New Baseband Radio Channel Impulse Processing Algorithms

Norbert MAJER[1], *Vladimír WIESER*[2], *Ján HARING*[3]

[1,2,3] Department of Telecommunications and Multimedia, Faculty of Electrical Engineering, University of Žilina, Univerzitná 1, 010 26 Žilina, Slovak Republic

[1] norbertmajer@zoznam.sk, [2] vladimir.wieser@fel.uniza.sk, [3] haring@fel.uniza.sk

Abstract. *In this paper the method for radio channel pulse response processing with baseband conversion by six-port reflectometer technique is described. The received signal is converted by baseband conversion, digitized and the pulse response of radio channel is processing by proposed algorithms. The algorithms were created in a program language Delphi 7, so they are working in the real time and are able to estimate the amplitude, phase and delay of the received signal in each propagation path.*

Keywords

Pulse response, radio channel, six-port reflectometer, pulse response processing algorithms.

1. Introduction

A radio signal (RF signal) travels by multiple paths in the radio channel to receiver antenna and is created by an interference of several copies of transmitted signal, which reflect from subjects that are placed in surrounding environment. This effect will cause, that each replica of RF signal will have a different amplitude, phase and delay, so delay spread and intersymbol interference (ISI) will emerge [3].

By estimation of quantity, amplitudes, phases and delays of dominant paths it is possible to describe the pulse response of radio channel. This information may be used to adapt bit rate, transmitter power, beam pattern of smart antenna and weights of Rake receiver [6].

In the present, methods used for the estimation of the channel pulse response apply a hardware solution, so called channel sounders [1], which process the received signal in RF band.

Complex receivers, a low flexibility for received signal processing are the main disadvantages of this solution. With hardware signal processing, the receiver is designed for dealing with a specific signal and any change of RF signal will cause a necessity to receiver change.

The solution of this problem is possible by a combination of six-port reflectometer technique (SPR) used for baseband conversion and a Software Defined Radio (SDR) [4]. In this system any change of RF signal is possible to be solved by change of the processing algorithm only.

2. RF Signal processing

The processing of RF signals is too complex in high-frequency bands and digitizing of RF signal is complicated in the present, because of A/D converters, which are able to digitize signals only to tens of MHz with satisfactory dynamic resolution. The solution of this problem lies in baseband real time signal conversion and its subsequent software analysis [5].

We are using the six-port reflectometer [2] (Fig.1) for RF signal baseband conversion. RF signal received by antenna is led to SPR, where a standing wave is created by interference of RF signal and signal from local oscillator (LO). Standing wave is detected by a four power detectors D1-D4, which are connected to A/D converters. The signal is digitized by A/D converters in the baseband and is processed by appropriate algorithms.

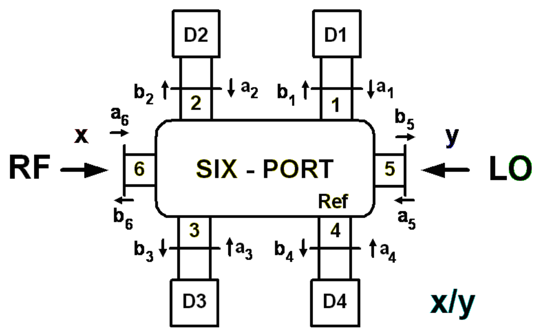


Fig. 1. Six-port reflectometer

3. Properties estimation of channel pulse response

We have proposed four algorithms for estimation of radio channel pulse response properties, which are not only hardware demanding but also a little time consuming. An algorithms´ task is the estimation of basic propagation paths parameters – amplitude, phase and delay of signals in each path.

The principle of proposed algorithms lies in the processing of channel pulse response in time domain. Incoming signal samples are stored in the memory bank and then compared with consecutive samples.

3.1 Power Descend Algorithm

PDA algorithm (Power Descend Algorithm) compares samples incoming in time *t* with the ones incoming in time *t*-1. If the amplitude of *t* time sample is bigger as the one in *t*-1time, then *t* time value is written into a variable *max*:

```
if (rxsignal[t-1] < rxsignal[t]) then
max: = rxsignal[t];
min: = rxsignal[t-1],
```

where *rxsignal[t]* is the amplitude of *t* time sample of incoming signal .

