Using Power Line Modems Measurements for Degradation Detection on Power Lines

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Outline

Motivation

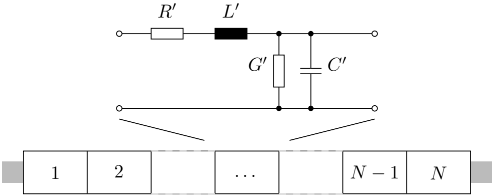
- Power lines on low voltage level are replaced in regular intervals to prevent outages
- Performing measurements ([1], [2]) to estimate remaining life time of the cables would be possible, but not cost efficient
- Smart meters and other power line modems get more and more common
- To perform equalization, power line modems perform channel measurements

Suggested approach

- Power line modems measure channel transfer function (CTF) $H(f)$ in periodic intervals
- Assumption: Topology, loads connected, etc. are unknown
- Power line modems save the initial CTF, measured on deployment as "healthy" state of the network
- $\rightarrow$ monitor for characteristic changes in the channel transfer function
- noise and changed loads are mitigated by averaging over many measured transfer functions
- simple algorithms implementable in the power line modems themselves shall estimate degradation existence and location

Simulation Model

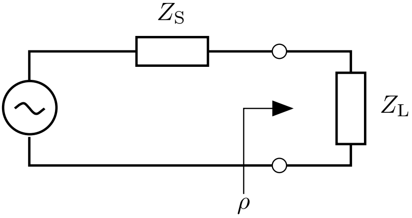
- Transmission line simulated as concatenation of N electrically small lumped circuit elements
- Lumped circuit elements defined by their per unit length (PUL) parameters R', C', L', G'
- Degradations of the power line may be simulated as change in PUL parameters of affected lumped circuit elements
- Usually degradations manifest themselves in altered conductance (up to five times the original value) or capacitance (up to several percent increase) [4]



- PUL parameters determine the wave impedance of the lumped circuit element
- changes in wave impedance lead to partial reflection of incoming waves
- reflection quantified by the reflection coefficient ρ, depending on the connected load Z_{L} and the source impedance Z_{S}:

$$\rho = \frac{Z_{\mathrm{L}} - Z_{\mathrm{S}}}{Z_{\mathrm{L}} + Z_{\mathrm{S}}}$$

- reflections also occur on at any non-matched endpoints



Proposed Algorithm

- Suggestion: Perform detection and localization using the time-domain of the degradation channel transfer function
- CTF of healthy state, $H'_{\mathrm{h}}(f) = H_{\mathrm{h}}(f) + N_1(f)$ known (impaired by noise)
- Current CTF $H(f)$ is composed of the healthy state $H_{\mathrm{h}}(f)$ and a degradation CTF $H_{\mathrm{deg}}(f)$
- Measurement of current CTF impaired by noise, too: $H(f) = H_{\mathrm{h}}(f) \cdot H_{\mathrm{deg}}(f) + N_2(f)$
- Dividing $H(f)$ by the measured healthy transfer function $H'_{\mathrm{h}}(f)$ leads to noise amplification where $H'_{\mathrm{h}}(f)$ is close to zero

$$\frac{H_{\mathrm{h}}(f) \cdot H_{\mathrm{deg}}(f) + N_2(f)}{H'_{\mathrm{h}}(f)} = \frac{H_{\mathrm{h}}(f) \cdot H_{\mathrm{deg}}(f)}{H'_{\mathrm{h}}(f)} + \frac{N_2(f)}{H'_{\mathrm{h}}(f)}$$

- To combat the noise amplification, we use water level regularization ([3]) on the recorded healthy transfer function
- Water level w applied to recorded healthy CTF to obtain replacement function $G(f)$:

$$G(f) = \begin{cases} w & \text{for } H'_{\mathrm{h}}(f) = 0 \\ w \cdot H'_{\mathrm{h}}(f)/|H'_{\mathrm{h}}(f)| & \text{for } H'_{\mathrm{h}}(f) < w \\ H'_{\mathrm{h}}(f) & \text{for } H'_{\mathrm{h}}(f) \geq w \end{cases}$$

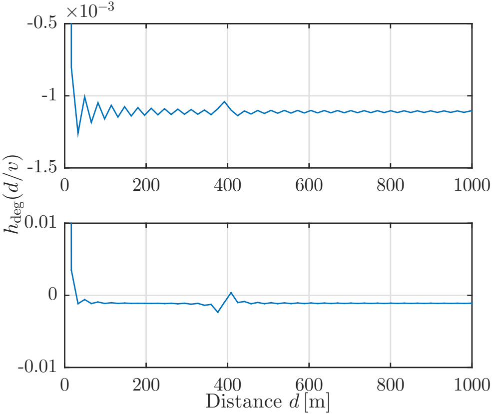
- Estimated degradation transfer function:

