
ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

# Fiber-Optic Technologies for wireline and wireless in-building networks

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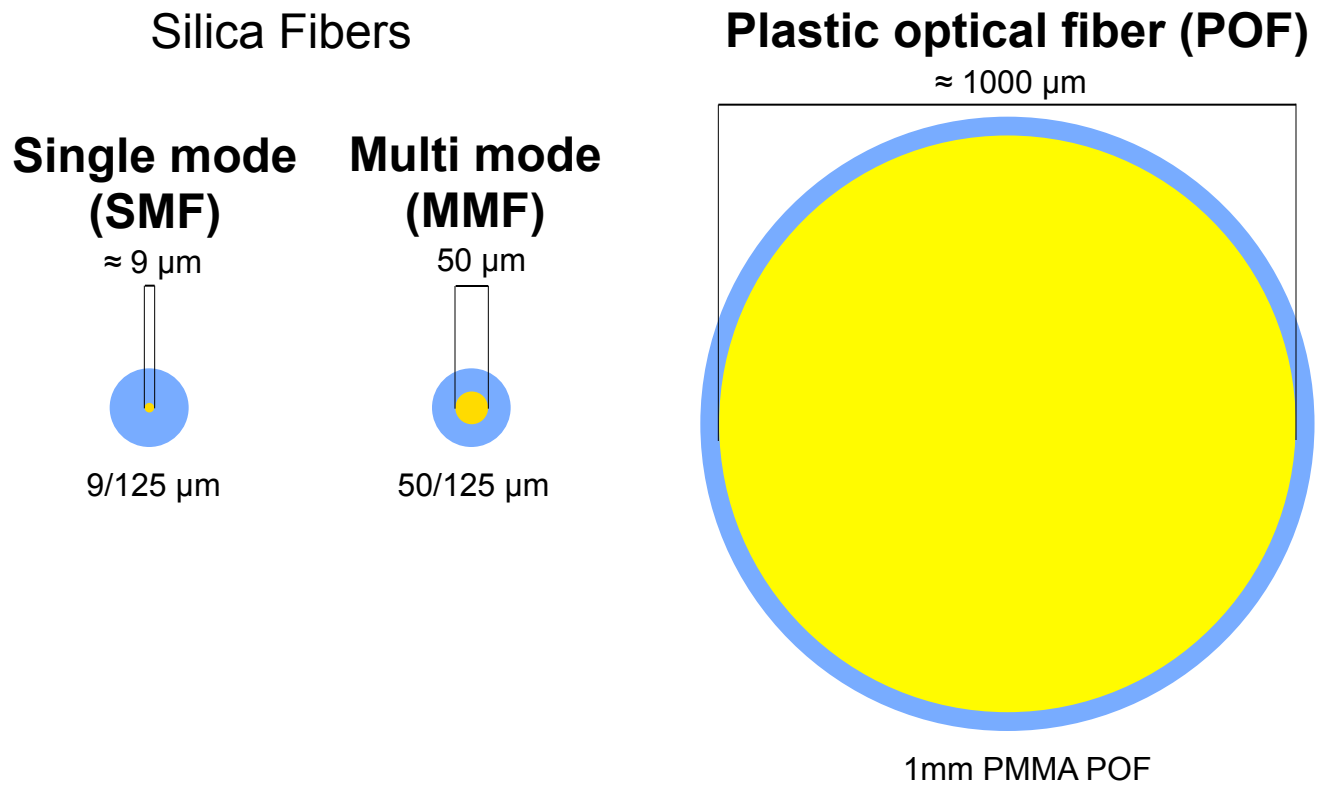
# Outline

This thesis investigates at a physical and transmission level fiber-optic technologies which enable broadband wired and wireless connectivity in indoor scenarios.

## Presentation summary

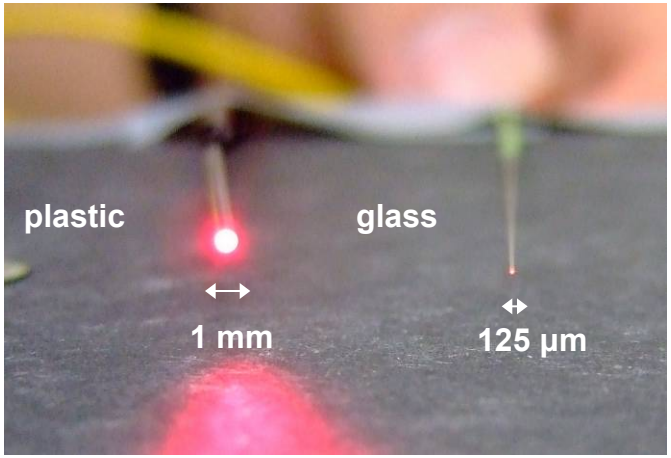
- Fiber-optic technologies: silica and plastic optical fibers
- Wireline connectivity in different in-building scenarios
- Wireless connectivity in different in-building scenarios
- Thesis Contribution
- In-building Distributed Antenna System based on Radio over multimode fiber
- Conclusions

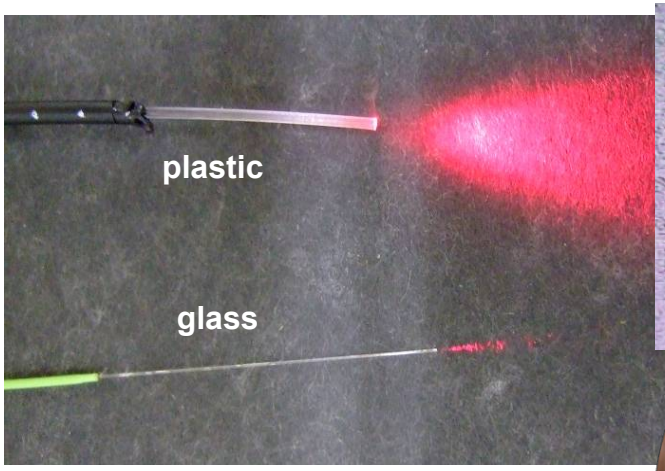
# Fiber-optic technologies: silica and plastic optical fiber

