ITG INFORMATIONSTECHNISCHE GESELLSCHAFT IM VDE

FG 5.4.1 Meeting, Krems/Austria, June 30th,2008

Data transmission with Multi Carrier Modulation over SI-POF – What is possible?

Dr. Andreas Bluschke, Michael Matthews, Dr. Gerald Nürnberger, Philipp Rietzsch, Rainer Steglich

Teleconnect GmbH Dresden

- **Introduction**
- Fast Ethernet demonstrator
- Calculation tool
- Future bandwidth requirements
- Conceptions for higher bit rates
- Conclusion

Introduction

- At 23rd Meeting of ITG-FG 5.4.1 (Erlangen, July 17th, 2007) we have shown Fast Ethernet transmission with multi carrier modulation (MCM) over 200 m SI-POF [1]. During the last year, we continued working on this topic.
- At ECOC, September 2007, our demonstrator 3G has been shown for the first time.
- This presentation summarizes the results for Fast Ethernet transmission and gives a perspective for transmitting higher bit rates over SI-POF.

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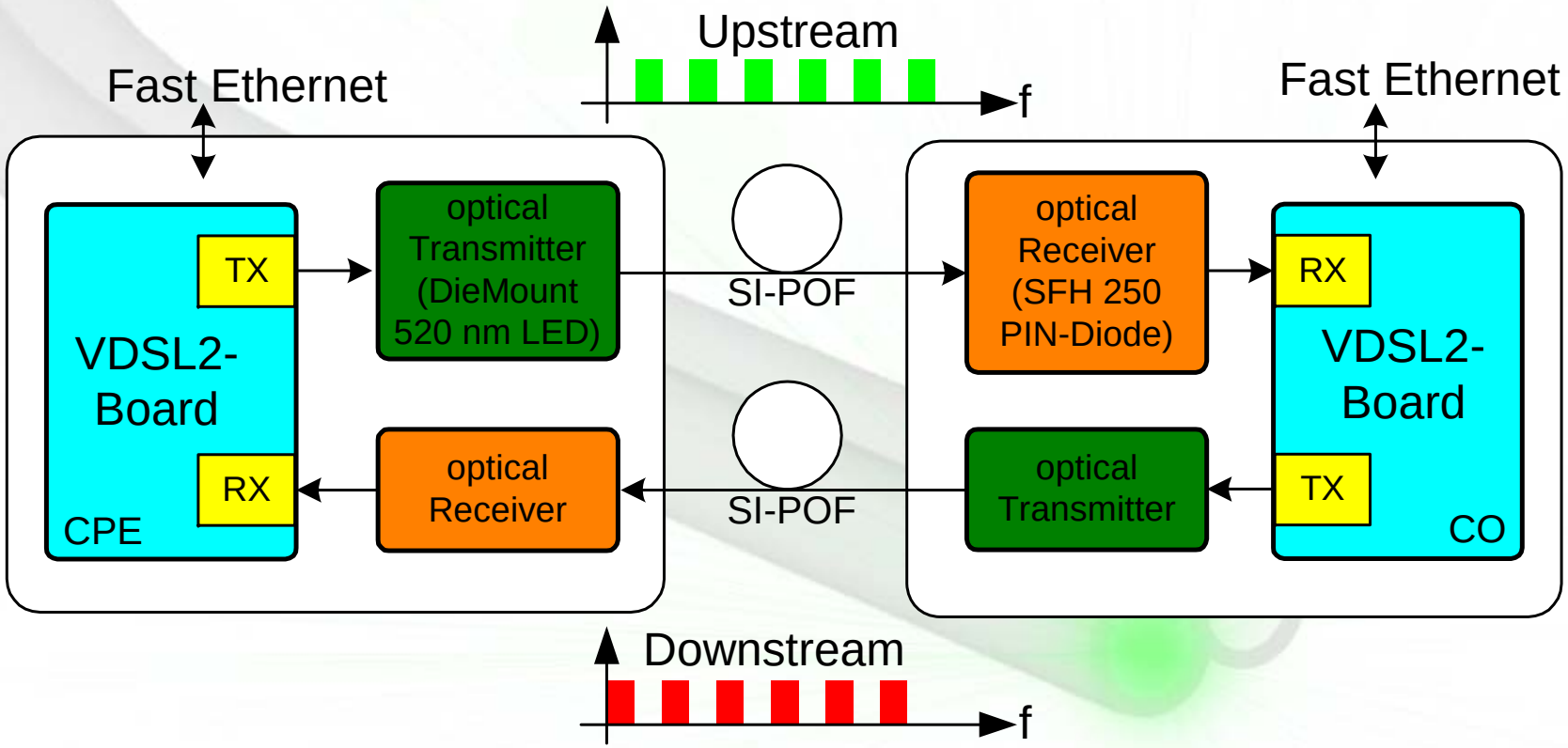
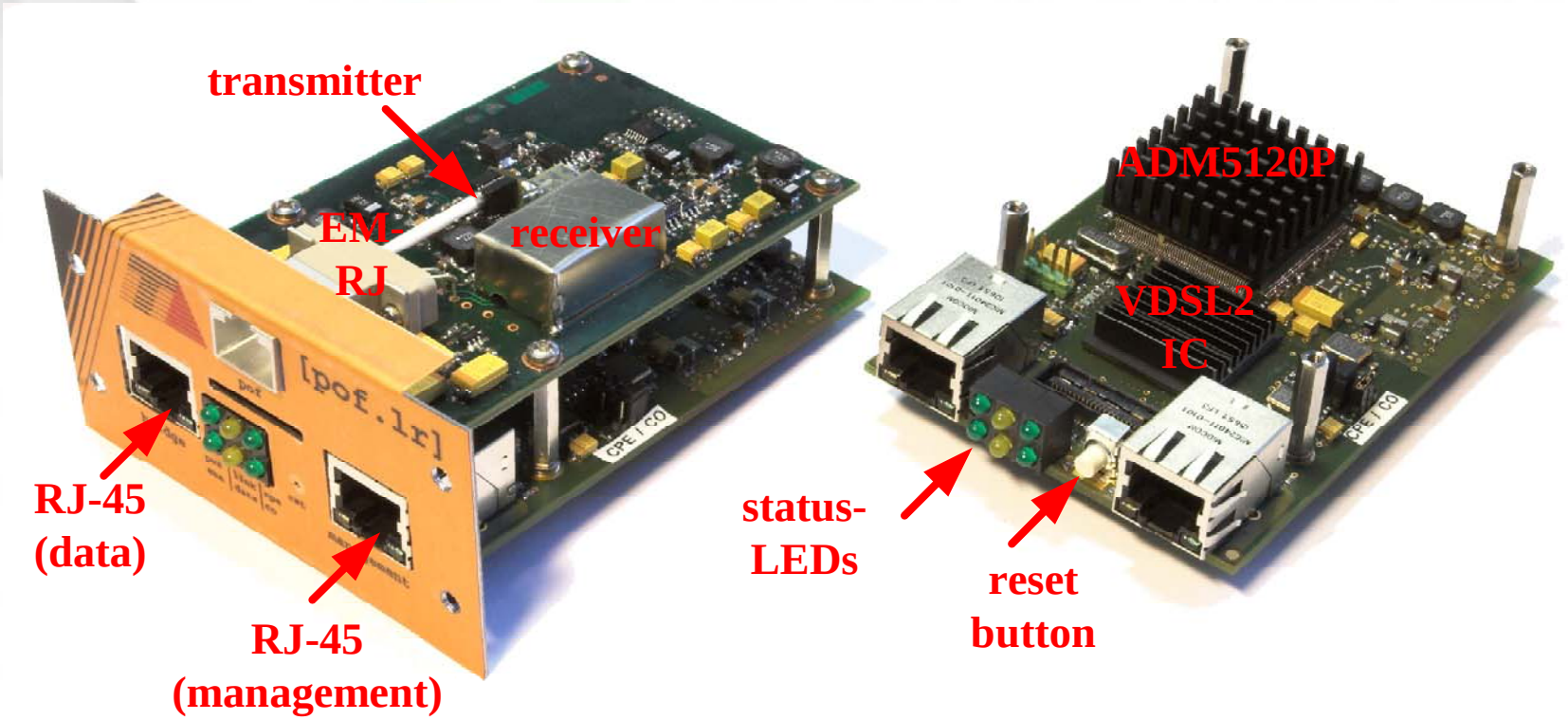
Block diagram of all our demonstrators

