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Performance analysis of spatial diversity algorithms on an 802.11a PHY

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Abstract – Simulations performed on an 802.11a PHY platform have proven the necessity of introducing some spatial diversity schemes on the transmission chain.

Basic antenna diversity designs – ThC (Threshold Combining), SDC (Selection Diversity Combining), MRC (Maximum Ratio Combining) and EGC (Equal Gain Combining) – have been tested. They clearly improve bit rate and packet error rate performance, and EGC provides higher antenna diversity gain then SDC. MRC achieves the highest antenna diversity gain compared to the other techniques.

Keywords: spatial diversity, receiver diversity, channel conditions, diversity combiner.

I. INTRODUCTION

Our analysis was performed in the context of a study of adaptive radio techniques, in the attempt to improve capacity performance of 802.11a WLANs. We have established our focus on spatial diversity techniques, and this paper presents the results of some receiver diversity implementations.

Both LOS (Line-of-Sight) and NLOS (Non Line-of-Sight) propagation conditions were simulated, as well as flat fading and dispersive fading conditions.

II. 802.11a PHY PERFORMANCE

The first step consisted of sets of simulations on the 802.11a PHY Simulink platform [1], aiming to establish the limitations of this scheme in terms of received SNR, bit rate, packet error rate, and number of propagation paths. The main blocks are: a data source, the modulator bank, the OFDM (Orthogonal Frequency Division Multiplexing) transmit assembly, the channel, the OFDM reception assembly, a frequency domain equalizer, and the demodulator bank. The code employs link adaptation scheme wherein we select the best coding rate and modulation scheme based on channel conditions.

We have simulated both LOS and NLOS propagation by combining and adapting channel blocks available in the Simulink Communications Blockset: e.g. Rician Fading Channel and Multipath Rayleigh Fading Channel. We have varied the number of paths in the case of the Rayleigh channel, and modeled indoor and outdoor environments by changing the delay spread according to standard values [2], table 1.

Table 1. 802.11a standard values for indoor and outdoor environments [2]

802.11a OFDM	Delay spread	Max Path Length Difference
Outdoor	1us – 20us	300m – 6km
Indoor	40ns – 200ns	12m – 60m

Table 2 synthesizes the main limitations of 802.11a PHY operation, obtained from our simulations. As the number of propagation paths is increased the overall performance degrades. Spatial diversity techniques are efficient in fighting multipath propagation effects and we will show how this can be achieved in the particular case of the 802.11a PHY. Incorporating any kind of spatial diversity scheme into an 802.11a system will obtain a high-rate packet transmission system suitable for high throughput applications like videoconferencing and multimedia [3].

Future standards like 802.11n specify the use of multiple-antenna systems, MIMO (Multiple Input Multiple Output), to achieve high data rates (135 Mbps) and link reliability by using multipath to a benefit, unlike traditional systems. Until then, basic antenna diversity designs will help increase capacity and reliability for 802.11a systems.

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Table 2. 802.11a PHY operation limiting parameter values

Rayleigh Channel / Parameters	Number of paths					
	2		3	4	5	>6
	Out door	**In door**	**In door**	**In door**	**In door**	**In door**
Dispersive fading						
min SNR [dB]	11-15	10	17	23	35	Needs special solutions (e.g. spatial diversity)
max Bit rate [Mbps] for min SNR	6	12	18	18	36	
max PER [%] for min SNR	10-12		12	18	14	
Flat fading						
min SNR [dB]	8-12	7	15	20	33	Needs special solutions (e.g. spatial diversity)
max Bit rate [Mbps] for min SNR	6	6	6	12	36	
max PER [%] for min SNR	12	10	4	18	12	

III. Receiver Diversity Schemes

Receiver diversity techniques are a means of implementing space diversity, and they involve the use of multiple antennas at the receiver. Our goal was to test and compare the performance of the 802.11a PHY with several receiver diversity configurations.