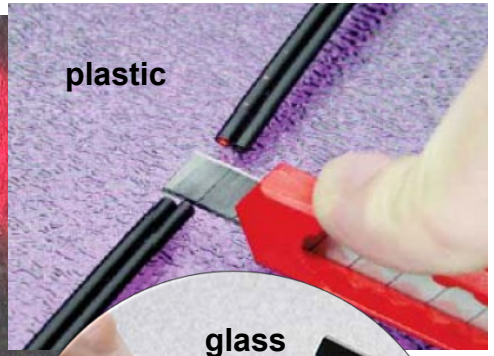


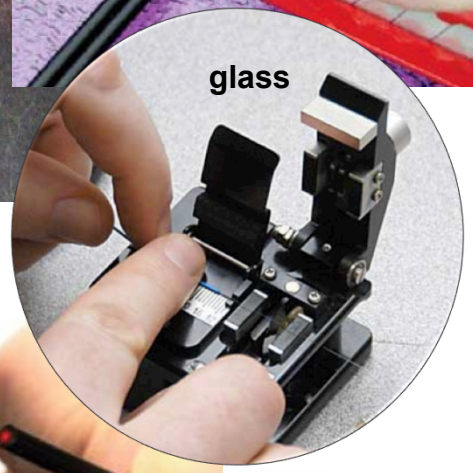

- Silica fibers are the widespread fiber-optic media and are standardized by many international organizations
- Plastic materials enable the possibility to have a larger core than silica. At present, only one type of POF (step-index) is standardized

# Fiber-optic technologies: silica and plastic optical fiber

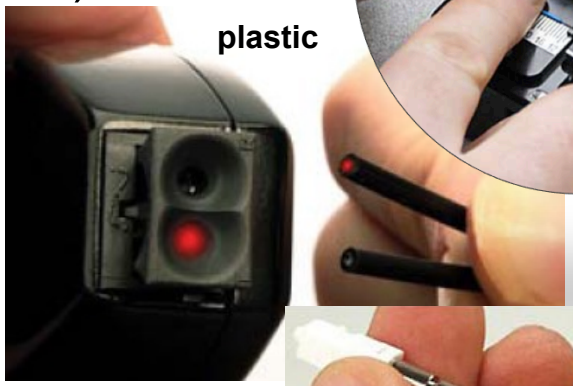


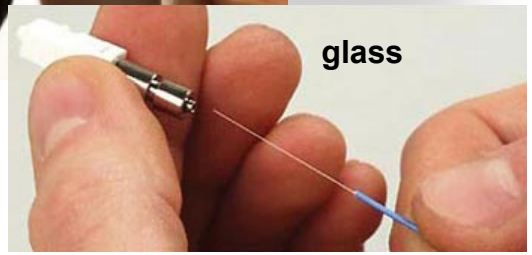

POF has <u>100x larger core diameter</u> (1 mm) than standard glass fibers




- ✓ Easy to install ("do-it-yourself")
- ✓ Cheap (plastic housing, LED)
- ✓ Robust to mechanical stress

- × Much lower bandwidth
- × Much higher loss (>160 dB/km)

} Short-range communications

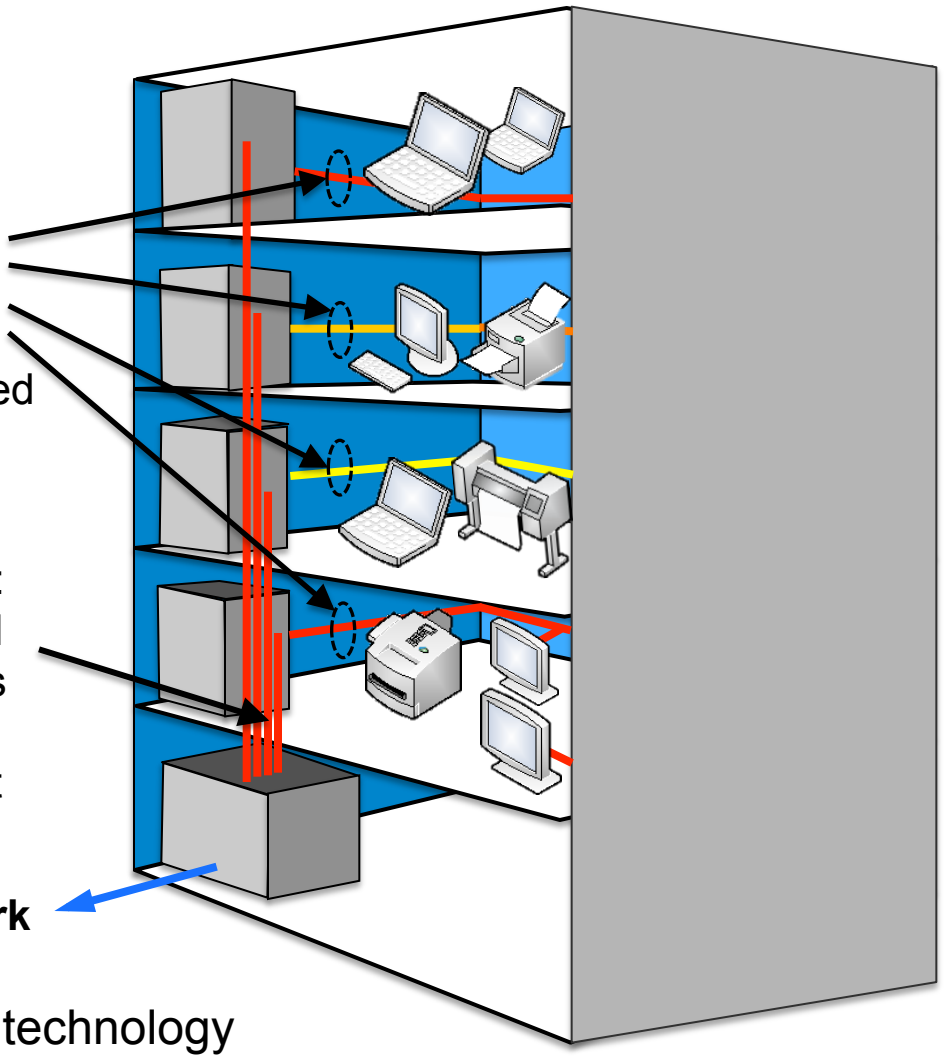


# Wireline connectivity in different in-building scenarios

- Large buildings

Horizontal distribution:
- Predominately copper (10/100/1000 Ethernet)
- POF as alternative
- Silica fiber for higher speed