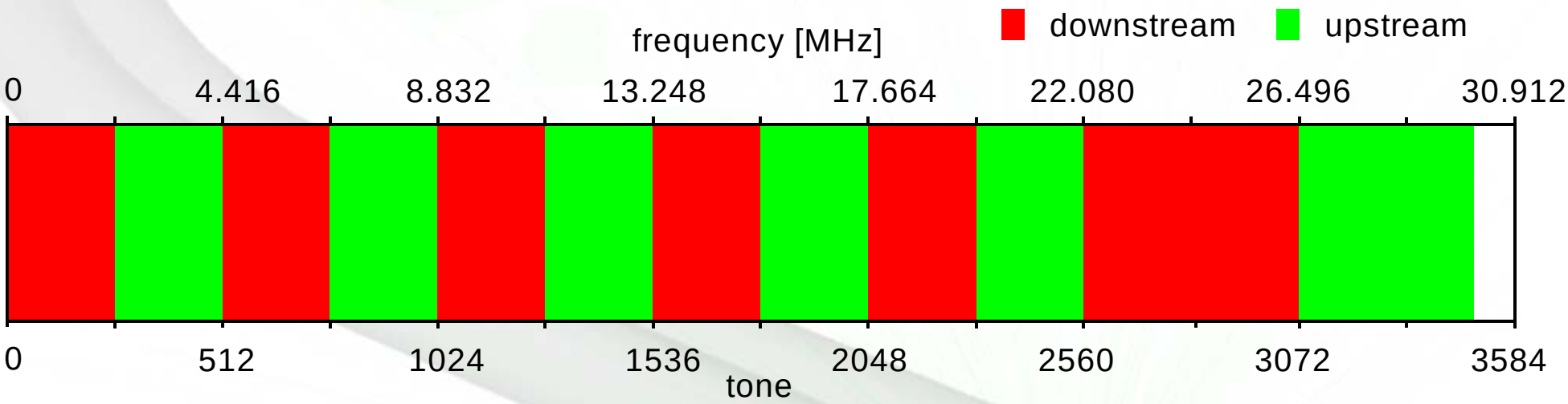


SI-POF Type: “Sojitz TC-1000W“

Demo 3G main components



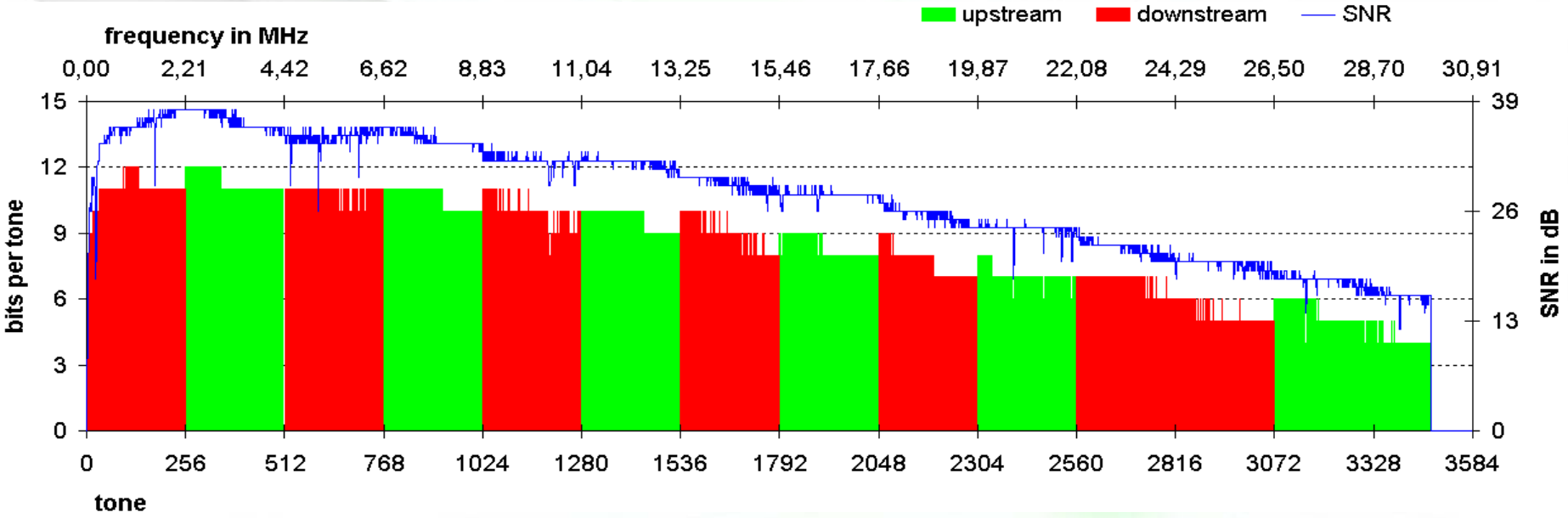
Preferred self-defined band plan



- 8.635 kHz tone spacing
- 3478 tones (29.997 MHz bandwidth)
- 6 bands per direction

Measurement results – 200 m bidirectional transmission

- 200 m SI-POF duplex transmission
- Aggregate bit rate: 216.7 Mbps



VDSL2 chipsets as basis

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- For Fast Ethernet transmission we consciously used existing VDSL2 chipsets to find rapidly a working solution. Because of the chipset characteristic we were fixed to the following conditions:
  - tones/carriers/subcarriers: 4096 respectively 3478
  - tone spacing: 4,3215 kHz respectively 8,625 kHz
  - used bandwidth: 17,7 MHz respectively 30 MHz (35,3 MHz)
  - QAM constellation: max. 32k-QAM
  - defined band plans.