The PDA algorithm calculates a constant descent d_c, which represents the difference between amplitudes of two consecutive samples (*t* and *t*-1):

$$d_c = (\mathrm{max} - \mathrm{min}) \quad (1)$$

Then PDA algorithm compares calculated constant descent with the required one d_r and if a condition $d_c > d_r$ is true, then algorithm evaluates this descent as the propagation path (square) (Fig.2) and stores amplitude, phase and delay of this path.

Repeating of this process is finished by all propagation paths finding (Fig.2).

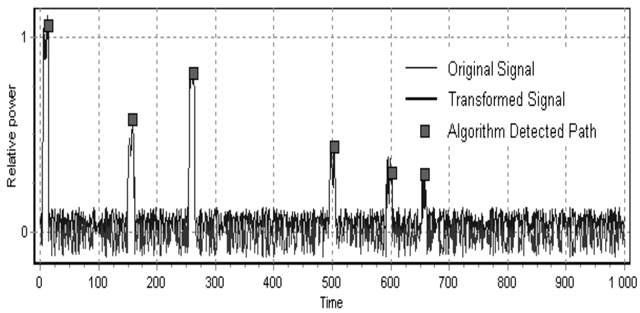


Fig. 2. Radio channel pulse response and indication of paths detected by PDA algorithm.

The value of required constant descent d_r designates a resolving ability of PDA algorithm. With higher values of constant descent d_r PDA algorithm finds the paths with bigger amplitude (dominant paths) only.

Because samples of incoming signal are directly written to variable *min*, the incoming signal is identical with a generated one (Fig.2), which is the main disadvantage of PDA algorithm. Therefore, PDA algorithm frequently assigns a noise as the propagation path (Fig.2).

3.2 Rectangular Window Function Algorithm

RWFA algorithm (Rectangular Window Function Algorithm) is designed on the same principle as the previous one, but with difference, that if the RFWA algorithm finds a local maximum, this value is hold on the same level during interval $t+\Delta t$ (width of the transmitted measurement pulse):

```
if (rxsignal[t-1]< rxsignal[t]) then
max: = rxsignal[t] = rxsignal[t+Δt];
min: = rxsignal[t+Δt+1];
```

The actual value of the signal amplitude *rxsignal*($t+\Delta t+1$) (Fig.3) is written to the variable *min* after the interval elapsed.

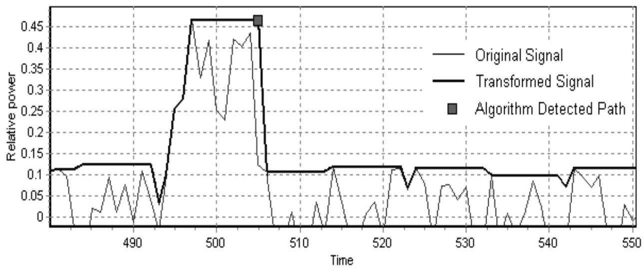


Fig. 3. Rectangular Window Function Algorithm RWFA

To identify individual paths of channel pulse response, the RWFA algorithm achieves better results as the previous one, but it is inappropriate in the radio channel with low signal to noise ratio (SNR) (Fig.4).

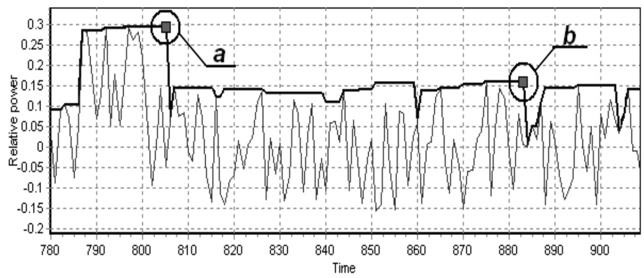


Fig. 4. a)correct b) incorrect indication of propagation path by RWFA algorithm

3.3 Exponential Power Descent Algorithm

The EPDA algorithm (Exponential Power Descend Algorithm) is different from the previously described algorithms. The signal is descending by exponential function from local maximum and signal samples are written to variable *min* (Fig.5).

```
if (rxsignal[t-1] < rxsignal[t]) then
max: = rxsignal[t];
min: = rxsignal[t]*exp(-α);
```

when α is the power descent constant.