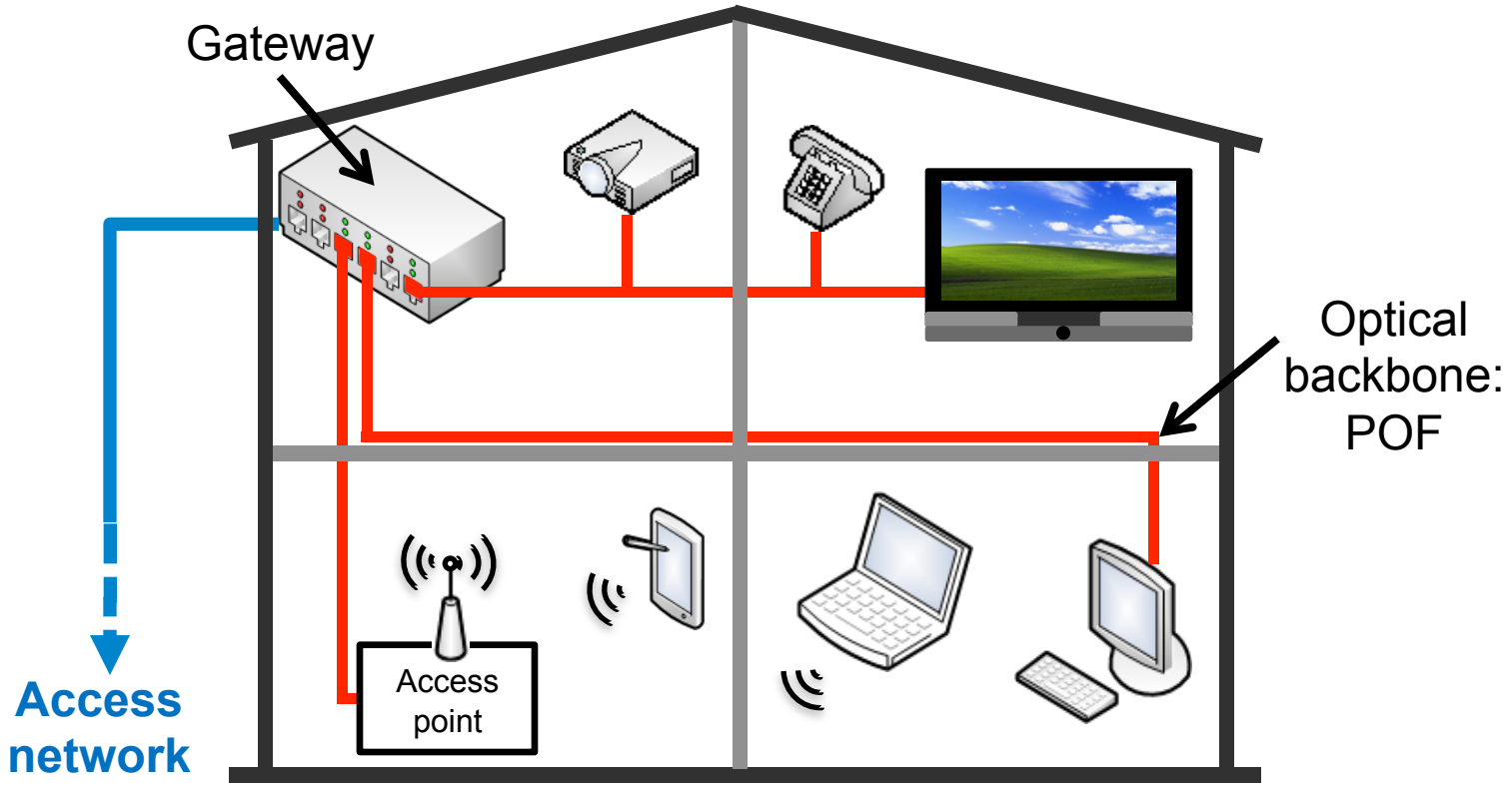
Vertical distribution:
- Silica single and multimode fibers for 10/40/100 Gigabit Ethernet




Multimode fiber is still the leading technology

# Wireline connectivity in different in-building scenarios

- Home and small office




Plastic optical fiber is a promising solution and alternative to copper cables to deliver gigabit and multi-gigabit connectivity within the home or the small office.

# Wireless connectivity in different in-building scenarios

## Why do fiber-optic engineers talk about wireless?

- Wireless communications are now driving the market
- The wireless backhaul network will be overloaded by the aggregate traffic of the wireless and mobile access points
- Wireless connectivity within a building can be an issue:
  - Coverage
  - Transmission speed
  - Electromagnetic exposure

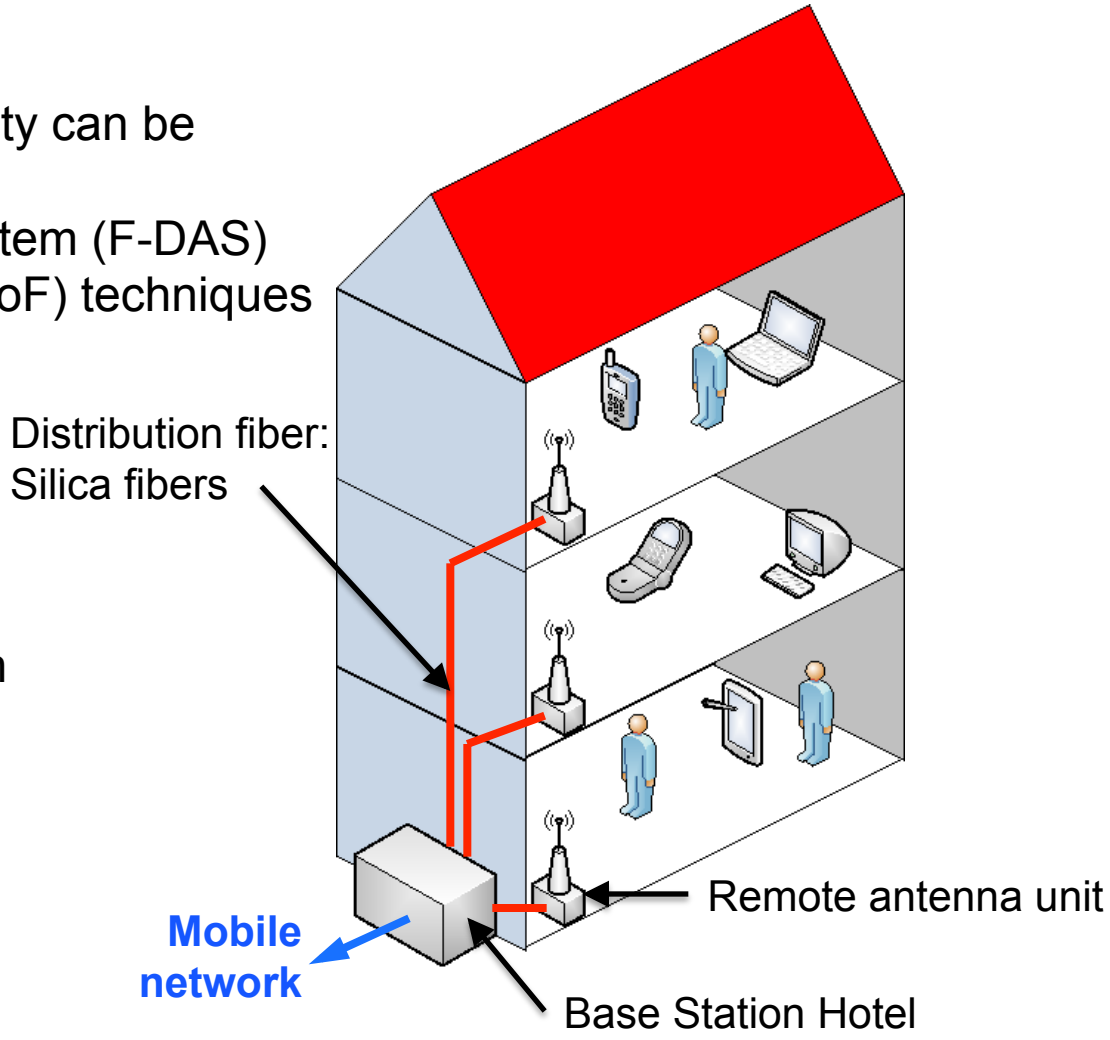
# Wireless connectivity in different in-building scenarios

- Large buildings

Mobile and wireless connectvity can be enhanced by using a
Fiber Distributed Antenna System (F-DAS) enabled by radio over fiber (RoF) techniques

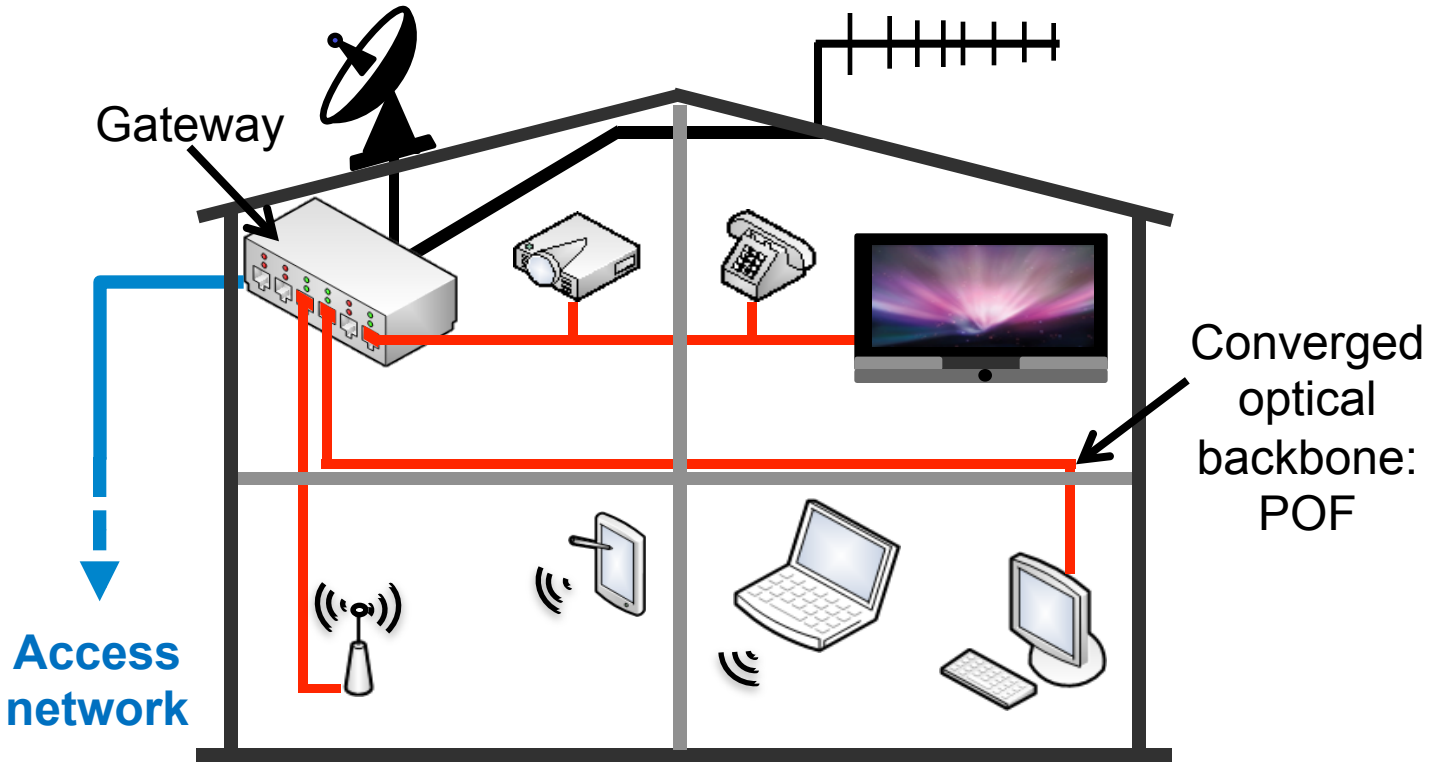
- ✓ Multi-operator, multi-service capabilities
- ✓ Future-proof (upgradable)
- ✓ Centralized scheme which simplifies maintenance

- × High investiment required
- × Usually competitive only for large premises



# Wireless connectivity in different in-building scenarios

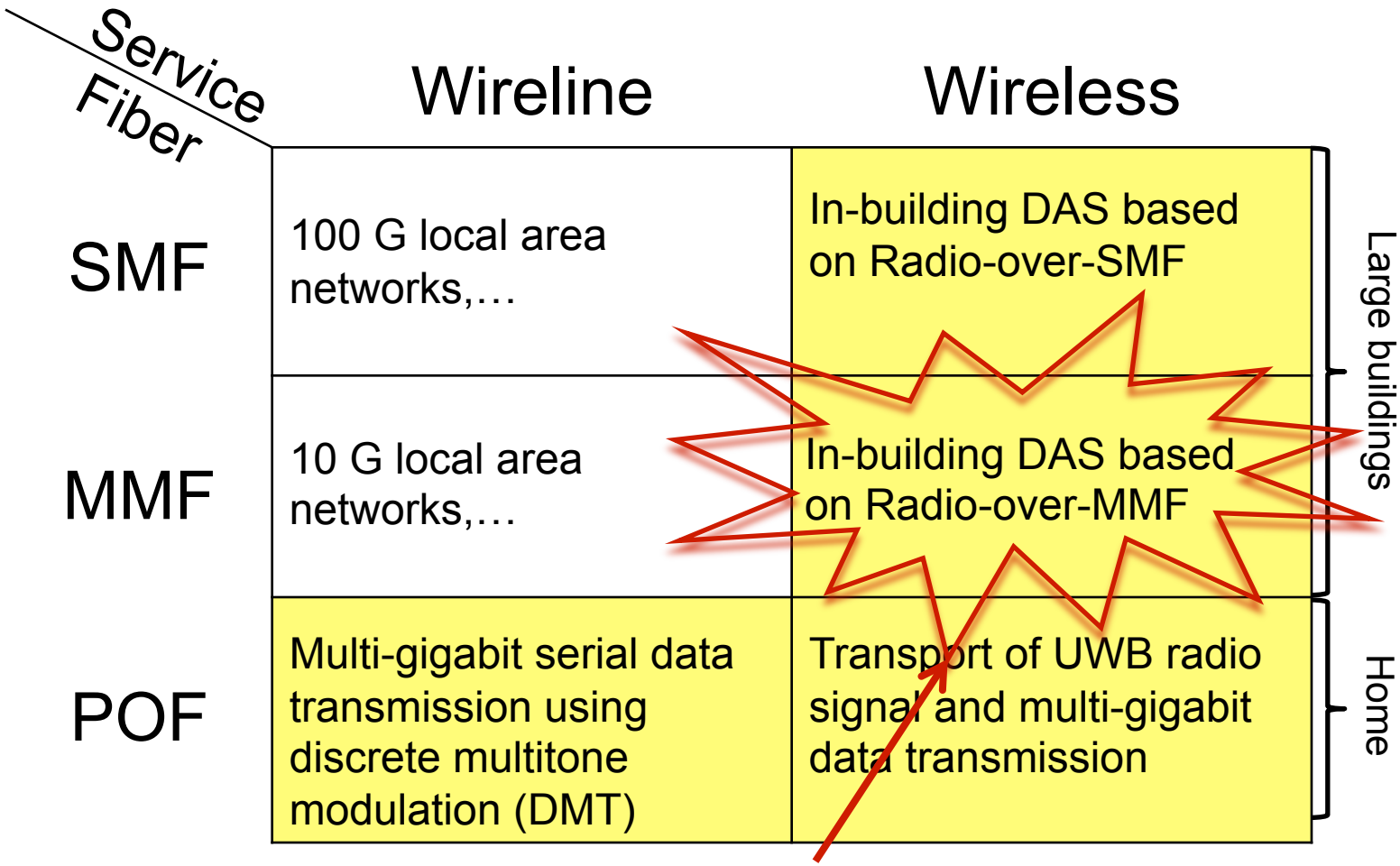
- Home and small office




- Low-cost solution required
- Multi-operator feature not necessary
- Competitiveness with copper solutions