$$H'_{\mathrm{deg}}(f) = H(f)/G(f)$$

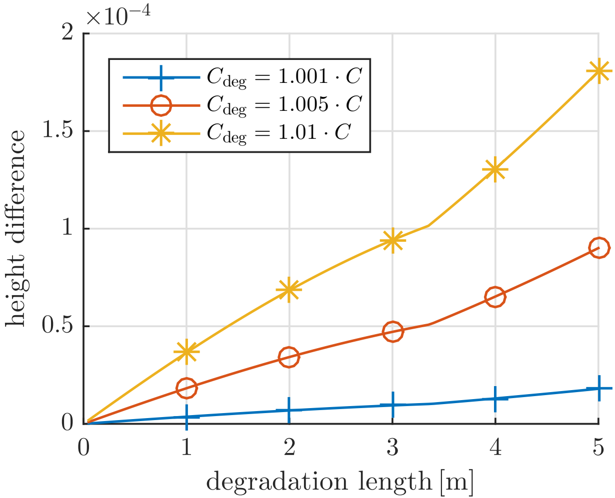
- Water level w needs to be optimized depending on noise and signal energy levels

Results

- One power line, 1 km in length, degradation of length 1 m at 200 m
- upper plot: 10 % capacitance increase, lower plot: 500 % conductance increase
- Line end impedances not matched
- Degradation impulse response mapped from time to distance using propagation speed



- Degradation with altered capacitance at $250\,\mathrm{m}$ of different severity and length
- Height of peak used as indicator how well the degradation may be detected



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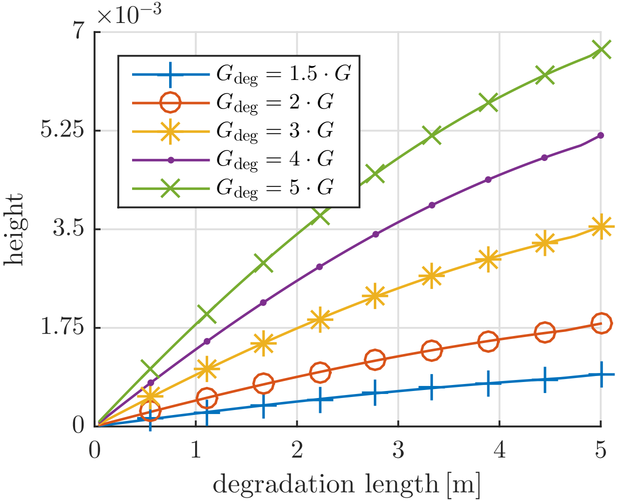
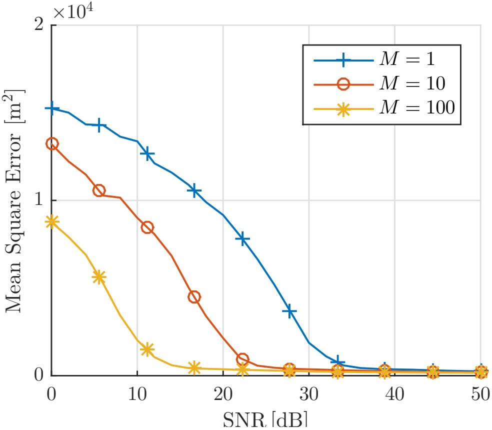


- Degradation with conductance increased by factor five at 200 m
- Noise characterized by signal to noise ratio (SNR) added to simulated channel transfer function
- Simple detection algorithm: Examine degradation impulse response after water level regularization for local maxima
- Simulated degradation impulse response averaged M times to combat noise



- Use super-resolution effects to reduce required bandwidth
- PLC Tomography: Estimate topology of PLC network ([5])
- Sophisticated detection algorithm that includes the topology of the network
- Alternative deconvolution approach including expected properties of the degradation transfer function
- Distributed algorithm involving all power line modems in a network

Conclusions

- Simple proof-of-concept regarding detection and localization of degradations shows promise
- Degradation kind, length and severity on degradation impulse response influence detection probability
- Low complexity detection algorithm implementable in the power line modems works for simple networks with few reflections

[1] V. Taylor and M. Faulkner, *Line monitoring and fault location using spread spectrum on power line carrier*, Generation, Transmission and Distribution, IEEE Proceedings-, vol. 143, no. 5, pp. 427–434, Sep 1996.

[2] *Ieee guide for determining fault location on ac transmission and distribution lines*, IEEE Std C37.114-2014, p. 1–76, Jan 2015

[3] R. W. Clayton and R. A. Wiggins, *Source shape estimation and deconvolution of teleseismic bodywaves*, Geophysical Journal International, vol. 47, no. 1, pp. 151-177, 1976

[4] M. Schuchardt, *Entwicklung eines Diagnosekonzeptes für Mittelspannungskabelanlagen mit Massekabeln*, Ph.D. Thesis, Technische Universität Berlin, 2013

[5] M. Ahmed and L. Lampe, *Power Line Communications for Low-Voltage Power Grid Tomography*, IEEE Transactions on Communications, Vol. 61, No. 12, pp. 5163-5175, December 2013.

Thank you for your interest!

Any questions?