In receiver diversity, the independent fading paths associated with multiple receive antennas are combined to obtain a resultant signal that is then passed through a standard demodulator. Most combining techniques are linear: the output of the combiner is just a weighted sum of the different fading paths or branches [4]. Fig. 1 illustrates the 3-receive antenna case. We have considered dispersive fading conditions and one can notice that the SNR is estimated on each of the three branches.

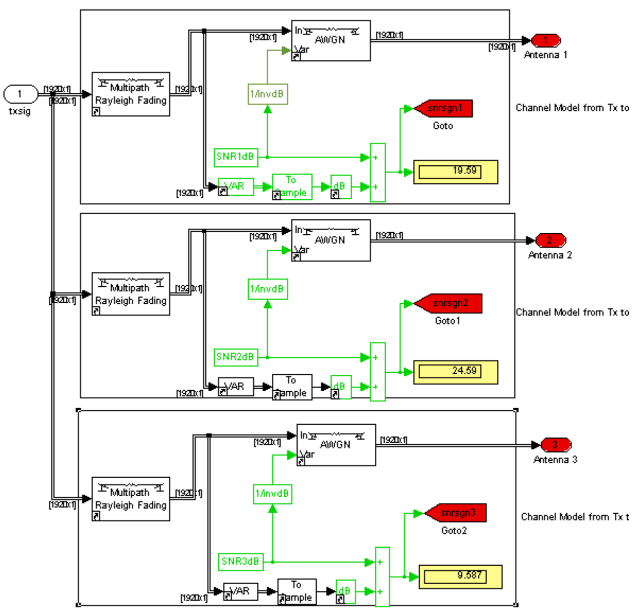

Fig. 1. Channel model for 1Tx-3Rx configuration

There are several types of diversity combiners, with different implementation complexity and overall performance. We have tested four of them: Threshold Combining (ThC), Selection Diversity Combining (SDC), Maximum Ratio Combining (MRC), and Equal Gain Combining (EGC).

In Threshold Combining (ThC) only one receiver is needed. The received signals are scanned in a sequential order, and the first signal with a power level above a certain threshold is selected. This signal is used as long as its power is higher than the threshold value. When it falls below the threshold the selection process is reinitiated. With only two-branch diversity this is equivalent to switching to the other branch when the SNR on the active branch falls below SNR_{Th}. This method is called switch and stay combining (SSC) [4]. Since the SSC does not select the branch with the highest SNR, its performance is between that of no diversity and ideal Selection Combining [4].

In pure Selection Diversity Combining (SDC), the received signals are continuously monitored so that the best signal can be selected. Since only one branch is used at a time, SDC often requires just one receiver that is switched into the active antenna branch. However, a dedicated receiver on each antenna branch may be needed for systems that transmit continuously in order to simultaneously and continuously monitor SNR on each branch [4]. The output of the combiner has an SNR equal to the maximum SNR of all the branches. SDC does not require co-phasing of multiple branches since only one branch output is used. To work properly each antenna branch must have relatively independent channel fading characteristics. To achieve this, the antennas are either spatially separated, use different polarization, or a combination of both [5].

In Maximum Ratio Combining (MRC) each signal is given a gain proportional to the ratio between the fading amplitude and the noise power. Since the signals are summed they must have the same phase to maximize performance. This requires not only separate receivers but also a co-phasing and summing device.

Equal Gain Combining (EGC) is a type of MRC. The weighting is equal, the weights are all set to the same value and are not changed after that. Then the signals are co-phased before the summation process just like in MRC.

IV. Implementation

Fig. 2 shows the threshold combing technique implemented with three receive antennas. All the received branches are scanned sequentially and the receiver outputs the first branch that has a SNR higher than the chosen threshold. The ThC block has a dialog window that allows the SNR threshold to be set by the user. The instantaneous SNRs of the received branches are obtained via the From blocks from the Multipath Channel block. The Constant block that can be seen in the figure below is the threshold SNR to which the SNRs of the three branches are compared. Only one of the If block's conditions can be true at a given moment of time, and therefore only the signal of one of the receiver antennas is passed to the output port.

