HADMÉRNÖK

VIII. Évfolyam 1. szám - 2013. március

Róbert Kovács
kovacs.robert@nbsz.gov.hu

DIVERSITY RECEPTION IN RADIOCOMMUNICATION LINKS

Abstract

The increased throughput capacity needs in wireless audio video and data transmission networks demanded by the information society of the 21st century are satisfied by commonly used, enhanced, digital high bitrate radio transmission technologies. Versatility in conditions of the surrounding enviroment (e.g. physical nature of atmosphere and ionosphere, mobile communications, urban environment, digital transmissions) implies continuous wide range fluctuation in radio channel parameters. To eliminate these negative effects there are some advanced technologies supporting our radio devices in the background. The purpose of this article is to present the fundamentals of one of these technologies namely the not generally known, but everyday used diversity reception technique and to provide a systematic overview of the variety of its application branches.

A 21. század információs társadalmának megnövekedett vezeték nélküli hang- kép- és adatátviteli igényeit általánosan használt, fejlett, digitális, nagysebességű rádiós technológiák biztosítják. A környezeti feltételek (pl. atmoszféra, ionoszféra fizikai tulajdonságai, mozgás közbeni kommunikáció, nagyvárosi környezet, digitális jelátvitel) a rádiócsatorna paramétereinek folyamatos, extrém értékek közötti változását eredményezi. A negatív hatások kiküszöbölésére rádiós eszközeinket fejlett technológiák támogatják a háttérben. A cikk ezek egyikének, a köztudatban kevésbé ismert, ám mindennap használatos diverziti vételtechnika alapjainak bemutatását, szerteágazó fajtáinak egységes rendszerbe foglalását célozza meg.

Keywords: *radio propagation, fading, diversity reception, multipath, signal combining, rádió hullámterjedés ~ fading, diverziti vétel, többutas, jelösszegzés*

1. INTRODUCTION

Nowadays, different types of wireless communications play a very important or an almost essential role in a life of human being of 21st century. In an every day life we are promted to use several kinds of sophisticated communication technologies even when we are not aware at all of doing that. It is really unobserved how we stepped into the age of new high data rate and high quality video broadcasting services like terrestrial digital video broadcasting (DVB-T) or using digital data transmissions embedded in conventional analogue radiobroadcast transmissions. The number of mobile applications is continously growing, e.g. global system for mobile communications (GSM), short message service (SMS), Bluetooth, wireless-Internet connections in our homes are basic services for our digital communication needs. The WIFI, WIMAX, LTE, HSPA are also technologies which are wellknown and available at relatively affordable costs for masses of people.

But, a question may be raised, e.g. what factors made it possible to develop and deploy these new techniques? Of course, the answer is not simple because these new enhancements could not have been acheived without a sort of developments in communication technologies. As a frequency spectrum is limited, it is not easy to provide higher data transmission rates at a given bandwidth which is inevitable for the new requirements. Improvements in spectral efficiency, using digital modulation, coding algorithms, electronic circuitry technology led to the necessity to cope with the challenges mentioned. Besides these segments a new approaches were also necessary the give answers for challenges of theory originated from the nature of wave propagation. One of these features is the diversity reception technique, which has been used in almost all segments of wireless communication applications to combat unlovely behavior of radio propagation.

2. WHY DIVERSITY ? – RADIO PROPAGATION BACKGROUND

The technical literature concerning radio propagation is quite extensive therefore hereby the most important related propagation issues are only mentioned, mostly based on [1].

RF signal transmission between two antennas commonly suffers from different factors that affects performance significantly.

The power loss in space as a power loss between transmitter and receiver is a result of three different phenomena. These are the distance-dependent decrease of the power density called *path loss* or *free space attenuation*, the *absorption* caused by the molecules in the atmosphere of the earth and *signal fading* caused by terrain and weather conditions in the propagation path. Path loss is a theoretical attenuation which occurs under free line of sight conditions and which increases with the distance between the transmitter and receiver. The frequency dependent atmospheric absorption is due to the electrons, uncondensed water vapour and molecules of various gases. In frequency domain it has two quite high peaks at 60GHz and 21GHz for oxygen and water vapor respectively.[1]

Fading is an attenuation that varies between a maximum and minimum value in an irregular way. It has two forms which are of different origin.

