sensitivity' performance of TETRA radio terminals and TETRA base stations. When dynamic sensitivity of receivers (mobile station, base station) is included in the power budget calculation, it is not necessary to define/use a margin for fast fading.

FAST FADING CAUSED BY NEARBY OBJECTS

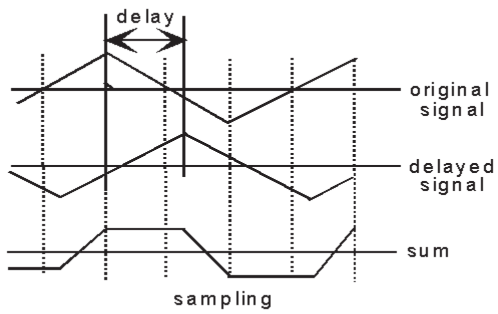
In urban areas, nearby objects will have a more severe and destructive impact due to the superposition of partial waves. Nearby objects can result in flat fading, when the reflected wave is 180° out of phase with the direct wave, and of equal strength. The result will be an electrical cancellation of the two signals at the receiving aerial. Fading dips caused by nearby objects will typically occur at λ/4 and the fading dips can be very deep.

With distant objects, the reflected wave may travel many wavelengths more than the direct wave, and thus the cycles of the modulating signal are out of phase. This is known as selective fading or Inter-Symbol-Interference (ISI). Rocks and large waterfronts, such as lakes or sea are known to create ISI.



Fast fading caused by nearby objects

Selective fading (reflections from distant objects)



Fast fading caused by distant objects

RICIAN FADING

The Rician fading model describes the effect of a direct wave and a reflected wave. The ratio of the direct to indirect signal energy is known as the 'Rice factor'. This fading type is applicable to partially obstructed propagation paths.

TECHNIQUES TO COMPENSATE FOR FADING

A number of techniques can compensate for some of the SNR losses in high-fade environments, helping to restore the quality of the recovered signal.

1. DIVERSITY

Diversity techniques are based on the fact that receiving multiple, uncorrelated samples of the same signal, at the same or delayed time, can reduce fast-fading dips, co-channel interference and avoid error bursts.

When two received signals are combined, the achieved signal quality is better than either of the partial signals alone. Diversity will improve the performance of the TETRA radio system in environments where significant RF signal reflections are expected or when there is no clear line of sight between a transmitter and the receiver.

The following diversity schemes can be applied to the base station:

SPACE DIVERSITY

Space diversity, also known as antenna diversity, is an antenna configuration that utilises two or more antennas to reduce fast-fading effects. Fast fading is caused by multi-path propagation and mostly by the reflections of the radio waves.

A radio receiver hears the wave on the direct path plus one or more reflected waves who can differ in phase, amplitude and polarization. The intercepted radio signals do therefore interfere and fluctuate very fast in amplitude.

To overcome loss of signal where a reflected wave is in anti-phase with a direct wave and to improve the quality and reliability of the radio link, antenna diversity can be applied with the TETRA base station. Space diversity performs very well with TETRA radio sites in all environments.

Horizontal space diversity requires two or more vertically polarized RX antennas to be separated horizontally by a certain distance. The gains derived depend upon the fading conditions and the final antenna configuration, such as the antenna height above surrounding terrain and the actual spacing between the antennas. The drawback of space diversity is that it requires a wide space separation with an additional cost for RF equipment and mechanical antenna support structures.

POLARIZATION DIVERSITY

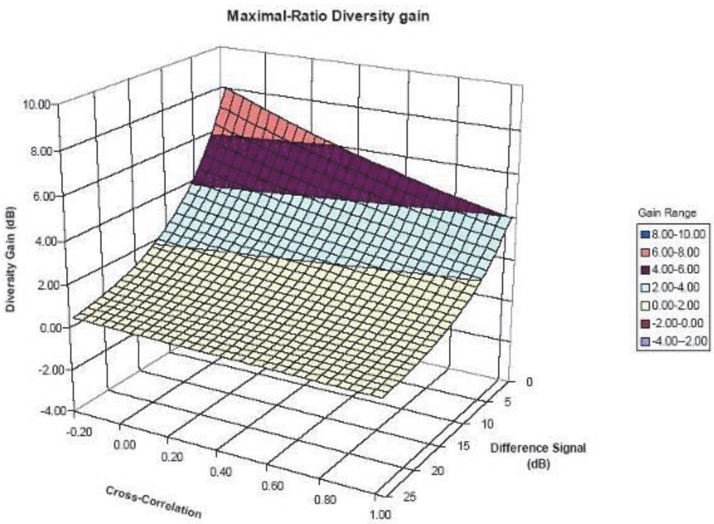
Polarization diversity can be applied by using cross-polarized antennas. Signals can be received using, for example, horizontal and vertical or ±45º slanted polarization in cross-polarized antennas.

The advantage of polarization diversity is that it does not require a wide space separation and, with the TETRA base station, can be achieved with one antenna. In urban environments where multipath propagation involves reflections on vertical surfaces (with high buildings and narrow streets), polarization diversity can immunize polarization mismatches that would otherwise cause signal fade.

Additionally, such diversity has proven valuable at radio and mobile communication base stations since it is less susceptible to the near-random orientations of transmitting antennas.

