Diversity Utilisation Techniques

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INTRODUCTION

• Diversity intends to receive multiple replicas of same signal and combine those in order to fight multipath fading.
• For maximum benefit the received signals should have comparable strength and exhibit independent fading.
• In practice some correlation exists and the independence between signals can be measured by using envelope cross-correlation

\[\rho = \frac{\sum_{i=1}^{N} [r_{i1}(t) - \bar{r}_1(t)][r_{i2}(t) - \bar{r}_2(t)]}{\sqrt{\sum_{i=1}^{N} [r_{i1}(t) - \bar{r}_1(t)]^2} \sqrt{\sum_{i=1}^{N} [r_{i2}(t) - \bar{r}_2(t)]^2}}\]

• The lower the correlation the better is the achieved diversity gain.
• The actual gain depends on the used diversity scheme, diversity combining technique and the propagation terrain.
DIFFERENT DIVERSITY TYPES - SPACE

• Space diversity schemes are the most common used in mobile radio base stations and are based on spacing two (or more) receiving antennas apart in order to obtain sufficient de-correlation.

• The needed spacing between antennas depends on the antenna height and coherence distance, which is greatly affected by the terrain and its properties.

• If multipath angle spread is small, as in macrocell BTSs, the coherence distance is large being typically $10\,\lambda - 20\,\lambda$. 

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DIFFERENT DIVERSITY TYPES - POLARISATION

- In mobile communications polarisation diversity is considerable choice instead of space diversity especially in urban areas
- Orthogonal polarizations exhibit de-correlated fading because of multipath propagation and especially multiple reflections
- The reflection coefficient is different for each polarization.

→ The phases of orthogonal polarizations undergo different changes in each reflection
- The path of the signal includes reflection and refraction, this causes coupling between orthogonal polarizations.
→ The polarization state of the signal will be independent of the transmitted signal polarization after sufficient random reflections, so receiver antennas having different polarizations can be used to obtain uncorrelated branches
- The more scatterers there are the better situation it is for polarization diversity scheme (urban environment introduces smaller cross-polarization discrimination XPD values)
Angular diversity can be exploited by two different techniques:

Separating of two or more antenna beams or antennas by small angles in vertical plane:
- The multipath components add up in different ways for different beams because of different angles of arrival
- This results in different frequency selective fading in different diversity branches.

Based on the use of adaptive antennas or electrically steerable antennas:
- Reducing of fading by aligning the angle of antenna beam so that the discrimination between the main signal and the delayed (reflected) signal increases
- When the main beam of antenna is steered so that the discrimination between delayed and main signal increases, the attenuation increases

Angular diversity is useful only when the angle spread is very high as in the case of indoors or urban area. It has been used in indoor WLANs.
DIFFERENT DIVERSITY TYPES – FREQUENCY

- Alternative technique in order to obtain de-correlated diversity branches is to transmit the same signal over different frequencies
- Frequency diversity uses multiple channels that are separated by at least the coherence bandwidth of the channel
  → Not a bandwidth efficient solution for TDMA/FDMA systems

- FH-CDMA can utilise frequency diversity through fast frequency hopping where each symbol is transmitted sequentially on multiple carriers that experience uncorrelated fading
DIFFERENT DIVERSITY TYPES – TIME

- The motion of mobile causes with scattering time selective fading in the vicinity of the mobile for the signal envelope.
- Time diversity obtained by transmitting the same information at multiple time periods that are separated by at least the coherence time of the channel.
- One drawback with time diversity is the delay, which is needed to collect the repeated transmissions.
- The coherence time depends on Doppler spread which is a function of mobile speed and used carrier function.
- The coherence time is large especially if the mobile is moving slowly and this can increase the required delay too much to be acceptable.
DIFFERENT DIVERSITY TYPES – MULTIPATH

- Path diversity is based on combining two or more radio paths with independent fading and delay
- Most common utilisation is DS-CDMA with RAKE receiver

- RAKE receiver can resolve multipaths via code correlation and combining.
- The multipath propagation can be achieved by using a signal bandwidth which is much larger than channel coherence bandwidth and the path delays are separated by at least one chip period

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DIVERSITY COMBINING

- The maximal use of diversity gain can be achieved by using an effective combining technique
- There are several algorithms and criteria according to which diversity branches can be combined (selective, maximal ratio, equal gain, switched ...)
- The received complex envelopes on different diversity branches of the transmitted signal $\tilde{s}_m(t)$ are:

$$\tilde{r}_k(t) = g_k \tilde{s}_m(t) + \tilde{n}_k(t), \text{ where } g_k = \alpha_k e^{-j\phi_k}$$

$g_k$ is the fading gain associated with the $k$:th branch and

$\tilde{n}_k(t)$ are branch independent AWGN processes
DIVERSITY IN RAYLEIGH AND RICEAN FADING CHANNELS

• The signal-to-noise pdf for Rayleigh fading can be shown to be

\[ p_\gamma(\gamma) = \frac{1}{\gamma_m} e^{-\frac{\gamma}{\gamma_m}} u(\gamma) \]

• The signal-to-noise pdf for Ricean fading can be shown to be

\[ p(\gamma) = \frac{1}{\gamma_m} e^{-\frac{\gamma}{\gamma_m}} \cdot e^K \cdot I_0\left(\sqrt{\frac{\gamma}{\gamma_m}} 2K\right) u(\gamma) \]