The *shadow fading* is an effect that is of main importance in mobile communication links. As mobile terminals move through different surrounding areas (urban, rural, mountains, buildings) occasionally, these obstacles will shadow or completely cut off the signal. The consequences of such shadowing effects will depend on the size of an obstacle and on the distance to it, the received signal strength will inevitably vary. It is possible to decrease the effect of shadow fading with some awareness in network planning. By placing the transmitter and receiver stations as high as possible or close to each other it is possible to avoid some obstacles in transmission.

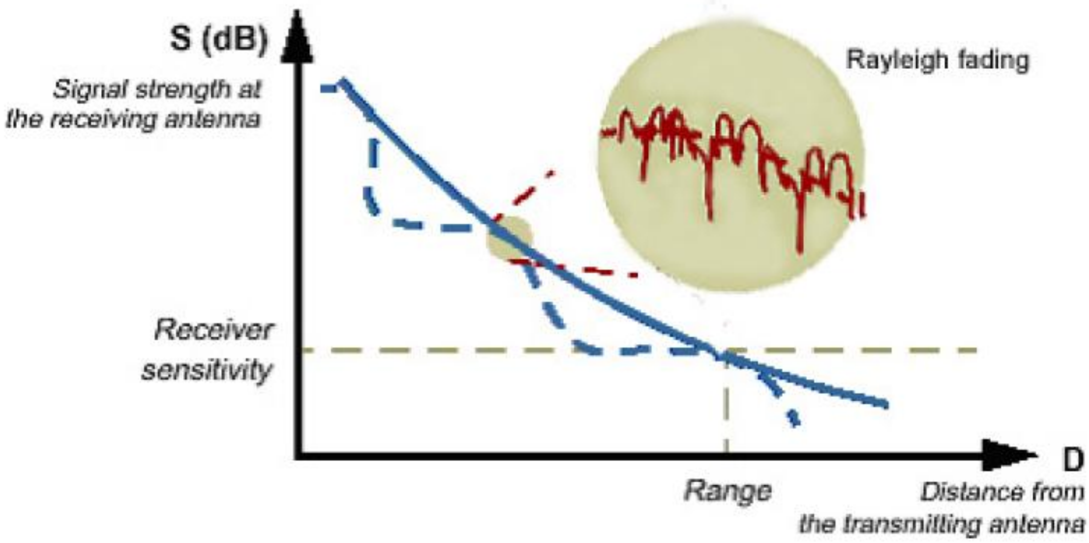

Figure 2.1. Shadow and Rayleigh fading

Source: http://www.es.lth.se/teorel/Publications/TEAT-5000-series/TEAT-5064.pdf (26/01/13)

The much more unpredictable power loss in communication links is a *Rayleigh fading, multi-path fading* or *short term fading*.

It is a result of a reception of a signal at the receiver reflected from many different objects and directions in the area which is illustrated by Figure 2.1. As different paths the waves are coming at different angles, the incoming signals of same origin will usually not be in phase at the receiver, therefore they will reinforcing or even extinguishing each other.