Possibilities of VDSL2 chipsets

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Theoretical maximal aggregate (US **+** DS) bit rates at 0 m:

- 17,7 MHz: 4 kbps x 15 x 4096 = 245 Mbps
- 30 MHz: 8 kbps x 15 x 3478 = 417 Mbps

With new VDSL2 chipsets:

- 35,3 MHz: 8 kbps x 15 x 4096 = 492 Mbps

The role of SI-POF in EFM (with VDSL2 based chipsets)

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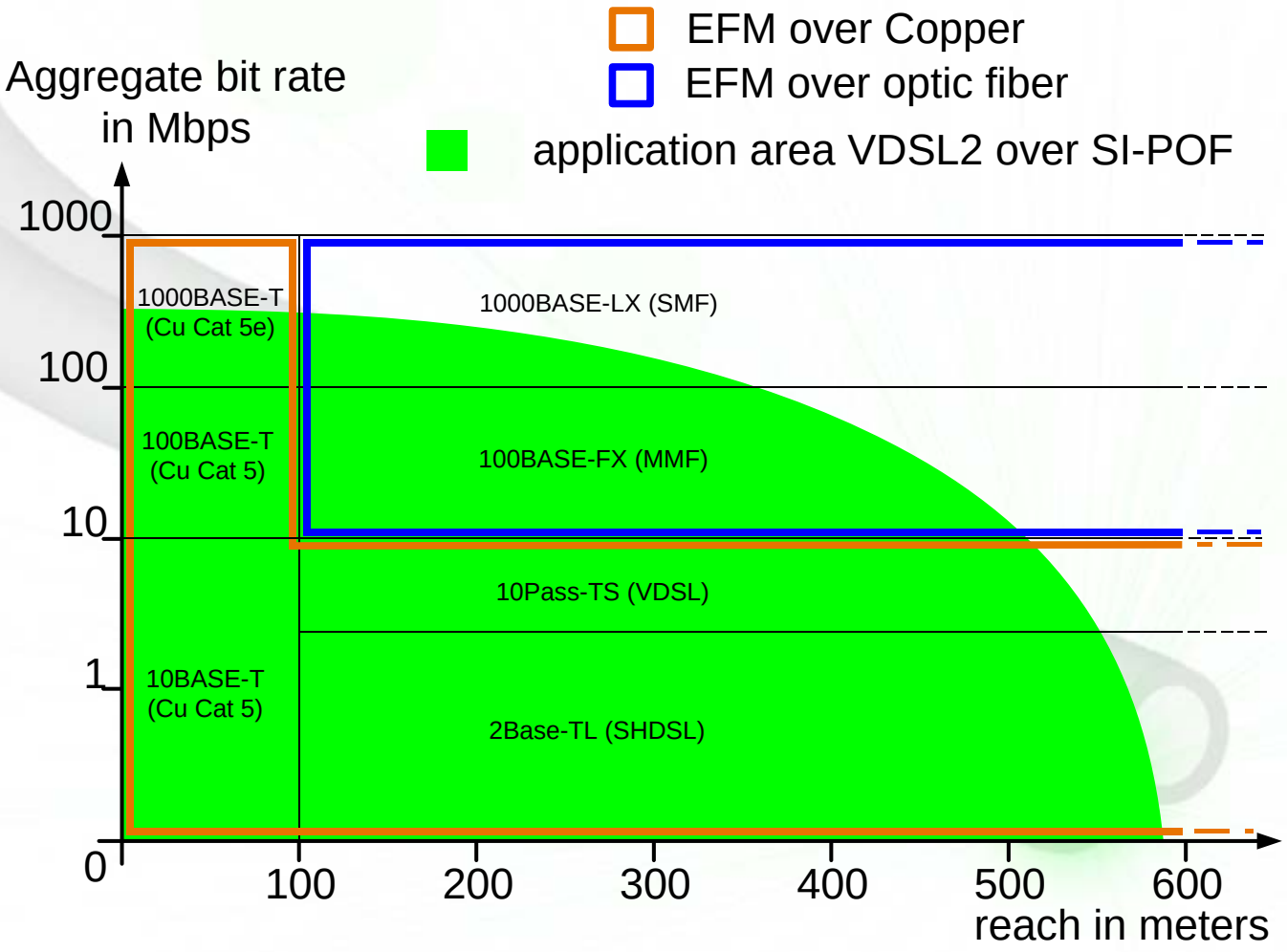

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Calculation tool

- Based on the Shannon-Capacity, Teleconnect developed a calculation tool, which is able to estimate the possible aggregate bit rate for MCM based SI-POF transmission systems. The inputs for the program are: length of the SI-POF, tone spacing, average optical power, SI-POF-attenuation, coding gain, margin, BER and the specified band plan.
- For Fast Ethernet transmission we reach common accord between theoretical approach and practical experience. So we decided to use the calculation tool also for higher bit rates.

Bit allocation

- Bit allocation of VDSL2 bases on Shannon capacity:

$$b(i) = \log_2\left(1 + 10^{\frac{SNR(i) + CG - MAR - \Gamma_{BER}}{10}}\right)$$

- *b(i)* = bits on tone i
- *SNR(i)* = SNR on tone i in dB
- *CG* = coding gain in dB (~ 5dB for Trellis and Reed-Solomon coding)
- *MAR* = desired margin in dB
- Γ_{BER} = gap in dB introduced by desired BER (9.75 dB for 10^{-7})

Calculation tool

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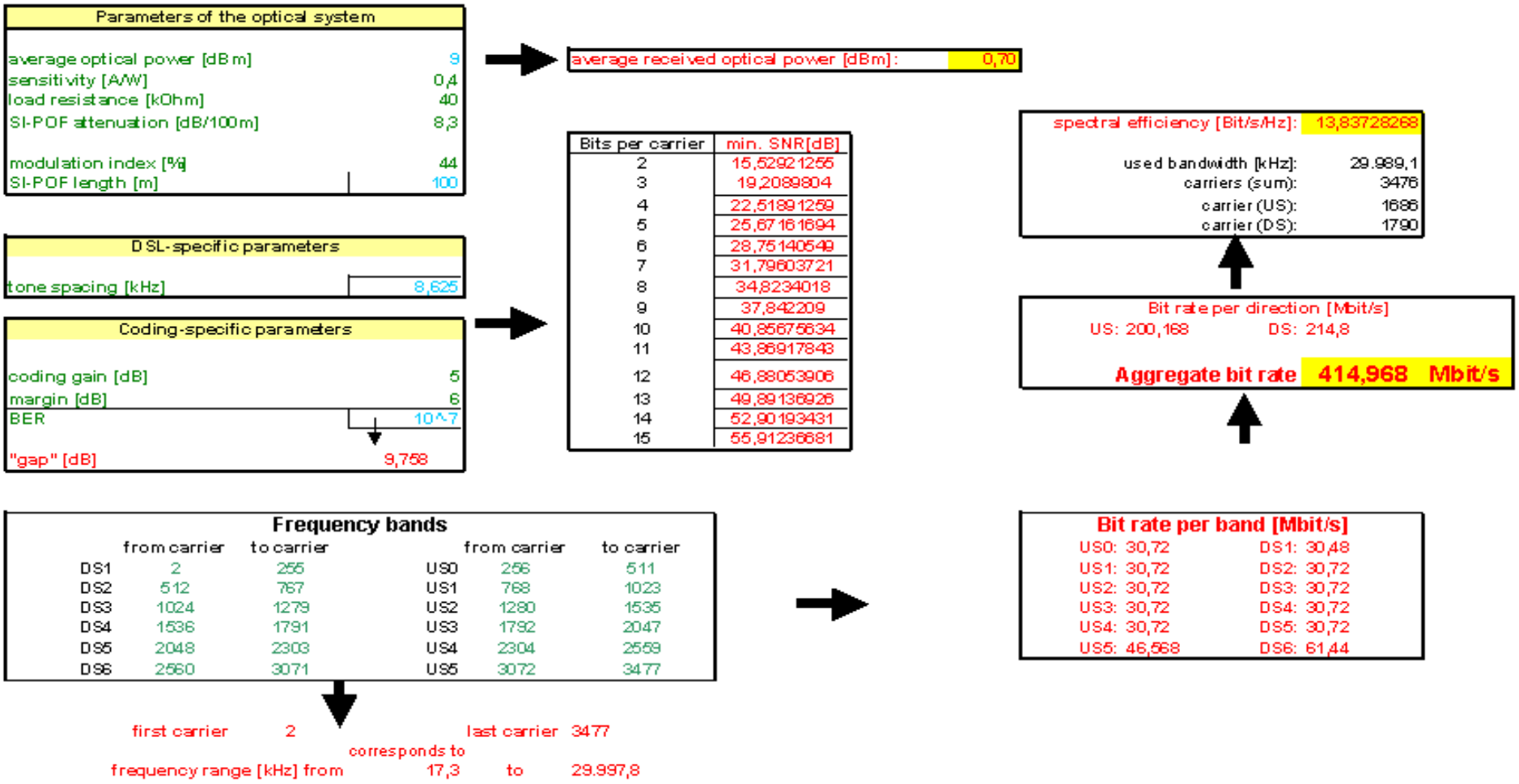

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Discussions with potential customers

- The discussions show that the potential customers believe in MCM. The requirements are different: some require low latency and reliability, others – low prices...

  ... and higher bit rates are required. For the next 3-5-... years 100 Mbps will not be enough.