RECEIVE ANTENNA DIVERSITY GAIN

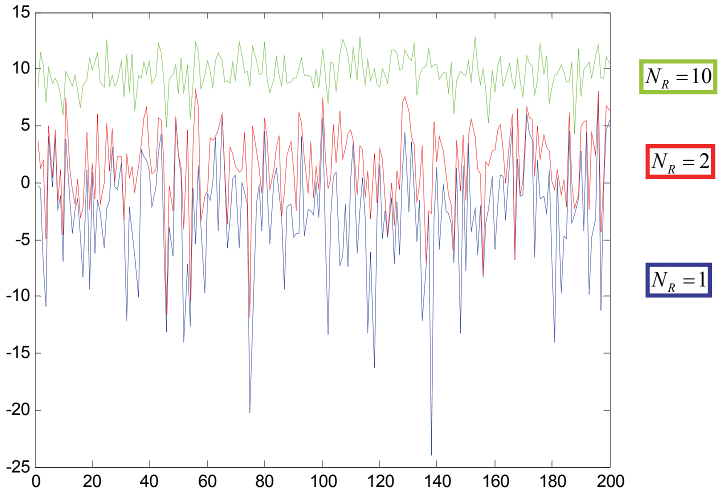
To determine the degree to which the rate and depth of fading is reduced, the cross-correlation factor of the multiple signals received is critical. The smaller the correlation factor, the better the antenna diversity gain. It is generally accepted that reasonable improvement in received-signal statistics can be achieved with a cross-correlation factor of 0.7. In order to fulfill the signal correlation requirement with TETRA sites, one has to mount all antennas above the average rooftop level with separation of the receiving antennas between six to eight wavelengths' horizontal separation. Larger separation is needed with vertical space diversity.



Maximal ratio diversity gain

Typically between 2 to 4dB of gain can be achieved with dual receiver diversity – a significant initial gain, under the assumption that the received signals are significantly uncorrelated and both signals are close in amplitude to each other.

However, even if we analyze the addition of further degrees of receiver diversity in ideal conditions (completely uncorrelated signals) – as shown in Figure 5 for 1-, 2-, and 10-way diversity in an environment with very deep fades – we achieve typical values of 1 to 2dB with each additional degree of diversity.



Simulation of 1, 2 & 10 receiver diversity gain

2. EQUALIZATION

Channel equalization is a filtering technique that decouples the received data into uncorrelated sub-streams which can be easily decoded. The equalizer is a device that attempts to reverse the distortion incurred by a signal transmitted through a channel. Its purpose is to reduce inter-symbol interference (ISI) to allow recovery of the transmitted symbols.

Equalization counters the effects of time dispersion (ISI), while diversity reduces the depth and duration of the fades experienced by a receiver in a flat fading (narrowband) channel.

3. CHANNEL CODING

Channel coding improves mobile communication link performance by adding redundant data bits in the transmitted message.

Channel coding is used by the Rx to detect or correct some (or all) of the errors introduced by the channel (Post detection technique). It is the objective of the first two techniques to bring independently, or in tandem, the Bit Error Rate (BER) of the signal to within 4% or better.

Channel coding applied thereafter (as is done in systems from all TETRA suppliers) ensures a clear audio signal conforming to the required intelligibility for its use in critical communications.

CONCLUSION

In summary, looking at these techniques, fast fading can be reduced in TETRA systems by implementing the following techniques individually or in combination:

IMPROVED ANTENNA CONFIGURATIONS (DIVERSITY)

- Two receiving antennas spaced horizontally or vertically
- Three receiving antennas spaced horizontally and/or vertically
- Six receiving antennas spaced horizontally

CHANNEL EQUALIZING TO COMBAT ISI

The TETRA standard identifies three channel equalizers. All three equalizers may be used in the MS and the first two in the base station.

- TU50: typical urban with speed 50 km/hr
- HT200: hilly terrain with speed 200 km/hr
- EQ200: equalizer test with speed 200 km/hr

CHANNEL CODING (ERROR CORRECTION)

- Block encoding (uses checksums)
- Convolution coding (extra bits added for forward error correction)
- Interleaving and re-ordering (possible error bursts are distributed)

A number of vendors propose the use of triple diversity and others the use of a combination of dual diversity combined with an equalization algorithm. Incidentally, the latest cellular systems also combine both techniques.

ADVANTAGES OF SYSTEMS USING DOUBLE DIVERSITY PLUS EQUALIZATION FILTER OVER TRIPLE DIVERSITY SYSTEMS

1. Diversity reduces the depth and the duration of a fade, and equalization counters the effects of time dispersion, so a system using both techniques is more versatile, improving performance not only in fringe coverage areas and in buildings but also in noisy and high mobility environments.

2. As the degree of diversity implemented increases, there are costs associated with a more complex antenna system, but also with the towers supporting the antennas. The wind-loading impact to towers caused by additional antennas and cabling is doubled in the transition from double to triple diversity.

3. The combined nominal gains resulting from the combination of double diversity and equalization filters (5-7dB) equal, and at times exceed, those derived from triple diversity systems (4-6dB).

In conclusion, two-way diversity with equalization provides a versatile deployment model overcoming coverage issues in-building and within fringe areas, high-noise and high-mobility environments. It provides comparable performance to three-way diversity, whilst reducing capital and operational expenditure.

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