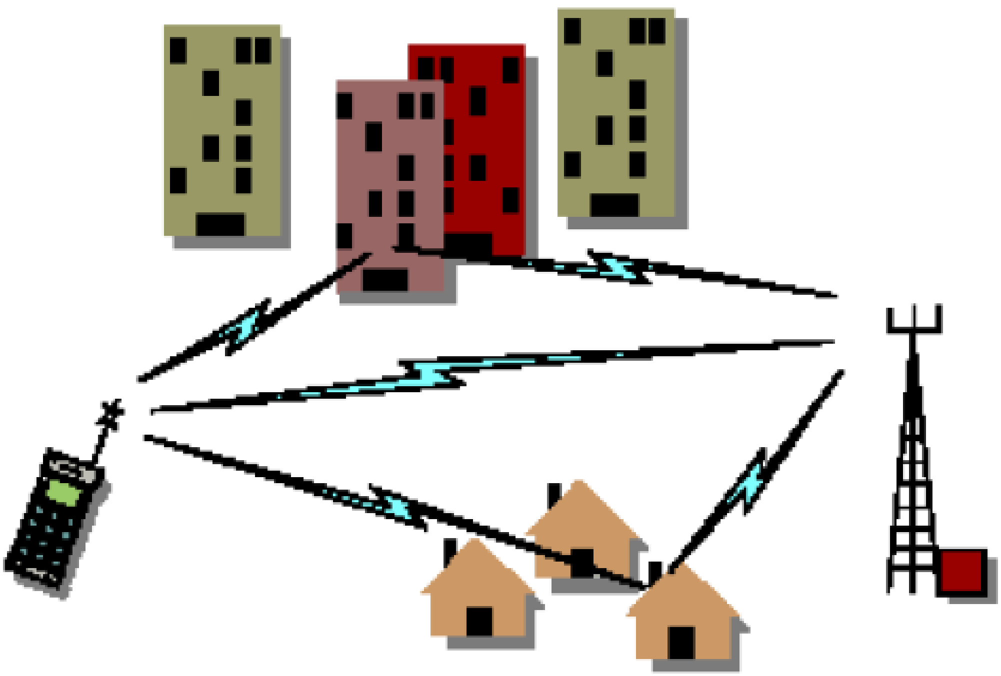

Figure 2.2. Multi-path propagation
Source: http://www.es.lth.se/teorel/Publications/TEAT-5000-series/TEAT-5064.pdf (26/01/13)

The movement of the mobile terminals causes continuous and unpredictable variations of the signal phases over time, making the overall attenuation in the link very variable with extremely high values (fading dips). Rayleigh fading is most perceptible in urban areas involving irregular signal strength variations. Dips will occur more frequently at higher frequencies and more rapid mobile movement.

To overcome this phenomenon is also important in high frequency band communications links where the reflection from the different layer heights of the ionosphere also results in a severe multi-path propagation circumstences.

3. DIVERSITY RECEPTION AT GLANCE

As explained above the quality of the communication radio link can be poor, particularly in urban environments. In such environments this propagation phenomenon affects the signal-to-noise ratio (SNR) and introduces signal distortion. This altogether results in a poor audio signal for analogue systems and a high bit-error rate for digital communications systems. In order to diminish the vulnerability of mobile systems against the destructive interference of multipath radiowaves, special reception techniques can be applied to merge the „original" and the reflected signals decreasing or eliminatig the data losses coming from the amplitude and phase differences of the signals. [2]

According to [1] the performance degradation shown in the difference between the mean signal-to noise ratio and non-fading signal can be solved by increasing the transmitting power and resizing the antenna, however the economical aspect of these solutions, especially for the small terminals, is not that attractive.

To overcome all these problems in order to enhance the signal quality special reception and transmission techniques are used, amongst them the multiple receiver combining techniques known as *diversity*.

4. TYPES OF DIVERSITY RECEPTION TECHNIQUES

The definitions and classifications of diversity reception can be found in several papers (e.g.: [1], [2], [3], [4], [5], [6], [7], [8], [9], [10]).

Basicly, the main purpose of using diversity is to improve the reliability of the analogue or digital message content in radio connections. To acheive this there are several methods to distinguish between the multi-path signals. Common base of the concepts is to separate the multi-path signals as individual channels experience different levels of fading and interference. [3] For this several approaches are known. The channel separation as an essence of the diversity can be carried out in different domains (e.g. space, frequency, phase (time), polarisation, angle of arriving or even modulation and code distance for digital signals).