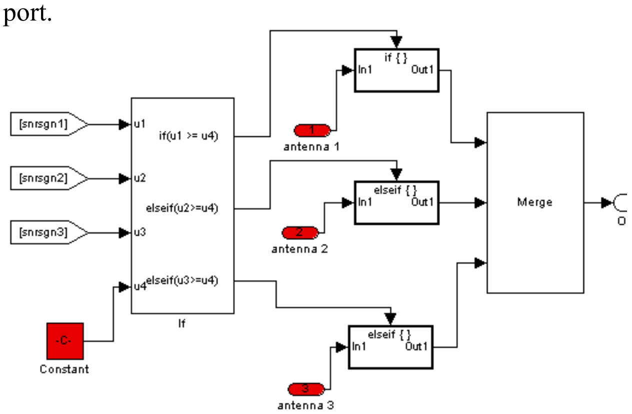

Fig. 2. ThC scheme for a 1Tx-3Rx configuration

Selection Combining takes the idea of threshold combining one step further by selecting the branch that has the highest SNR out of the received branches. This algorithm is implemented in Simulink by comparing the instantaneous SNRs of the incoming signals and outputting the signal from the branch with the highest SNR.

Similar to Threshold Combining, the conditions of the If blocks cannot be fulfilled simultaneously and therefore the signal from only one of the branches is passed to the output port at a given moment of time. The block diagram is too large to be presented here.

In the Equal Gain Combining technique the signals from the receive antennas are weighted by a gain that is preserved constant throughout the reception process. We have chosen the gain equal to $1/N_{Rx}$, where N_{Rx} is the number of receive antennas. The resulting signals are summed and yield an output that is a combination of all the received branches.

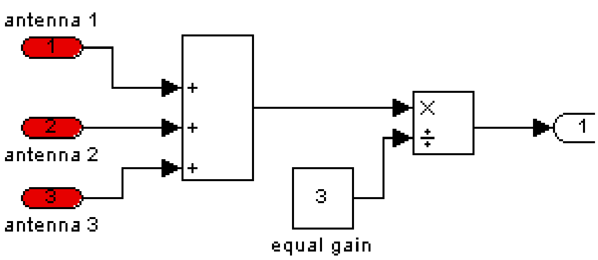

Fig. 3 EGC scheme for a 1Tx-3Rx configuration

Maximum Ratio Combining technique proposes a means of combining the signals from all receiver branches, so that signals with a higher received power have a larger influence on the final output. The design depicted in Fig. 4 computes the gain of each branch according to the relation:

$$a_i = \frac{SNR_i}{\sum_{i=1}^{N_{Rx}} SNR_i} \quad (1)$$

where: a_i is the gain of branch i; SNR_i is the instantaneous SNR of branch i; N_{Rx} is the number of receive antennas.