Typical Home Network 2015

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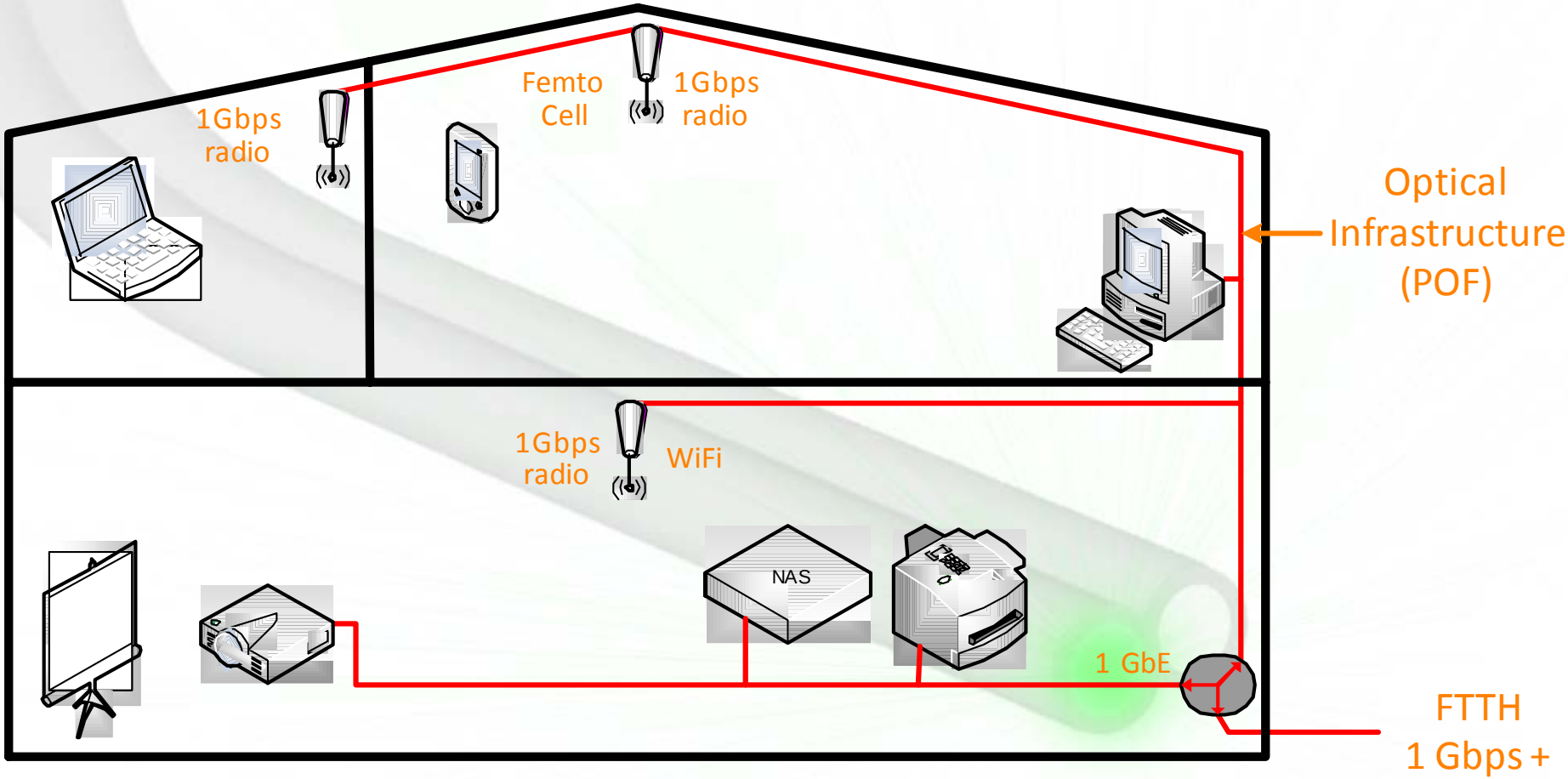
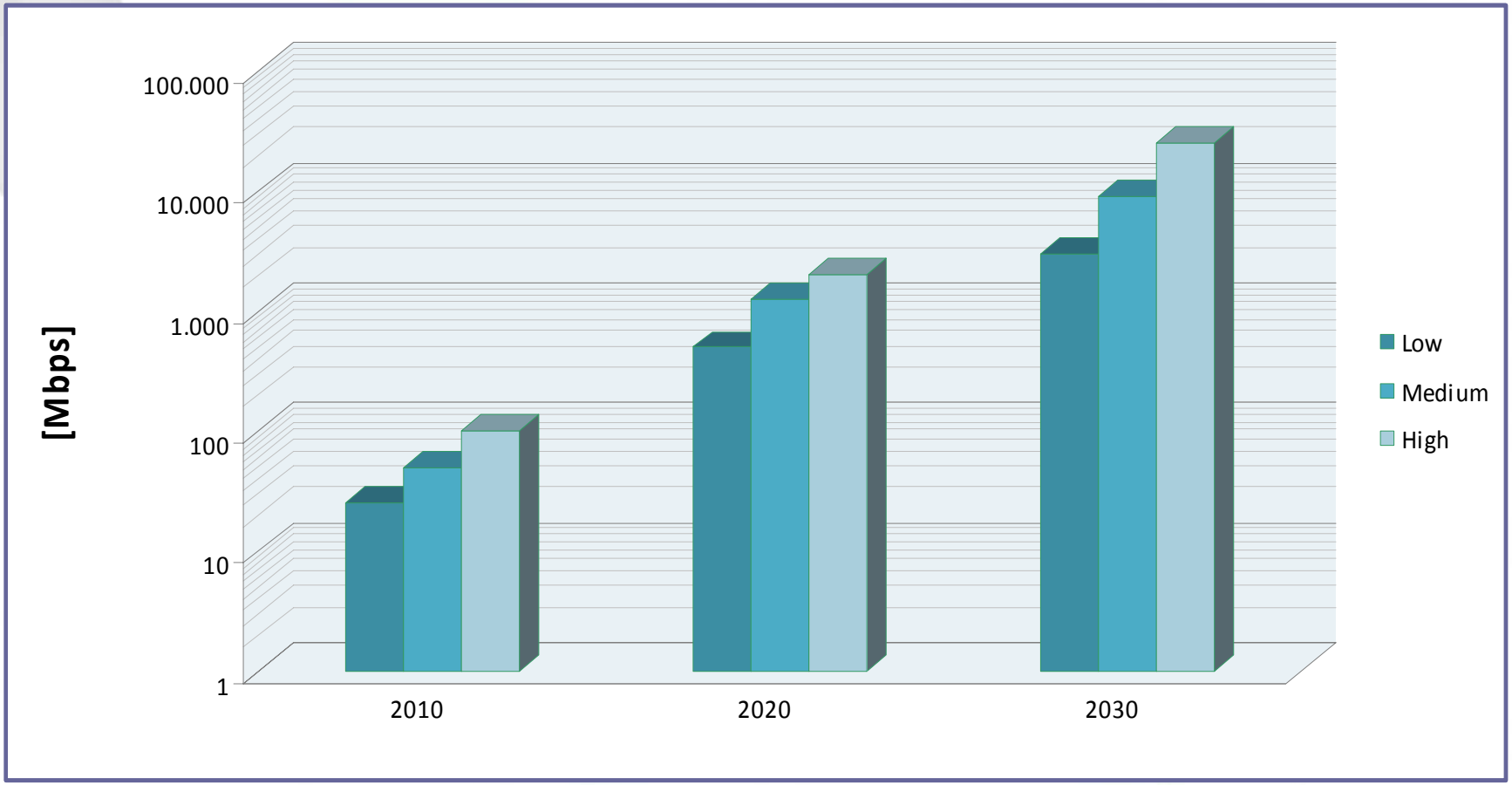