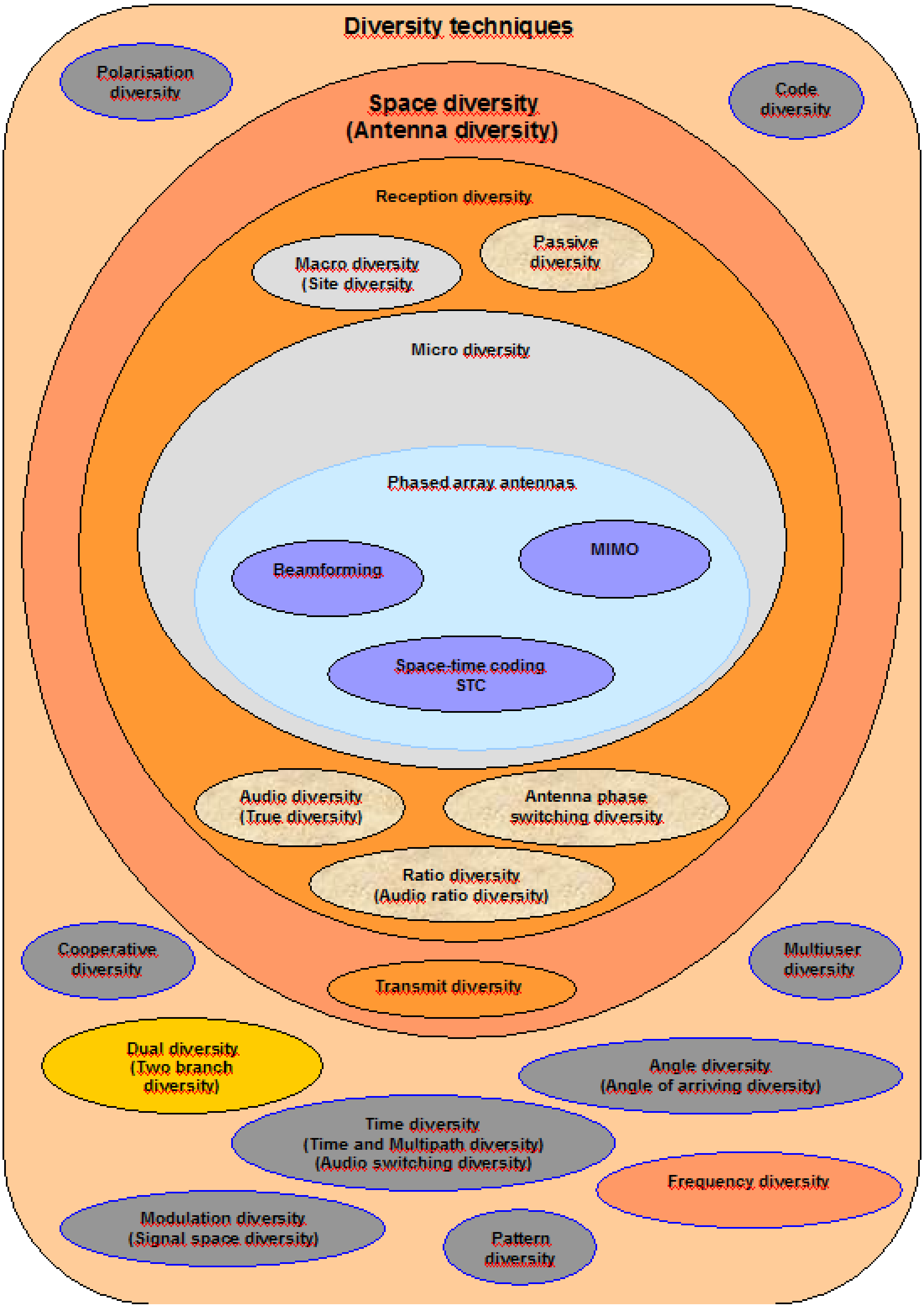

Figure 4.1. Scheme of diversity reception techniques

There are several possibilities to approach the classification of diversity techniques (Figure 4.1.) The basic case is the consideration of the mechanism how the independent fading signals are being produced in domains. Another possibility is to examine the method of linear combining of the signals received. The scheme above represents the first because it is more detailed and more informative therefore in the explanation below this method will also be followed. The latter one is discussed in Chapter 4.4.

4.1. Space diversity

As the most common and probably the simplest mechanism for achieving diversity branches *space, spatial* or *antenna diversity* as a traditional way of diversity uses multiple antennas separated by a distance from each other. As it is mentioned in [7] as a definition for space diversity, "***r****adio reception involving the use of two or more antennas located several wavelengths apart, feeding individual receivers whose outputs are combined; the system gives an essentially constant output signal despite fading due to variable propagation characteristics, because fading affects the spaced-out antennas at different instants of time*".

This statement summarizes the nature of antenna diversity though sometimes there might be some overlapping among diversity classes.

Considering semibranches of space diversity, depending on the side the antenna multiplication is used (transmitter or receiver) we can differentiate *transmit* diversity and *reception* diversity respectively. [3]

Using two antennas (called *dual* or *two-branch* diversity [5]) at the receiver with a distance between them the phase delay makes multi-path signals arriving at the antennas differ in fading. The minimum spacing required for sufficient low correlation between fading signals is usually some 0.5 wavelengths. When spacing is smaller than 0.5 wavelengths other diversity mechanisms will have strong influence. [1] According to [4], by placing two receivers (with 2 separate antennas) at a sufficient distance from one another, multipath will become uncorrelated between both receivers. Thus, statistically, the chance for destructive fading at both ends decreases significantly.