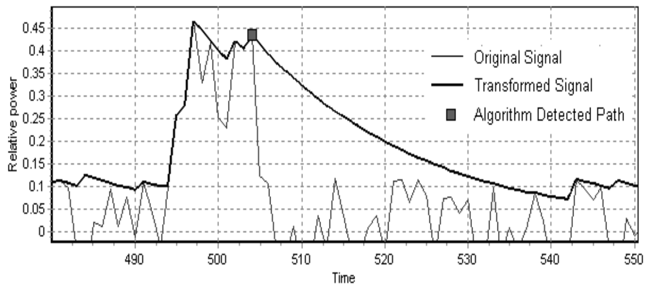


Fig. 5. Exponential Power Descent Algorithm EPDA (detail)

In reality, this algorithm doesn't work with original signal envelope, but with envelope of a transformed signal (Fig.5,6).

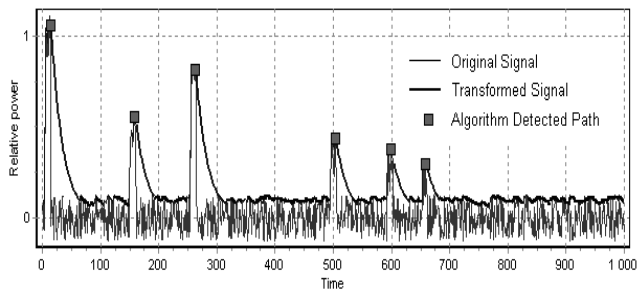


Fig. 6. Exponential Power Descent Algorithm EPDA

By this processing, the EPDA algorithm achieves much better results as previously described algorithms and the run time is not increased.

3.4 Modified Exponential Power Descend Algorithm

MEPDA algorithm (Modified Exponential Power Descend Algorithm) is slightly more demanding for run time and achieves only a little bit better results as EPDA algorithm. The difference between both algorithms lies in the using a modified exponential function, describing the signal descends from local maximum (Fig.7).

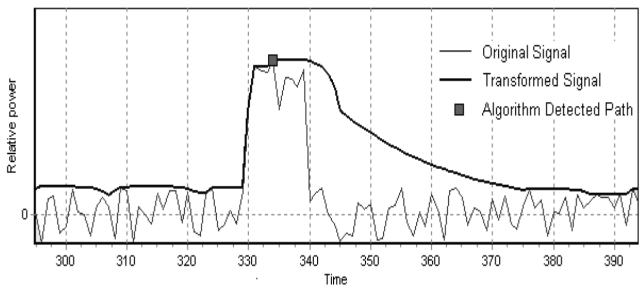


Fig. 7. Modified Exponential Power Descend Algorithm MEPDA

4. Comparison of algorithms

To compare proposed algorithms, a new program was created, which generates the channel pulse response and compares a true quantity of paths with the quantity found by individual algorithms:

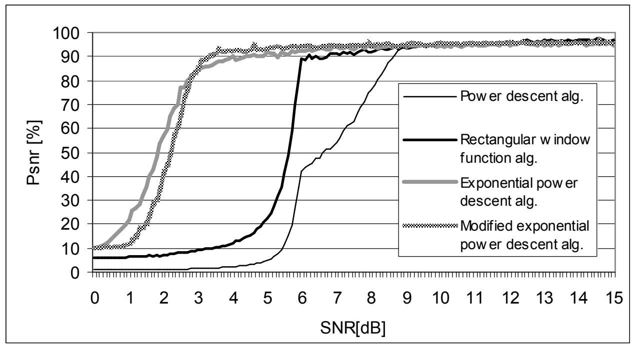
```
if (Nf[i] <= Ng[i]) then
P[i]: = Nf[i]/Ng[i]*100;
else
P[i]: = Ng[i]/Nf [i]*100;
```

where N_f – is the number of paths found by algorithm, N_g – is the generated number of paths, *P[i]* – is the probability of recovery of all paths for one pulse response and *i* - is the repetition number for one SNR value.

The number of generated pulse responses was chosen to 1 000 for one SNR value. The value of SNR varied from 0 dB to 15 dB by 0.1 dB step. The probability of recovery of all paths for given value of SNR:

$$P_{SNR} = (\sum_{i=1}^{1000} P[i]) / 1000 \ [\%] \tag{1}$$

The P_{SNR} cumulative distribution function is displayed on Fig. 8.