  - F-DAS is not the rigth solution
  - Convergence with wired services

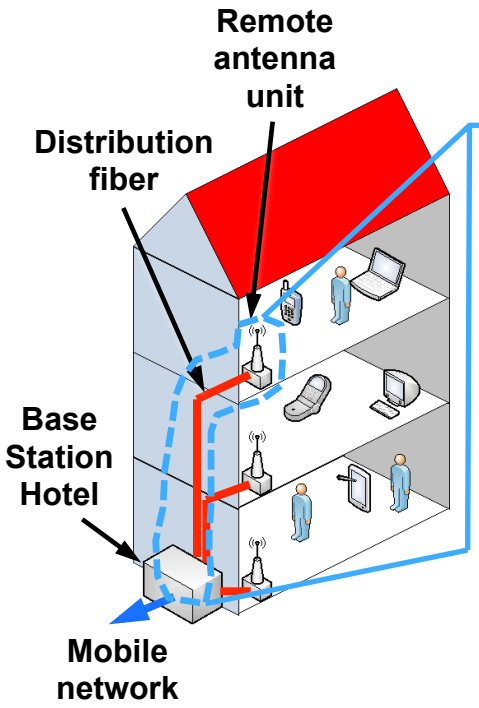
# Thesis contribution

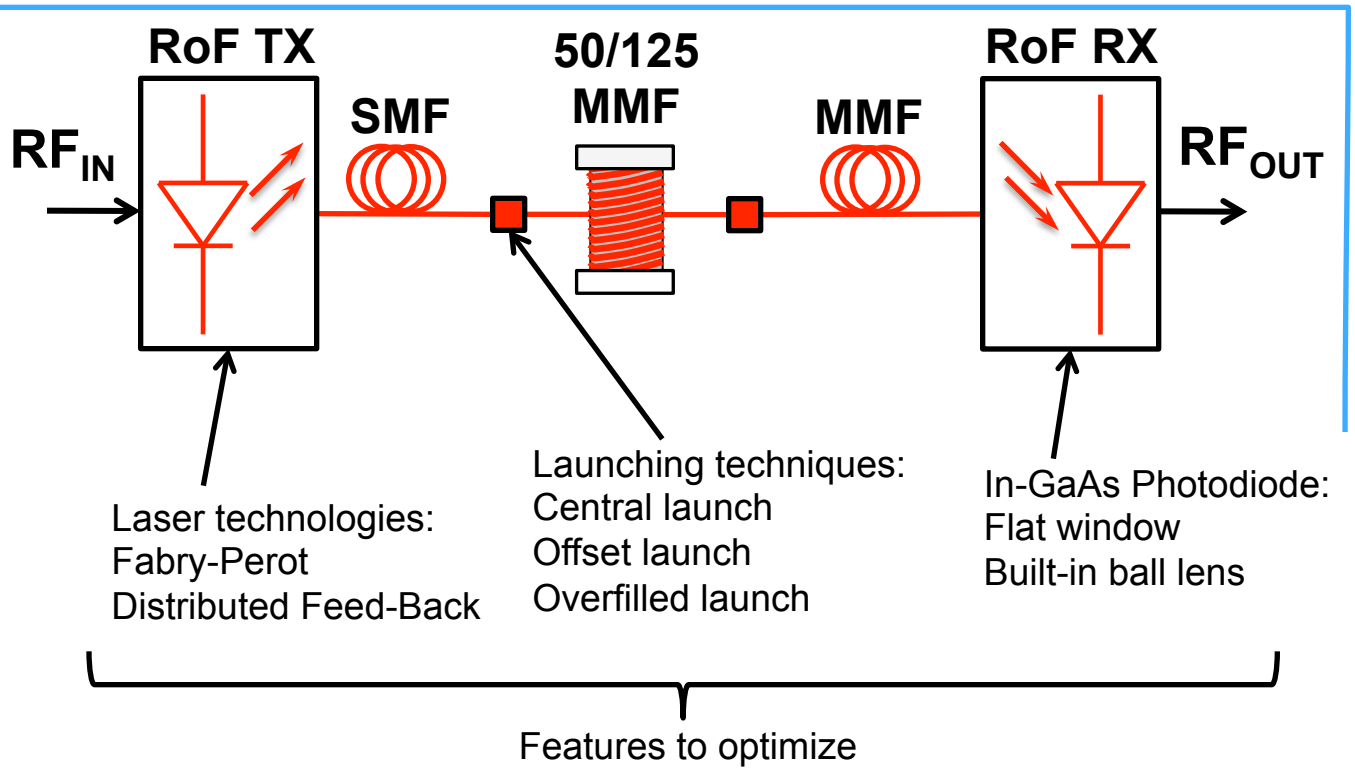



**In the following slides I will illustrate this topic**

# Basic point-to-point Radio-over-MMF link

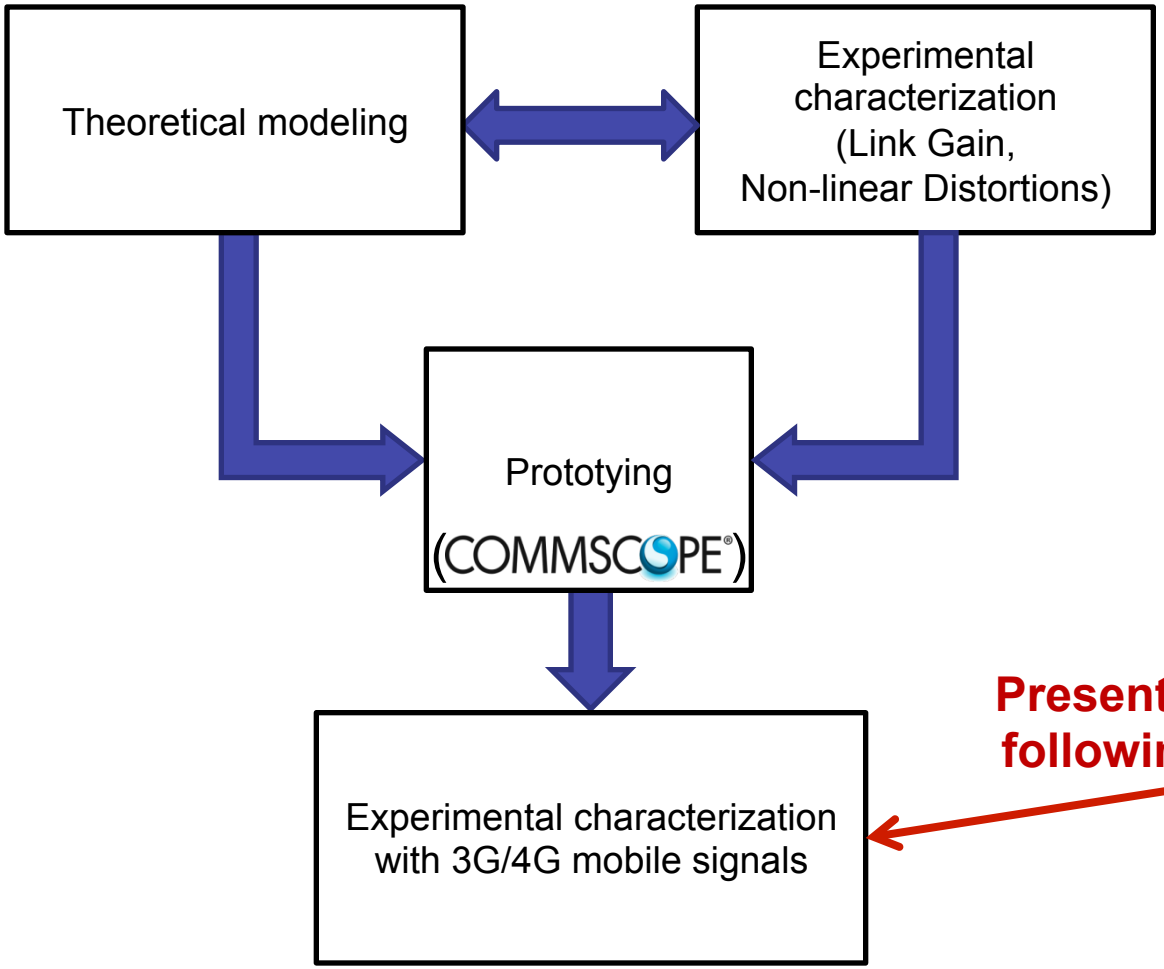
RoF: Radio over Fiber
MMF: Multi Mode Fiber
SMF: Single Mode Fiber
TX: Transmitter
RX: Receiver
RF: Radio Frequency