Based on the antenna separation if the distance between the antennas is in order of one wavelength, this is called *microdiversity*. If the antennas are well separated (at several wavelength distance) the terms of *macrodiversity* or *site diversity* are used. [3]

There is a special case of antenna arrays considered as a set of antennas close to each other and used for *MIMO* (Multiple Input Multiple Output) channels, *space time coding (STC)* and *beamforming* techniques can be considered as a part of microdiversity. [3]

Of course, beamforming with a standalone antennas far apart (specially at higher frequency band) can be considered as a macrodiversity application as well. (This option is not indicated in the scheme.) It is necessary to mention that MIMO technology can also be considered as both transmit and reception diversity type and there are also some applications where even in HF band researches are executed to study the effectiveness of diversity in *array processing*. [11]

4.2. Frequency diversity

Frequency diversity is based on a supposition that the same signal transmitted on different frequencies simultaneously will not suffer the same fading on each frequency carriers. Depending on the number of frequencies this mechanism need multiplicativ number of transmitters and receivers and frequency bandwidth as spectrum usage as well. This method became wellspread in OFDM modulation systems and spread spectrum technologies (e.g. WIFI and WIMAX).

4.3. Other branches of diversity reception

As it is shown in Figure 4.1 there are several other terminologies used in wireless communications. These would be the followings:

In the case of *polarization diversity* the signal is transmitted over antennas of different polarization. On the receiver side two receivers and a combinig technique are needed to obtain the signal.

The fundamental of *angle* or *angular diversity* is that signals coming from different directions will suffer different and independent level of fading. Using receiver antennas capable to form a direction sensitive pattern, it is possible to acheive diversity gain in the system.

Time and multi-path diversities are related mechanisms mostly applicable in digital transmission. *Time diversity* is achieved by transmitting the same bit of information repetitively at short time intervals. Fading variations for these different repetitions of a signal will be independent. *Multi-path* diversity is using time diversity in multi-path environments getting the information from repetitive signals traveling different paths. [12]

Pattern diversity can be achieved when patterns of two diversity antennas are compared. When using two different antennas, the radiation patterns are different so the signals arriving at the antennas will be from different directions and uncorrelated. Pattern diversity is never applied alone, it usually appears in addition to space diversity. [13]

As a definition of *multiuser diversity* in [14] we can find the followings:

"Multiuser diversity is a diversity technique using user scheduling in multiuser wireless channels where user scheduling allows the base station to select high quality channel users so as to transmit information through a relatively high quality channel in time, frequency and space domains based on the channel quality information fed back from all candidates UEs."

It means that the users in the system communicate simultanously and each of them have different and variable time-slots in the communication channel. The multiuser diversity gain can be obtained by letting the user with the best instantaneous channel quality to communicate. A fundamental property of multiuser diversity is that the more users that are available, the higher expected channel quality of the best user. [15] Further descriptions are available in [16], [17] and [18] respectively.

Through *cooperative diversity*, sets of wireless terminals benefit by relaying messages for each other to propagate redundant signals over multiple paths in the network. This redundancy allows the ultimate receivers to essentially average channel variations resulting from fading, shadowing, and other forms of interference. [19]

A very challenging method of increasing the diversity order is the *signal space* or *modulation diversity*. Using a multidimensional rotating of constellations of digital modulations as QAM is investigated in enhancing the throughput capability of transmission channels with high spectral efficiency.

There are some classifying approaches studied in [6] for *passive diversity, antenna phase switching diversity, audio switching diversity* and *ratio diversity*. As their definition of deployment models are explained in details there, thus this article does not discuss them. For reasons of simplification it can be assumed that these diversity types belong to a branch of reception diversity methods. The main difference between those systems is the nature and place of combining decision made in the structure of receiving process.

4.4. Combining techniques

Using diversity reception there are several signal combining techiques to use in order to counteract small scale fading. The method of istantaneously selecting between the multipath signals to acheive improvement in the output signal of the receiver is called *diversity combining*.

Assuming that signal fading behaviours at each particular antenna tend to be independent and the output signals are uncorrelated linear combining techniques are used to derive an output signal with better parameters than any of particular multipath signals.

The most common combining techniques are selection combining (SC), maximum ratio combining (MRC), equal gain combining and switch and stay or switch combining (SSC).

In *selection combining* instantaneously the stronger (i.e. the signal with the greatest signal to noise ratio) is selected. *Switch combining* uses switching when SNR of one signal falls below a certain signal threshold. (Figure 4.2.)