Obr. 8. The cumulative distribution function of paths recovery probability

Setting the recovering paths probability to 90%, it is obvious (Fig. 8) that PDA algorithm reaches the worst results (required SNR = 9 dB). The RWFA algorithm reaches the requested value of P_{SNR} approximately with SNR = 6 dB. The best results were achieved by EPDA and MEPDA algorithms, with necessary value of SNR = 3 dB.

The EPDA algorithm was selected for the next application, because of its short run time and good behavior of cumulative function curve (Fig. 8).

The results of the EPDA algorithm are dependent on power descent constant α. The distribution functions of EPDA algorithm for different values α in dependence on SNR values are shown on Fig. 9.

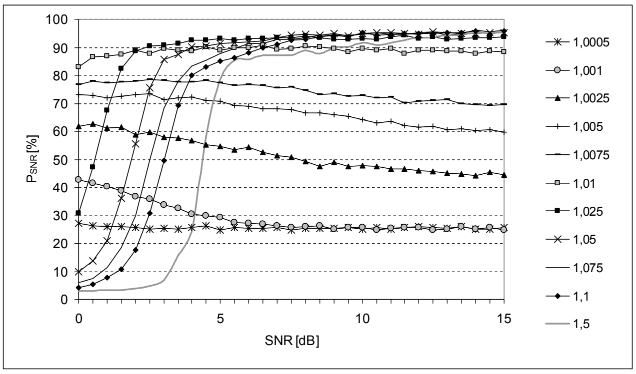


Fig. 9. The performance of EPDA algorithm with different α values

From Fig. 9 it is obvious, that EPDA algorithm reaches a recovery successfulness of all paths with value approximately 83 %, even with SNR = 0 dB (α = 1.01). The recovery successfulness of all paths is greater than 90 % for values α > 1.01, but SNR values have to be higher. The value α = 1.025 appears to be optimal one, for which the algorithm reaches P_{SNR} ≈ 90 % with necessary value of SNR = 2.5 dB. The P_{SNR} is approximately 95 % for SNR > 2.5dB.

Conclusion

In this contribution the method for dominant parameters estimation of radio multipath channel pulse response with baseband conversion by six-port reflectometer technique is described. The proposed method uses the six-port technique for baseband conversion and signal processing is realized by algorithms implemented in software defined radio. The Exponential Power Descend Algorithm is the most perspective, because achieved recovery successfulness of all signal paths is approximately 90 % for SNR value ≈ 2.5 dB.

Our next work is directed toward using proposed algorithm for channel estimation in ultra-wideband communication systems (UWB).

Acknowledgements

This paper was supported by the scientific grant agency VEGA in the project No. 1/4067/07.

References

[1] TRAUTWEIN U., HAMPICKE D., SOMMERKORN G., THOMA R. *Array Based Measurements of the Time-Variant Directive Radio Channel*, EuMC Munich Germany, 1998.

[2] MAJER, L., STOPJAKOVÁ, V. *Monolitic RF receiver in 2GHz frequency region using six-port technology*. Proceedings of IEEE Vršov 2006, Vršov, Czech Republic, September 19-21, 2006, p.99-102.

[3] JANASWAMY R. *Radiowave propagation and smart antennas for wireless communications*. Kluwer Academic Publischers 2001. ISBN 0-7923-7241-7

[4] HICKLING, R. *New Technology Facilitates True Software Defined Radio*. http://rfdesign.com/mag/504rfdf1.pdf, 2005.

[5] MARSAN E., BOSISIO G. R., WU K. *A C-Band Direct Digital Receiver MMIC and its Carrier Recovery Circuit*, Poly-GRAMES Research Centre, Montreal Canada, 2002.

[6] GALLAGHER T.M. *Characterization and Evaluation of Non-Line-of-Sight Paths for Fixed Broadband Wireless Communications*, Dissertation submitted to the faculty of the Virginia Polytechnic Institute, 2003.

About Authors...

Vladimír WIESER was born in Púchov in 1954. He received the M.S. degree in electrical engineering and communication from Military Academy Brno, Czech Republic, in 1978 and Ph.D. degree from Military Academy Liptovský Mikuláš in 1996. Since 2001 he works as Ass. Prof. in Department of Telecommunication and Multimedia of University of Žilina, Slovak Republic. His research includes mobile communication networks, especially power and rate adaptation, radio resource management.

Norbert Majer was born in Zvolen in 1983. He received the M.S. degree in Telecommunication from University of Žilina in 2007 and now is Ph.D. student in Department of Telecommunication and Multimedia of University of Žilina.