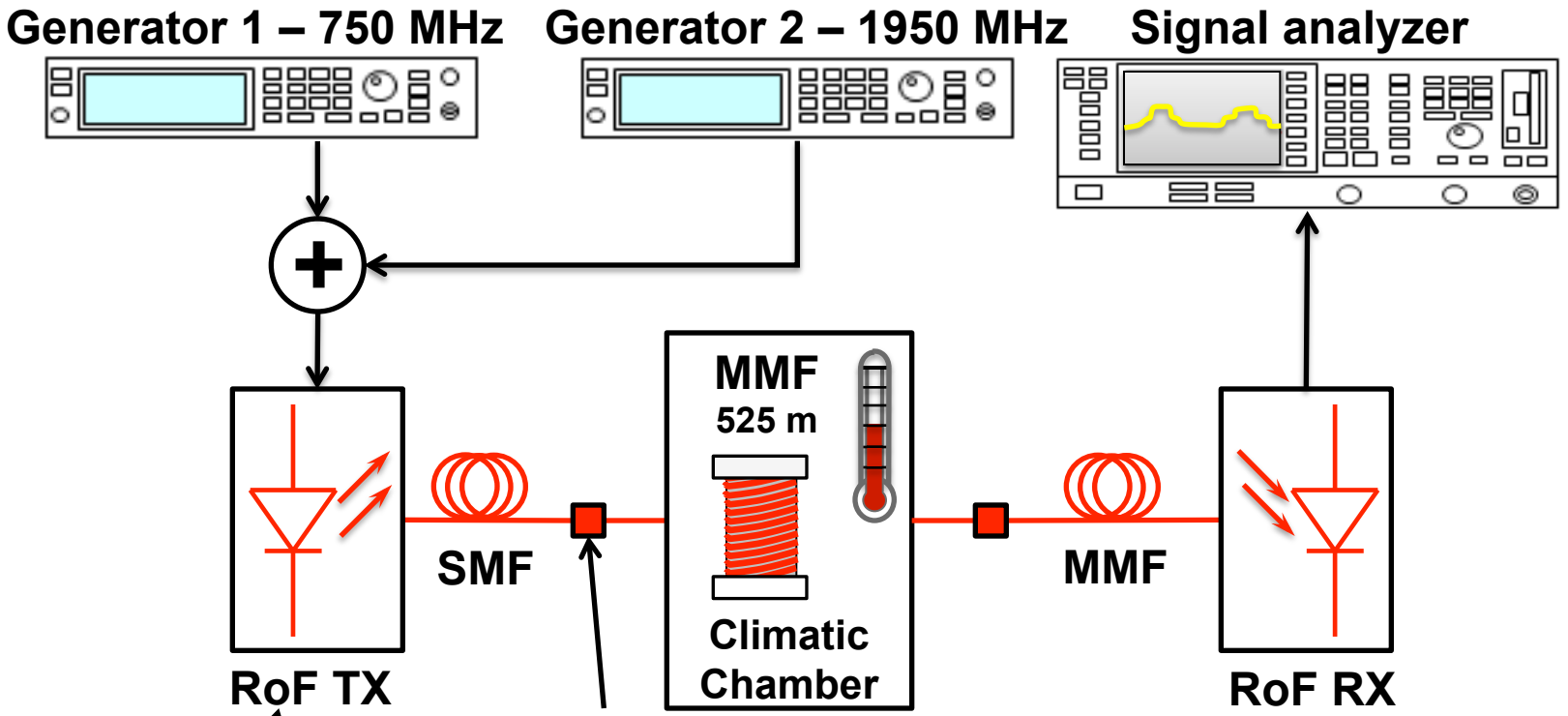

Main impairments to be considered: **modal noise**, laser non-linearity, noise

# Block diagram of the research activity in the third year



# Dual-band LTE signal transmission: experimental setup

LTE: Long Term Evolution

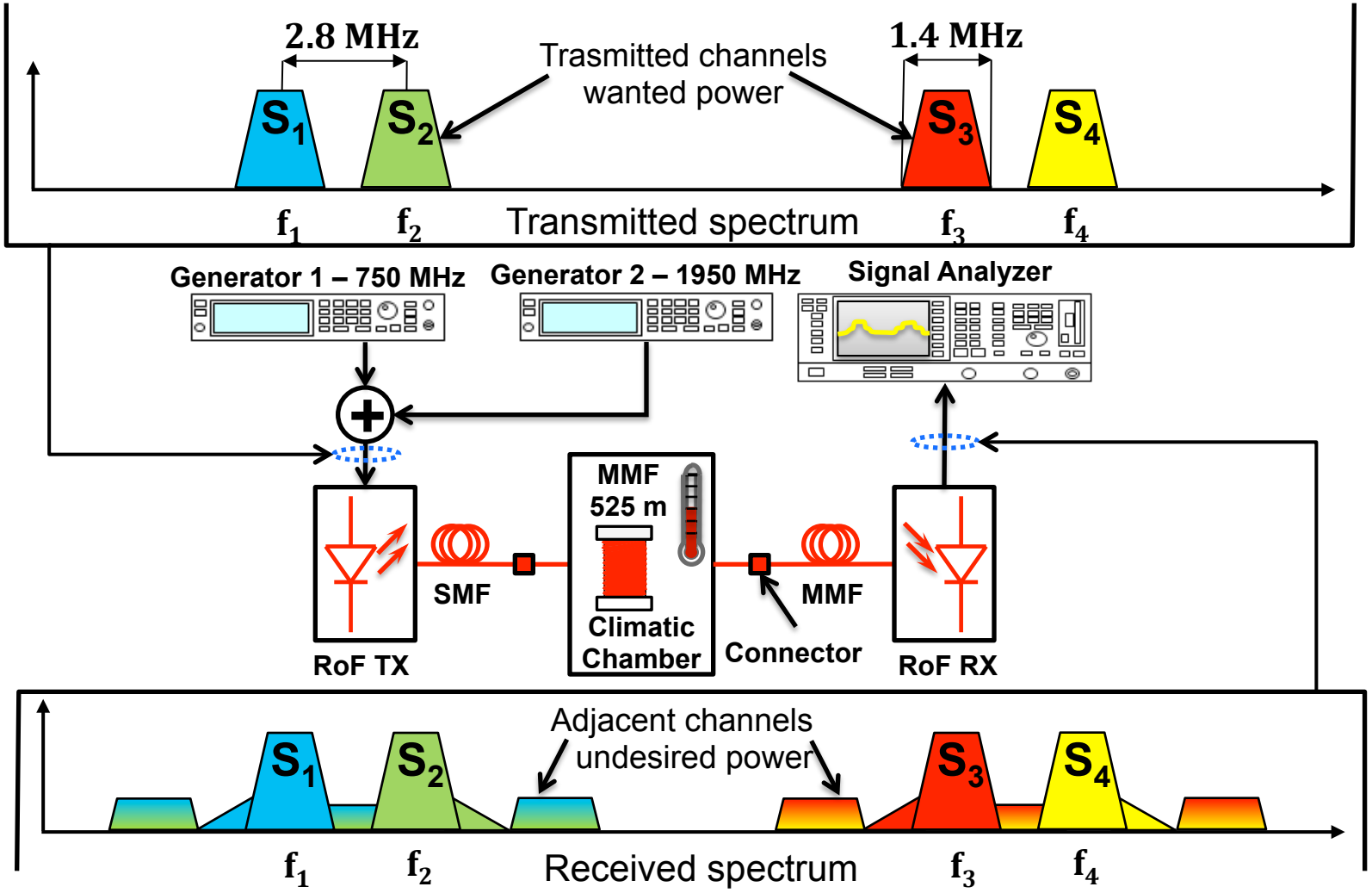



Optimized TX:
Fabry-Perot LD
with high linearity and
low frequency chirping

Optimized launch:
Central launch using
simple connector

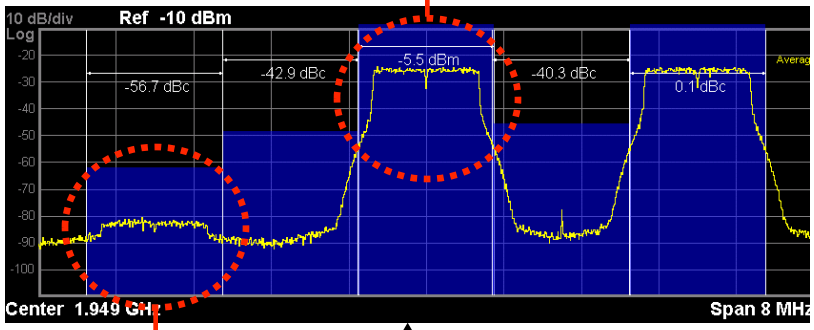