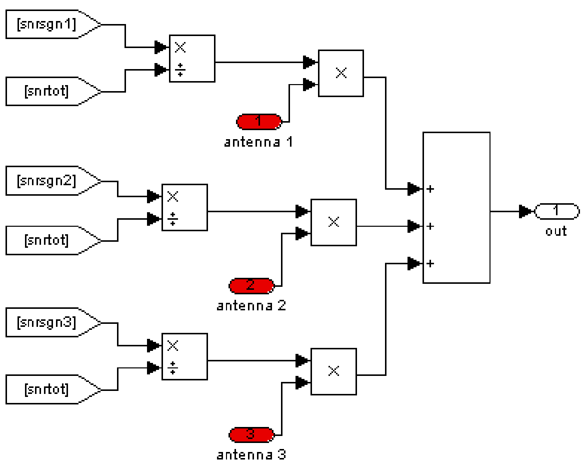

Fig. 4. MRC scheme for a 1Tx-3Rx configuration

V. SIMULATION RESULTS

First we should mention our simulation settings. The symbol period was chosen 0.08us, the number of OFDM symbols per block – 20 symbols, the number of OFDM symbols in the training sequence - 4 symbols, low SNR thresholds: [10 11 14 18 22 26 28], hysteresis factor for adaptive modulation - 2 dB, Viterbi traceback depth – 34. The channel fading mode was chosen dispersive fading and the maximum Doppler shift, 10 Hz. The receiver $SNR_{Threshold}$ was set to 20 dB.

ThC as presented in the previous section, chooses from the received branches, the first one that has a SNR above a specified threshold. Its major drawback however is that some other branches may have an even better SNR than the chosen branch, and, still, they are suppressed. To mitigate this disadvantage, an optimised threshold has to be found. On the other hand, ThC technique has the advantage that, should a branch have a very low SNR, it does not influence the output of the receiver, as only one branch at a time is selected.

Table 3 shows the results of simulations carried out by tuning the average received signal to noise ratios SNR_1, SNR_2 and SNR_3. Observe that these values represent the average SNR of the received signal, while the instantaneous SNRs that are involved in taking the decision on the branch to be selected at a given moment of time are displayed underneath the Multipath Channel's block mask. These different notions can be observed at the result of the simulation with the settings SNR_1=18 dB, SNR_2=25 dB and SNR_3=30dB, where we have an estimated SNR of 17.55 dB and a PER of 62 %. These poor results occurred because the ThC receiver has chosen the first branch with the instantaneous SNR exceeding the threshold value of 20 dB.

Also, the settings SNR_1=5 dB, SNR_2=5 dB and SNR_3=30dB illustrate the advantage that the poor SNR of some paths do not affect the output of the receiver. The artificially high values are chosen for the sake of exemplification and are unlikely to be encountered in real life transmissions.

Table 3. Threshold Combining Simulations for a 1Tx-3Rx Configuration

SNR_1 [dB]	SNR_2 [dB]	SNR_3 [dB]	PER_{inst} [%]	SNR_{est} [dB]	Data rate [Mbps]
25	30	15	26	14.69	18
35	25	20	22	32.63	54
20	30	24	54	17.55	24
15	20	30	16	21.19	18
18	30	25	62	17.55	24
5	5	30	16	24.24	24
30	25	10	26	21.01	36

A SDC receiver compares the received branches among each other and outputs the one with the highest SNR. Compared to the ThC technique, it has the advantage that it selects the actual best signal in terms of received power, and not merely the first one that meets a certain criteria. Besides, it also maintains the property that branches with poor SNR do not influence the output of the receiver.

Table 4 provides proof of the latter statements. It can be noticed that, under the same simulation settings, the SDC receiver has provided much better SNRs, and thus, better data rates than the ThC receiver.

Table 4. Selection Combining Simulations for a 1Tx-3Rx Configuration

SNR_1 [dB]	SNR_2 [dB]	SNR_3 [dB]	PER_{inst} [%]	SNR_{Est} [dB]	Data rates [Mbps]
25	30	15	32	20.17	36
35	25	20	24	20.15	18
20	30	24	12	24.46	48
15	20	30	36	22.79	36
18	30	25	24	24.26	24
5	5	30	8	34.62	54
25	30	10	16	22.94	36

The average SNR gain increases with the number of receiver antennas, but not linearly. The highest gain is obtained by going from no diversity to two-branch diversity. Increasing the number of diversity branches from two to three will give much less gain than going from one to two, and in general increasing the number of receivers yields diminishing returns in terms of the SNR gain [4].

A major disadvantage of both ThC and SDC is that they only switch to another branch after fading has occurred.

