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Analysis of the new modulation and coding techniques for VDSL

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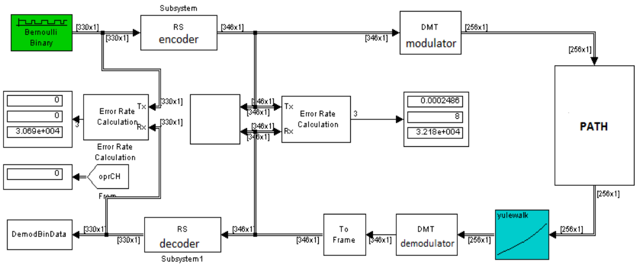
***Abstract*—Nowadays, the demand on higher transmission speed increased, because of more users using the Internet and the applications are demanding the higher transmission speed, too. In this article, we would like to give you our vision on increasing the transmission speed in VDSL technology.**

I. Introduction

THE motivation to write this article was based on positive results from our testing in Matlab. We tried to overload the measured channel capacity. The overloading was made in terms of sending more modulation symbols than the SNR measurement provided for certain distance. We used two model situations. Let's assume, that we have two results of channel capacity for the distance 400 m. One result was for modulator settings for 300 m, where we could put more modulation symbols, because the signal-to-noise ratio was higher and we could get into the distance 400 m by using the Reed-Solomon codes and correct the errors, that happened during the transmission, because of lower signal to noise ratio in the distance 400 m than in the distance 300 m. In this case, we used virtually higher capacity of the transmission channel, for the distance 400 m (capacity was used from the distance 300 m). The result was that more transmission errors occurred. We thought, if it was possible to correct these errors using Reed-Solomon codes. Below is the description of our analysis.

II. Analysis

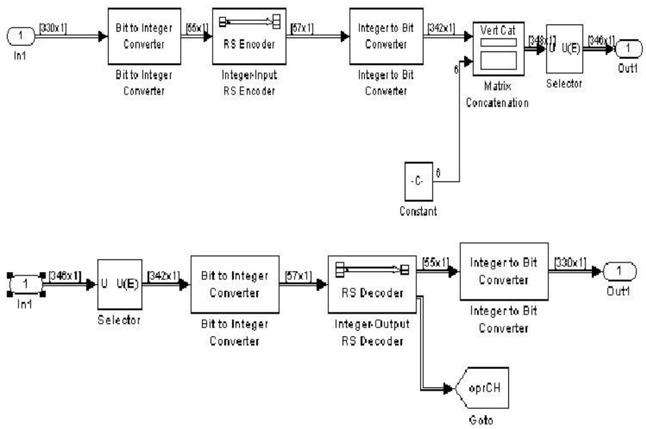
For the purpose of analysis, we used the communicatiom model, created in Matlab [2].



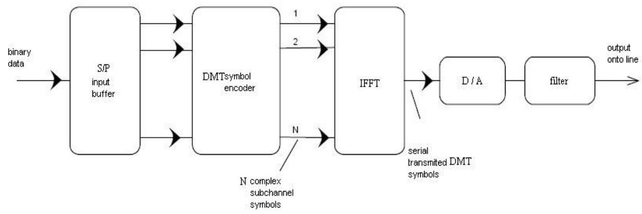
Picture 1. Simulation model

. The simulation model was composed of the Bernoulli binary generator as a source of data, Reed-Solomon encoder, DMT modulator, transmission path with errors simulation, DMT demodulator, Reed-Solomon decoder and receiver of the transmitted data. There were two errors couters, the first on was for modulation errors and the second one was for errors after application of Reed-Solomon codes.

First of all, we measured the capacity of the channel, without the Reed-Solomon codes, for the distances 300m, 400m, 500m, and 600m. In the case of errors in certain distance, we made another measurement, to accommodate the modulator to get errorless capacity and so ytransmission speed in each measured distance.



Picture 2.: Reed-Solomon encoder, decoder



Picture 3.: DMT modulator

After measurements, we had the number of modulation symbols N, that could be transmitted in the certain period of time, for each distance, for which the measurements were made. The N parameter was then used as a length of the codeword for Reed-Solomon codes. Assuming the equation for FEC and capacity of the channel, that was:

$$K/N < C \quad (1),$$

where N was the number of the modulation symbols (and a length of the codeword as well), K was the amount of the useful information and C was the channel capacity.
Because

$$N=K+2*T \quad (1.1),$$

And the N parameter was set by the measurement of the channel capacity, we had two parameters to vary with (K and T). The equation (1) can be also written in this way:

$$K/(K+2*T) < C \quad (2),$$

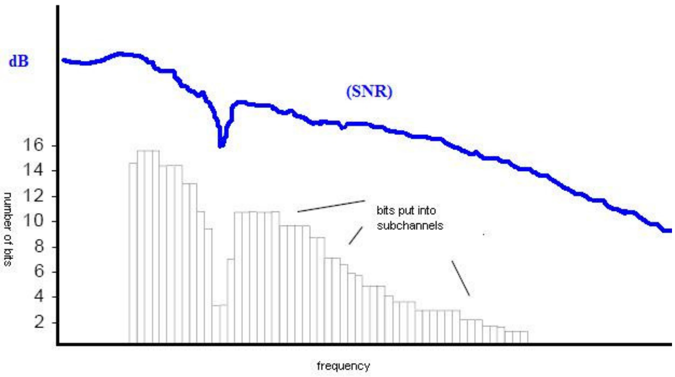
From this equation number 2, we can say, that if we want to transmit more data, that the parameter K represents, we must increase the T value, that represents the number of errors per frame, that the Reed-Solomon codes should be able to correct. So, if we want to increase the amount of the date K to be transmitted through the channel with the capacity C, we should increase the T parameter value. If we set the C value for 300 m and the real distance is 400 m, we should be able to correct more errors, but the result is higher transmission speed, even if more errors occurred during the transmission, because we can correct these errors by using the Reed-Solomon codes and the amount of data used for the parity of FEC is less than the gain of data in bits that we obtained by application of more modulation symbols transmitted per the unit of time, and Reed-Solomon codes. If we use higher channel capacity (can be achieved also by moving SNR function curve upper than measured) than measured, let's say
in 400 m if we use the capacity for 300 m, the N parameter will be higher, what means, that:

$$K / (K+2*T) \quad (3),$$

where

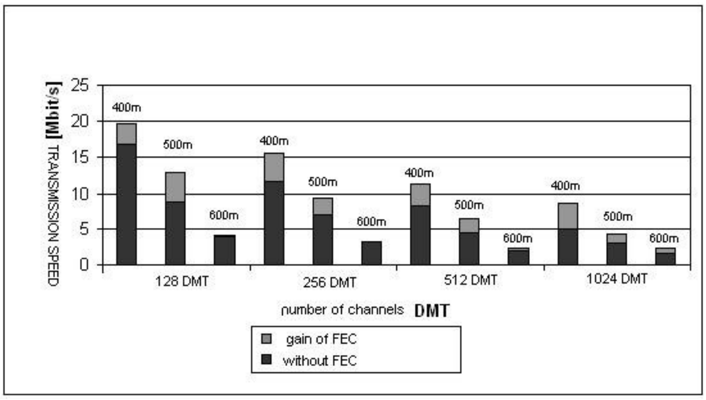
$$K+2*T=N \quad (4),$$

the K parameter can be higher, so the amount of the useful data can be increased, so the transmission speed will be higher. If we no keep the settings (N ,K) for the channel capacity measured for 300 m and apply it for the distance of 400 m, we will have to accommodate the T parameter according to the equation number (2).



Picture 4.: Signal-To-Noise Ratio

From the signal-to-noise ratio and measurement of the channel capacity in bits/s, we can find out the number of transmittable symbols, what is the codeword length as a parameter for the Reed-Solomon codes. Because of the characteristics of the metallic lines, used in DSL, the signal-to-noise ratio with increasing the distance, decreases, because of the influence of the metallic lines distortions. So, if we want to increase the transmission speed in longer distance, we should use the Reed-Solomon codes and so we can afford to use higher channel capacity then the metallic lines in required distance can provide us. Reed-Solomon codes are well behaving, because they can locate and correct the errors that occure during the transmission. Below, we will prove, that even if more parity bits are necessary to correct more errors when the channel capacity is overloaded (in the distance of 400 m we used settings of modulation for 300 m), we will still get gain in the terms of transmission speed.



Picture 5.: The results of testing

The picture number 5 shows us the results from the testing of the previous assumptions. Because of positive results, we wanted to define what was happening and wanted to understand, why we can get this gain in the transmission speed. From the results, we can say, that there is some gain visible. Next question is, whether the gain versus the parity length is still providing the gain in terms of more user data to be transmitted. We made an analysis from the table below (obtained from the measurement in Matlab made in [3]),

l [m]	N	K	bit/symbol	RSoprCH [symbol]	frVST [bit]	frM [bit]	RpM [Mbit/s]	RpC [Mbit/s]	errM [bit]	errC [bit]	sum(snr) [10^6dB]	max(snr) [dB]	mean(snr) [dB]
300	51	49	6	1	294	311	24.88	23.52	12	0	21.55	51.13	16.83
325	51	49	6	1	294	311	24.88	23.52	19	0	20.36	49.55	15.91
350	51	49	6	1	294	311	24.88	23.52	47	11	18.76	47.99	14.65
350	51	43	6	4	258	311	24.48	20.64	51	0	18.16	47.47	14.19
350	46	44	6	1	264	278	22.24	21.12	27	3	17.55	47.14	13.71
350	46	40	6	3	240	278	22.24	19.2	18	0	18.36	47.28	14.34
375	46	40	6	3	240	278	22.24	19.2	61	0	16.44	45.99	12.84
400	46	40	6	3	240	278	22.24	19.2	142	0	14.25	44.71	11.14
425	46	40	6	3	240	278	22.24	19.2	332	13	11.79	43.43	9.21
425	46	36	6	5	216	278	22.24	17.28	323	0	10.11	42.96	7.9
425	36	30	6	3	180	217	17.36	14.4	90	0	10.01	43.7	7.82
450	36	28	6	4	168	217	17.36	13.44	240	0	8.34	41.85	6.51
450	32	26	6	3	156	197	15.76	12.48	150	0	6.29	42.16	4.91
475	32	24	6	4	144	197	15.76	11.52	317	0	3.11	40.96	2.43
475	30	26	5	2	130	151	12.08	10.4	24	0	1.42	40.72	1.11
500	30	26	5	2	130	151	12.08	10.4	95	0	-0.82	39.48	-0.64
500	27	23	5	2	115	136	10.88	9.2	45	0	-1.29	35.41	-1.01

Tab.: 1. Results of testing

where we put the gain in the transmission speed in bits on one side and the amount of data used for parity of FEC on the other side. Let's say that the gain for 350m was 20,64 Mbits/s – 19,2 Mbits/s, what equals to 1,44 Mbits/s. One more parity symbol was used, and if each parity symbol in this case means 6 bits, 1*6 is 6 more bits to transmitt. If we subtract 1,44 Mbits/s – 6 bits/s, the result is 1,444 Mbits/s. This means, that even if more parity symbols were used to get into longer distance errorless, we still will get the gain in terms of percentage, here 1,444 / 19,2, what equals to cca 7,52 % of gain. From the results we can say that even if more errors occured when the channel was overloaded in terms of more symbols transmitted in a unit of time, if we correctly set the Reed-Solomon codes, we will be able to repair the errors that occure during the transmission and because the errors count is not increasing faster than the Reed-Solomon possibility to correct it, these codes are good choice for increasing the transmission speed in VDSL. Our next idea is also to try to de ne the maximum of the channel overloading to de ne the maximum speed that using of these codes can provide. Let's assume the limmity:

$$\lim_{T \to \inf} (K/ (K + 2*T)) < C \quad (5),$$

How K value can be changed when increasing the T parameter? We can say, that if T increases, there is a possibility to increase the K, which represents the amount of data, what is in terms of transmission speed positive. But we must keep in mind also the equation mentioned above N = K + 2*T. So, the upper limmity of increasing the the parameters K and T is de ned by this equation (5). Another fact that follows these assumptions is that if we want to increase the transmission speed in longer distance, we must use the number of bits assigned to a frame from lower measured distance, or just use higher number of bits than assigned by modulator (for example using higher signal-to-noise ratio to assign the number of bits to a frame).

III. ADVANTAGES OF FEC

Reed-Solomon codes and the RM OSI model

From the RM OSI model perspective, the modem is working on the physical layer. There are two possibilities of implementing the Reed-Solomon codes. The rst one is the implementation into the modem, where we can have modulation and FEC in one device. The second one is, that we can make a device called Reed-Solomon codec and use it on the customers premisses. The thing is, that the de nition of Reed-Solomon codes parameters should be same on each side of the transmission, what means that the generating polynome must be the same, to be able to encode and DECODE the information transmitted through the channel.

Reed-Solomon codes and synchronisation

The problem, that was not solved yet, was the synchronisation of the FEC. Let's say, that two clients want to communicate and both are using the modem with Reed-Solomon codes. First of all, there must have the same generating polynome for the codes on both sides. Second condition that must be accomplished is, that during the settings of the connection on both sides, all parameters must be set propperly (parameter N, K, T) and the same on both sides. This can be done by setting some exchange of parameters at the beginning of the communication. This will be time consuming at the beginning, but can be usefull in terms of modem settings to higher transmission speed.

Reed-Solomon codes versus agregation

Another benefit is, that using Reed- Solomon codes we can get higher transmission speed without the agregation of lines with lower speed together. And so, if we do agregate these lines with Reed-Solomon codes, we can get much more higher capacity and so transmission speed than with aggregation and without Reed-Solomon codes. We can play with these settings to obtain as high speed as possible.

Reed-Solomon impleamentation

The possible implementation could be based on defining the Galois field from the channel capacity measurement. After the mesurement we have defined the number of modulation symbols that can be transmitted in the transmission period of time per unit, so called modulation speed. Each combination of modulation symbols is a codeword of FEC. The number of symbols possible to transmitt in a period of time is a multiplication of codeword length. So, if we use higher codeword length, let's say in the distance 350m if we use the codeword length appropriate for 300m, which is higher, we can get higher modulation speed, but with more errors. But if we use some portion of the codeword for correction of the transmission errors, so called parity of the FEC, we will get higher transmission speed in 350m, than if we use the modulation settings for 350m. So, there is a benefit of using the FEC, here the Reed-Solomon codes, in ability to increase the transmission speed and get better results than before.

IV. CONCLUSION

From the text above, we can say, that it is possible to increase the transmission speed by appropriate use of the FEC, in this case Reed-Solomon codes, to get into longer distance with higher transmission speed. This also means, that we can keep the existing infrastructure of metallic lines and using the mathematical methods we can get into longer distance with higher transmission speed as well as increasing the amount of data, that we are willing to transmitt by increasing the N parameter over the measured value. One thing that is not defined yet is the maximum increase of the frame length parameter in each distance compared to measured value in this distance. This idea can be an issue for further research in this topic. We just wanted to show, that there is a way how to increase the transmission speed using the mathematical methods.

V. REFERENCES

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