• In general the relative advantage of diversity is greater for Rayleigh than for Ricean fading (this is because as the Rice factor K increases there is less difference between the instantaneous signal-to-noise ratios on the various diversity branches)

• The performance will always be better with Ricean fading (for a given average received signal-to-noise ratio and diversity order).
DIVERSITY UTILISATION – SELECTIVE COMBINING

• Selection combining is the most simple and perhaps most used combining technique
• The selection between two diversity branches is made by comparing their carrier to noise ratio (C/N)
• The diversity branch with higher C/N-ratio is simply connected to the output

\[ \gamma = \text{MAX} \{ \gamma_i \} \quad i = 1,2,\ldots L \]

• For independently faded branches the cdf can be written:

\[ F_{\gamma_s}(x) = \left[ 1 - e^{-\frac{x}{\bar{\gamma}_c}} \right]^L \]

• The average symbol energy-to-noise ratio with Selective Combining:

\[ \bar{\gamma}_s = \int_0^\infty x p_{\gamma_s}(x) dx = \bar{\gamma}_c \sum_{k=1}^{L} \frac{1}{k} \]
The largest diversity gain is obtained with 2-branch diversity!
DIVERSITY UTILISATION – MAXIMUM RATIO COMBINING

- In maximum ratio combining all diversity branches are co-phased before weighting and summing.
- The weighting is proportional to the signal level and the combining is performed bitwise from all receiver paths.

MRC utilises maximum likelihood (ML) receiver. For sent signal $\tilde{s}_m$ the receiver needs to maximize the metric:

$$\mu(\tilde{s}_m) = \sum_{k=1}^{L} \text{Re} \left\{ g_k^* \int_0^T \tilde{r}_k(t)\tilde{s}_m^*(t)dt \right\} - \sum_{k=1}^{L} |g_k|^2 E_m$$

After weighting, co-phasing and combining, the envelope of the composite signal component is $\alpha_M = \sum_{k=1}^{L} \alpha_k^2$ and symbol energy-to-noise ratio $\gamma_{sr} = \sum_{k=1}^{L} \gamma_k$, where $\gamma_k = \alpha_k^2 \frac{E_{av}}{N_0}$ and $E_{av}$ is the average symbol energy in signal constellation.
DIVERSITY UTILISATION – MAXIMUM RATIO COMBINING

→ When comparing to SC the MRC seems to give 2 dB better performance at $F_\gamma = 10^{-4}$
DIVERSITY UTILISATION – EQUAL GAIN COMBINING

• The measurements of signal-to-noise ratio can be avoided by using equal gain combining, which is simpler than maximal ratio combining but also less sufficient

• In EGC the diversity branches are just summed after co-phasing (as in MRC they were weighted)

• Equal gain combining is useful for modulation techniques having equal energy symbols e.g. M-PSK

In EGC the receiver maximises the metric

\[ \mu(\tilde{s}_m) = \sum_{k=1}^{L} \text{Re} \left\{ e^{-j\phi_k} \int_{0}^{T} \tilde{r}_k(t)\tilde{s}_m^*(t)dt \right\} \]

After co-phasing and combining the envelope of the composite signal

\[ \alpha_E = \sum_{k=1}^{L} \alpha_k \quad \text{And the symbol-to-noise ratio is} \quad \gamma_s^{EG} = \frac{\alpha_E^2 E_{av}}{L \cdot N_0} \]

The performance of equal gain combining is almost as good as in maximal ratio combining. The achieved gain is shown in some literature to be less than a decibel worse than in case of maximal ratio combining.
DIVERSITY UTILISATION – SWITCHED COMBINING

• Switched combining is almost similar to selection combining.

• The switch of diversity branch occurs if the signal-to-noise ratio in used branch diminishes below some threshold value and the signal-to-noise ratio of other diversity branch is above certain threshold value.

• The big advantage of switched combining is that only one detector is needed.

• Out of many variations of switched combining, Stüber analyses two-branch SSC (Switch and Stay Combining).

In SSC the receiver switches to and stays with an alternative branch when the signal-to-noise ratio drops below a certain threshold. SSC is shown to offer most improvement just above the threshold level.
DIVERSITY UTILISATION – SWITCHED COMBINING

→ SSC seems to always perform worse than SC except at the switching threshold, where the performance is the same.
### COMPARISON OF POLARISATION AND SPACE DIVERSITY IN GSM1800

Results from selected IEEE conference proceedings

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<th>Area type</th>
<th>XPOL 90%</th>
<th>HV Pol 90%</th>
<th>HV Pol 90%</th>
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<td>2.9 dB</td>
<td>-</td>
<td>-</td>
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</tbody>
</table>

→ X-Polarisation div seems to work better especially in indoor and urban environments

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COMPARISON OF POLARISATION AND SPACE DIVERSITY IN GSM1800 - INDOOR

Indoor Environment, Signal Reliability 90%

RSSI [dBm]

Quality [0-7]

No Diversity
Hor. Space Div.
Pol. Div. (Suhner)

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COMPARISON OF POLARISATION AND SPACE DIVERSITY IN GSM1800 - URBAN

Urban Environment, Signal Reliability 90%

Quality [0-7]

RSSI [dBm]

No Diversity
Hor. Space Div.
Pol. Div. (Suhner, main lobe)
Pol. Div. (Suhner, side lobe)

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Literature used: