Limits of Ultra-Wideband Communication Over Copper

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Outline

- Background and motivation
- Wideband cable-models and measurement results
- Throughput analysis and results
- Conclusions and outlook
Background

- Wireline communications: data transmission over telephone wires
- Breakdown\(^1\) of broadband access technologies:

![Pie chart showing wireline, cable, and rest percentages.]

\(^1\)Average over OECD countries, December 2005
Motivation

Digital Subscriber Line (DSL) achieves high rates by exploiting wide bands of the copper cable channel

- Current DSL standards foresee the use of bands up to 30MHz
- Cable properties have been studied by means of measurements, characterization and modeling up to frequencies of 30MHz
- Very short cables (up to 200m) can be exploited even more
- Prerequisite for further evaluation: cable models for higher frequencies
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Reference models

- **Insertion loss** [Chen98]:
  \[ H_{IL}(f, L) = e^{-L/L_{\text{mile}}} \left( k_1 \sqrt{f} + k_2 f \right) - jL/L_{\text{mile}}k_3 f \]  
  with \( L_{\text{mile}} = 1609.344 \text{ m} \), \( k_1 = 4.8 \cdot 10^{-3} \), \( k_2 = -1.709 \cdot 10^{-8} \), \( k_3 = 4.907 \cdot 10^{-5} \)

- **FEXT** [ETSI01]:
  \[ H_{FEXT}(f, L) = k_{XF} f / f_0 \sqrt{L/L_0} |H_{IL}(f, L)| \]  
  with \( f_0 = 1 \text{ MHz} \), \( L_0 = 1 \text{ km} \), \( k_{XF} = 10^{-45/20} \)

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Measurement setup

- **Insertion loss:** $H_{\text{ins}} = \frac{V'_{1}}{V_{1}}$
- **NEXT:** $H_{\text{NEXT}} = \frac{(V_{3} - V_{2})}{V_{1}}$
- **FEXT:** $H_{\text{FEXT}} = \frac{(V'_{3} - V'_{2})}{V_{1}}$
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Cables:
- Cable No. 1: 200m EULEV 10x2x0.4 TEH 240 1402/010 on drum
- Cable No. 2: 50m EULEV 10x2x0.4 TEH 240 1402/010 wrapped to a ring with a mean diameter of 0.55m

Gain/phase-analyzer parameters:

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Stability and reproducibility of UWB measurements

50m-cable: mean insertion loss and 95% confidence interval

![Graph showing magnitude and phase vs frequency for 50m-cable measurements.]
Stability and reproducibility of UWB measurements

50m-cable: mean FEXT and 95% confidence interval
50m-cable: mean NEXT and 95% confidence interval
Long-term variations of UWB cable properties

50m-cable, long-term measurements: FEXT coupling function ensemble mean (corresponds to mean over time) and minimum/maximum range (gray-shaded fields)
200m-cable, long-term measurements: FEXT coupling function ensemble mean (corresponds to mean over time) and minimum/maximum range (gray-shaded fields)
Comparison with extrapolated 30MHz-models

50m-cable, insertion loss: ensemble mean and extrapolated Chen-model (1)
Comparison with extrapolated 30MHz-models

50m-cable, FEXT: ensemble mean and extrapolated ETSI-model (2)
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Ingress/egress: constraints imposed by CISPR22

Receive PSDs (solid lines), transmit PSD (dashed-dotted lines) and noise PSD caused by CISPR22 ingress (dashed line)
Ingress/egress: constraints imposed by CISPR22 and 1 FEXT

Receive PSDs (solid lines), transmit PSD (dashed-dotted lines) and noise PSD caused by CISPR22 ingress one equal-length FEXT disturber (dashed line)
Capacity versus exploited bandwidth for CISPR22 ingress

![Graph showing capacity versus exploited bandwidth for CISPR22 ingress. The x-axis represents exploited bandwidth in MHz, and the y-axis represents data rate in Gbit/s. The graph includes curves for different cable lengths: 100 m, 150 m, 200 m, 250 m, and 300 m. Each curve shows the expected data rate for a given bandwidth and cable length.]
Capacity versus exploited bandwidth

Capacity versus exploited bandwidth for CISPR22 ingress one equal-length FEXT disturber

![Graph showing capacity versus exploited bandwidth for different lengths of cable (100 m, 150 m, 200 m, 250 m, 300 m)].

- The x-axis represents exploited bandwidth in MHz, ranging from 0 to 100 MHz.
- The y-axis represents data rate in Gbit/s, ranging from 0 to 0.5 Gbits/s.
- Each line corresponds to a different cable length:
  - 100 m
  - 150 m
  - 200 m
  - 250 m
  - 300 m

The graph illustrates how the capacity (data rate) increases with exploited bandwidth and decreases as the cable length increases.
'Usable' bandwidth versus length

![Graph showing 'Usable' bandwidth versus loop length in m, with y-axis in MHz and x-axis in m. Two lines represent CISPR 22 ingress only and CISPR 22 ingress + 1 FEXT.]
Capacity versus loop length

- CISPR 22 ingress only
- CISPR 22 ingress + 1 FEXT
Conclusion

- Good match between measured insertion loss results and the extrapolated 30MHz-models
- Reasonable match between measured crosstalk-coupling functions and the extrapolated 30MHz-models
- Considering CISPR22, we do not need to look beyond 100MHz!
- Considering CISPR22, the limits are ...
  - \( \approx 0.5 \text{ Gbit/s} \) without FEXT
  - \( \approx 200 \text{ Mbit/s} \) with one (strong) FEXT disturber
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Thank you!