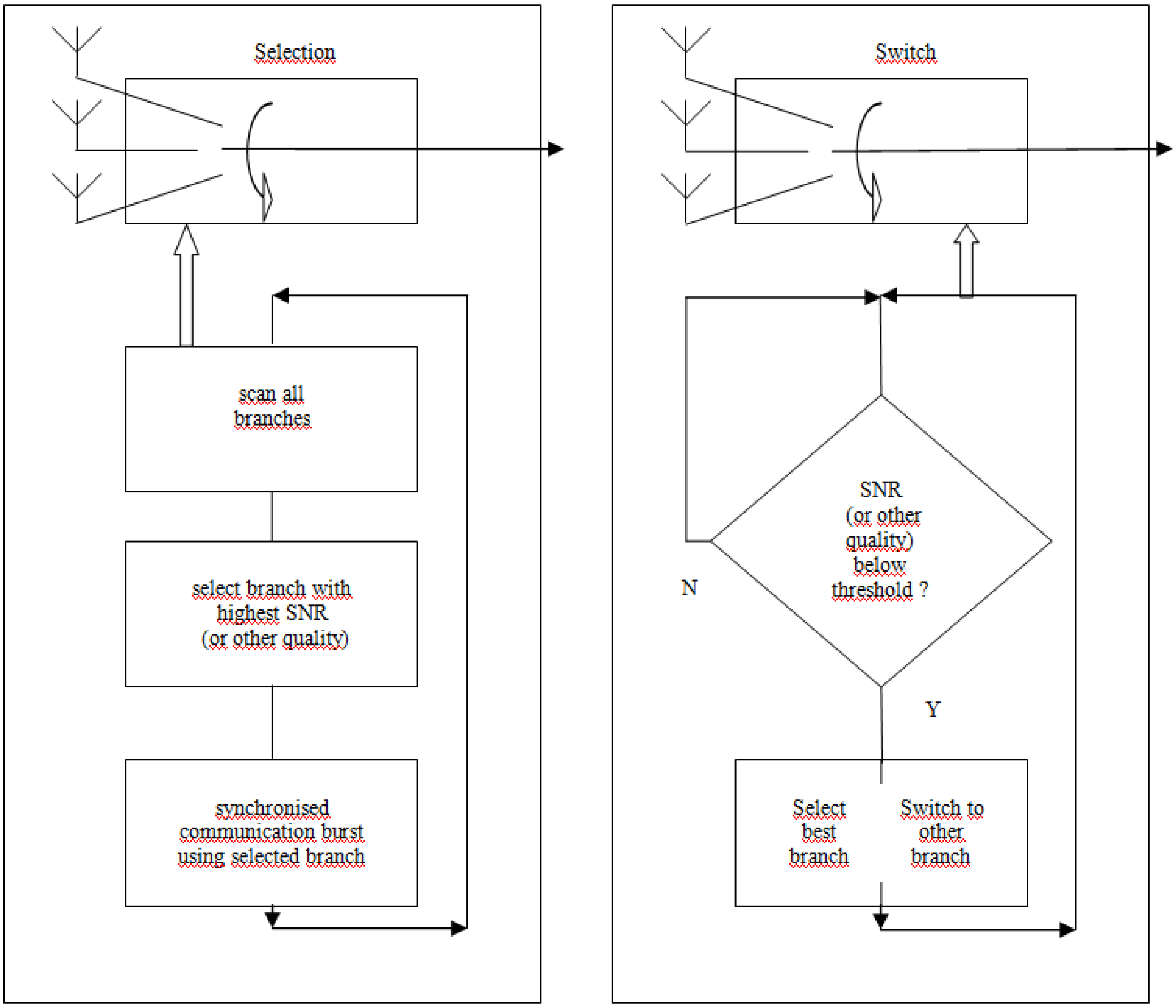

Figure 4.2. Selection and switched combining [1]

While *equal gain combining* adds the signals when they are in phase, *maximum ratio combining* obtains the weights of the SNRs. MRC is therefore the most sofisticated method but produces the best result in terms of output SNR.

There are also some other combining methods used in diversity reception (e.g. *feedback* or *scanning* diversity), where the signals are scanned in a fixed sequence and the selected signal above given threshold performs the output until it falls below the threshold.