[http://partages.univ-rennes1.fr/files/partages/Recherche/ENSSAT/web/communication/evenements/2007/opmo/benoit.charbonnier.pdf]

Projected bandwidth requirements per home



[FTTCouncil Europe, Feb. 2008]

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VDSL2 over POF – Conceptions for higher bit rates

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- Our first ideas (requires more than one VDSL2 chipset):
  - Port-trunking / Bonding,
  - Wavelength division multiplexing,
  - Upscaling of VDSL2 output signals with different carrier frequencies (6 x 30 MHz → 180 MHz),
  - „Antiparallel“ frequency bands

  - The better solution: „MCM over POF“ or to „widen“ existing VDSL2 chipsets! We discussed the following questions:

„MCM over POF“

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- Idea: **leaving VDSL2 defaults** (30 MHz, 4096/3478 tones, 4,3125/8,625) and checking what is possible to change with firmware modifications and where more flexibility could be included in the future.
- **What can be realized?** Could more flexibility be implemented?
- Could all tones be used in every direction? (We do not need band plans for duplex transmission)
- What are the implementation **limits** (IFFT, FFT, ADC, DAC...Constellation Mapper)? **Estimation** of MMACS is very difficult.

„MCM over POF“

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- Can the tone spacing be flexible? Can the tone spacing, starting from a certain frequency, be reduced?
- Can a selected frequency range (1-10 MHz) be moved up higher to other ranges (for instance, 41-50 MHz)?
- Can algorithms be implemented, which analyses the difference between the SNR ratios for a number of tone groups?
- Is the margin for every **tone adjustable?** (so far only per direction)

Results of discussion with VDSL2 chipset providers

- In principle, our requirements can be realized. For the realization the chips need to be re-designed (larger die and higher costs).
- Without purchase commitment – no business.
- → we left our „modification idea“ for VDSL2 chipsets and moved to existing FPGA solutions
- We are now investigating in two directions:
  - FPGA realization (modification of FPGA development board, which was the basis of VDSL2 chipset development) – more than 400 Mbps with existing modified VDSL2 boards should be possible
  - Investigation of an MCM solution which works without IFFT/FFT.

Possibilities of „modified VDSL2 chipsets“

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Symbol rate	tones	Bandwidth	0 m [Mbps]	50 m [Mbps]	100 m [Mbps]
[kSymbols/s]		[MHz]	(bit/s/Hz)	(bit/s/Hz)	(bit/s/Hz)
8	2048	16,4	245 (15)	213 (13)	196 (12)
8	4096	32,7	492 (15)	426 (13)	383 (11,7)
32	2048	65,5	983 (15)	846 (12,9)	693 (10,6)
64	1656	106	1590 (15)	1313 (12,4)	875 (8,3)
64	2048	131	1966 (15)	1558 (11,9)	880 (6,7)