EGC receiver outputs a signal that is a weighted sum of all the received branches. The gain of each branch is maintained constant throughout the reception. This method is designed on the premises that it is unlikely that the SNR of one branch would be significantly lower than the SNRs of the other branches. It is obvious that, as the signals from all receive antennas are combined to yield the output of the ECG receiver, a significant higher fading that affects one of the branches would diminish the quality of the output of the receiver. Such an unlikely situation is still taken into consideration in the simulations preformed (Table 5).

Table 5. Equal Gain Combining simulations for a 1Tx-3Rx Configuration

SNR_1 [dB]	SNR_2 [dB]	SNR_3 [dB]	PER_{inst} [%]	SNR_{Est} [dB]	Data rates [Mbps]
25	30	15	65	8.625	12
25	35	20	6	15.65	24
30	30	24	28	20.13	36
15	20	30	34	14.68	12
25	30	25	14	20.14	24
5	5	30	56	3.141	6
25	30	10	12	14.76	12

MRC receiver outputs a signal that is a weighted sum of all the received branches. But, unlike EGC, the gains of each branch are updated at the reception of every frame and they are proportional to the power of the received signal. Table 6 shows the results of the simulations performed on a 1Tx-3Rx configuration and by comparing them to those from Table 5 performed with the same simulation settings, with an EGC receiver, we can draw the conclusion that MRC receivers perform an improved combining of the incoming signals.

Table 6. Maximum Ratio Combining Simulations for a 1Tx-3Rx Configuration

SNR_1 [dB]	SNR_2 [dB]	SNR_3 [dB]	PER_{inst} [%]	SNR_{Est} [dB]	Data rates [Mbps]
25	30	15	26	10.53	12
25	35	20	22	18.22	18
30	30	24	31	15.78	12
15	20	30	18	18.22	24
25	30	25	16	26.66	36
5	5	30	36	10.54	12
25	30	10	32	16.41	24

VI. CONCLUSIONS

A major drawback of ThC is that some other branches may have an even better SNR than the chosen branch, and, still, they are suppressed. To mitigate this disadvantage, an optimised threshold has to be found. On the other hand, ThC technique has the advantage that, should a branch have a very low SNR, it does not influence the output of the receiver, as only one branch at a time is selected.

SDC has the advantage that it selects the actual best signal in terms of received power, and not merely the first one that meets a certain criteria. Besides, it also maintains the property that branches with poor SNR do not influence the output of the receiver.

A major disadvantage of both ThC and SDC is that they only switch to another branch after fading has occurred.

EGC provides higher antenna diversity gain then SDC. MRC realizes the highest antenna diversity gain compared to the other techniques.

The performance of the diversity combiners increases with the number of antennas, but not linearly, and will eventually stop growing beyond a certain number of antennas.

Until the 802.11n standard is ratified (at the earliest 2006) 802.11a products combined with spatial diversity techniques will offer a series of so-called "pre-n" products [6].

REFERENCES

[1] Martin Clark, MATLAB Central model: IEEE 802.11a WLAN PHY, The MathWorks

[2] *IEEE Std 802.11a*-1999 (Supplement to IEEE Std 802.11-1999) Telecommunications and information exchange between systems. Local and metropolitan area networks. Specific requirements Part 11: Wireless LAN Medium Access Control (MAC) and Physical Layer (PHY) specifications High-speed Physical Layer in the 5 GHz Band

[3] Mohinder Jankiraman, *Space-time Codes and MIMO Systems*, Artech House, 2004

[4] Andreea Goldsmith, *Wireless Communications,* Stanford University, Cambridge University Press, 2005

[5] Balvinder Bisla, Roger Eline, Luiz M. Franca-Neto, Intel Communications Group, Intel Corporation, *RF System and Circuit Challenges for WiMAX,* Aug 20, 2004, volume 8, issue 3, ISSN 1535-864X

[6] Sumeet Sandhu, IEEE Task Group 802.11n: *Multiple-antenna techniques for high throughput wireless LANs*, Intel Corporation, June 2004