The processes mentioned above are sometimes used in combination, but mostly out of the scope of terrestrial communication links. [1], [8], [10]

5. SUMMARY

The purpose of this article was to present the fundamentals of diversity reception techniques. By representing the main factors like path loss, and fading that affect the performance of the radio propagation channel, a focus was put on the definition of diversity reception. Studying the technical literature related to diversity reception techniques, diversity branches were overviewed in details to describe their specifity.

It has been concluded that several approaches are available to distinguish between different types of diversity. It has been pointed out that the channel separation as an essence of the diversity can be carried out in different domains e.g. space, frequency, phase (time), polarisation, angle of arriving or even modulation and code distance for digital signals. As most spread technical solutions, space and frequency diversities has been described.

Finally, the basic types of signal combining techniques like the most common selection combining (SC), maximum ratio combining (MRC), equal gain combining and switch and stay or switch combining (SSC) have also been introduced.

As a main achievement of this paper diversity branches were summarized in a visual scheme to illustrate the versatility of the technology and the variety of its branches.

References

[1] Vanja Plicanic: Antenna Diversity Studies and Evaluation. Master of Science Thesis, Department of electroscience, Lund University, Sweden http://www.es.lth.se/teorel/Publications/TEAT-5000-series/TEAT-5064.pdf – (2013.01.26.)

[2] [P. Mattheijssen, Matti H. A. J. Herben, G. Dolmans, L. Leyten: Antenna-Pattern Diversity Versus Space Diversity for Use at Handhelds. IEEE Transactions on Vehicular Technology, 4 Vol. 53 (2004) 1035-1042 http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=1541759&url=http%3A%2F%2Fieeexplore.ieee.org%2Fxpls%2Fabs_all.jsp%3Farnumber%3D1541759 http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.60.8790 – (2013.01.26.)

[3] Wikipedia Diversity scheme http://en.wikipedia.org/wiki/Diversity_scheme – (2013.01.26.)

[4] Space and Frequency Diversity Ceragon Newsletter, December 2008. http://www.ceragon.com/newsletter_page.asp?id=32 – (2013.01.26.)

[5] Adam Farson: Note on dual-diversity reception with the IC-7800 http://www.ab4oj.com/icom/ic7800/7800div.html – (2013.01.26.)

[6] Wireless Microphone Systems: Diversity Reception http://www.download.n7tgb.net/Misc/wg_diversity.pdf – (2013.01.26.)

[7] The Free Dictionary: Space diversity reception http://encyclopedia2.thefreedictionary.com/space+diversity+reception – (2013.01.26.)

[8] L. C. Godara, Handbook of Antennas for Wireless Communications. CRC Press, 2002. Receive Diversity http://www.comm.utoronto.ca/~rsadve/Notes/DiversityReceive.pdf – (2013.01.26.)

[9] Joseph Boutros, Emmanuele Viterbo: Signal Space Diversity: A Power- and Bandwidth-Efficient Diversity Technique for the Rayleigh Fading Channel. IEEE Trans. Inform Theory, Vol. 44. No. 4, july (1998) 1453-1466 http://www.ecse.monash.edu.au/staff/eviterbo/papers/itjul98s.pdf5 – (2013.01.26.)

[10] M. K. Simon, M.-S. Alouini: Digital Communication over Fading Channels, 2nd ed. New York: Wiley, 2005

[11] http://www.antenna-theory.com/arrays/diversity.php – (2013.01.26.)

[12] Schwartz M., Bennet W.R., Stein, S., Communication Systems and Techniques, Vol.4, McGraw-Hill Book Company, US 1966

[13] Sulonen K., *Evaluation of Handset Antenna Configurations*, Dept. of Electrical and Communications Engineering, Helsinki University of Technology, March 1999

[14] http://humancommunications.wikia.com/wiki/Multiuser_diversity – (2013.01.26.)

[15] http://ieeexplore.ieee.org/xpl/login.jsp?tp=&arnumber=5165300&url=http%3A%2F%2Fieeexplore.ieee.org%2Fiel5%2F7693%2F5165281%2F05165300.pdf%3Farnumber%3D5165300 – (2013.01.26.)

[16] http://www.eecs.berkeley.edu/~dtse/ima810.pdf – (2013.01.26.)

[17] www.web.njit.edu/~simeone/p776seven.ppt – (2013.01.26.)

[18] www.kth.diva-portal.org/smash/get/diva2.../FULLTEXT01 – (2013.01.26.)

[19] http://www3.nd.edu/~jnl/pubs/thesis.pdf – (2013.01.26.)