Calculation without gap between tones

Bit rate = Symbol rate x spectral efficiency x number of tones

Possibilities of „modified VDSL2 chipsets“

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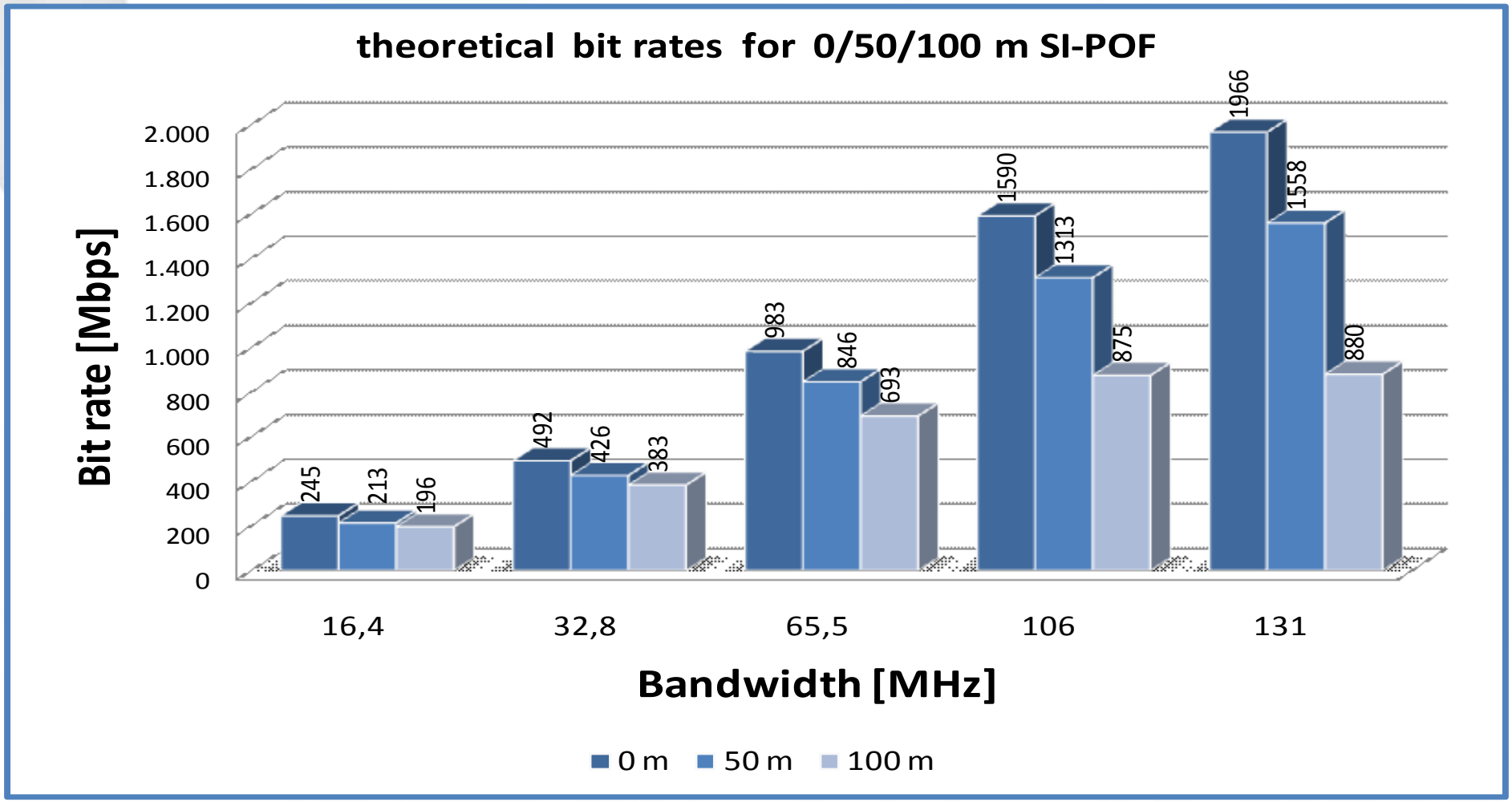

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Conclusion

- MCM (VDSL2) is ideally suited for Fast Ethernet transmission over more than 200 m SI-POF.
- For transmission of higher bit rates changes in tone spacing and/or amount of tones are essential.
- The theoretical approach with our calculation tool leads us to the conclusion, that transmission of 1 Gbps is possible up to a SI-POF length of about 90 m.

References

[1] Bluschke, A.; Kiss, N.: Multicarriermodulation-Systeme für SI-POF - Fast Ethernet-Übertragung über 200+ m. 23. Fachgruppentreffen der ITG-FG 5.4.1 „Optische Polymerfasern“ am 17.07.2007 in Erlangen

Thanks for your attention!

A Part of this work was realized during the EU-project POF-ALL (Paving the Optical Future with Affordable Lightning-fast Links – IST-FP6 STEP Project number 027549). The authors thank all colleagues for support and collaboration.

Please contact us!

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Dr. Andreas Bluschke (blua@teleconnect.de)
Dr. Gerald Nürnberger (nueg@teleconnect.de)

Telefon 0351/4236-210
Fax 0351/4236-209

Teleconnect GmbH
Am Lehmberg 54
01157 Dresden