Optimized RX:
Multimode fiber pig-tailed
Built-in ball-lens
Low-noise amplifier

# Adjacent Channel Leakage Ratio (ACLR) test: meaning



# ACLR test: results

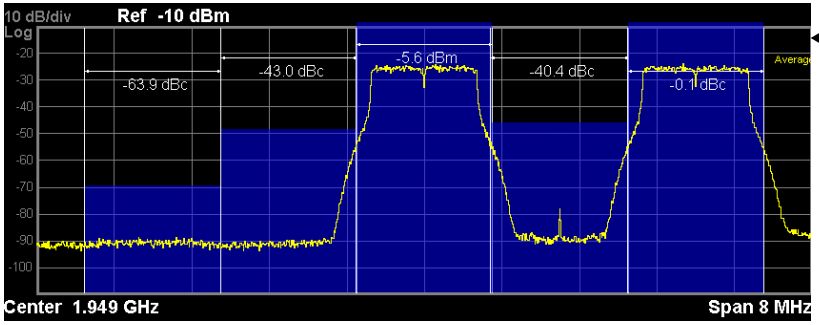
$$ACLR(dBc) = Adjacent\ Ch(dBm) - Tx\ Ch(dBm)$$

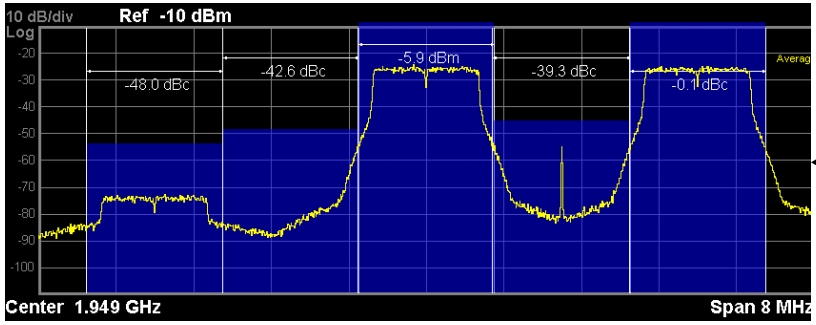



| ACLR 1950 MHz band | Back-to-back | 525m MMF |
|---|---|---|
| ACLR mean (dBc) | -60.31 | -56.64 |
| ACLR 99% max (dBc) | -57.65 | -48.14 |
| ACLR 99% max (dBc) | -63.27 | -63.87 |

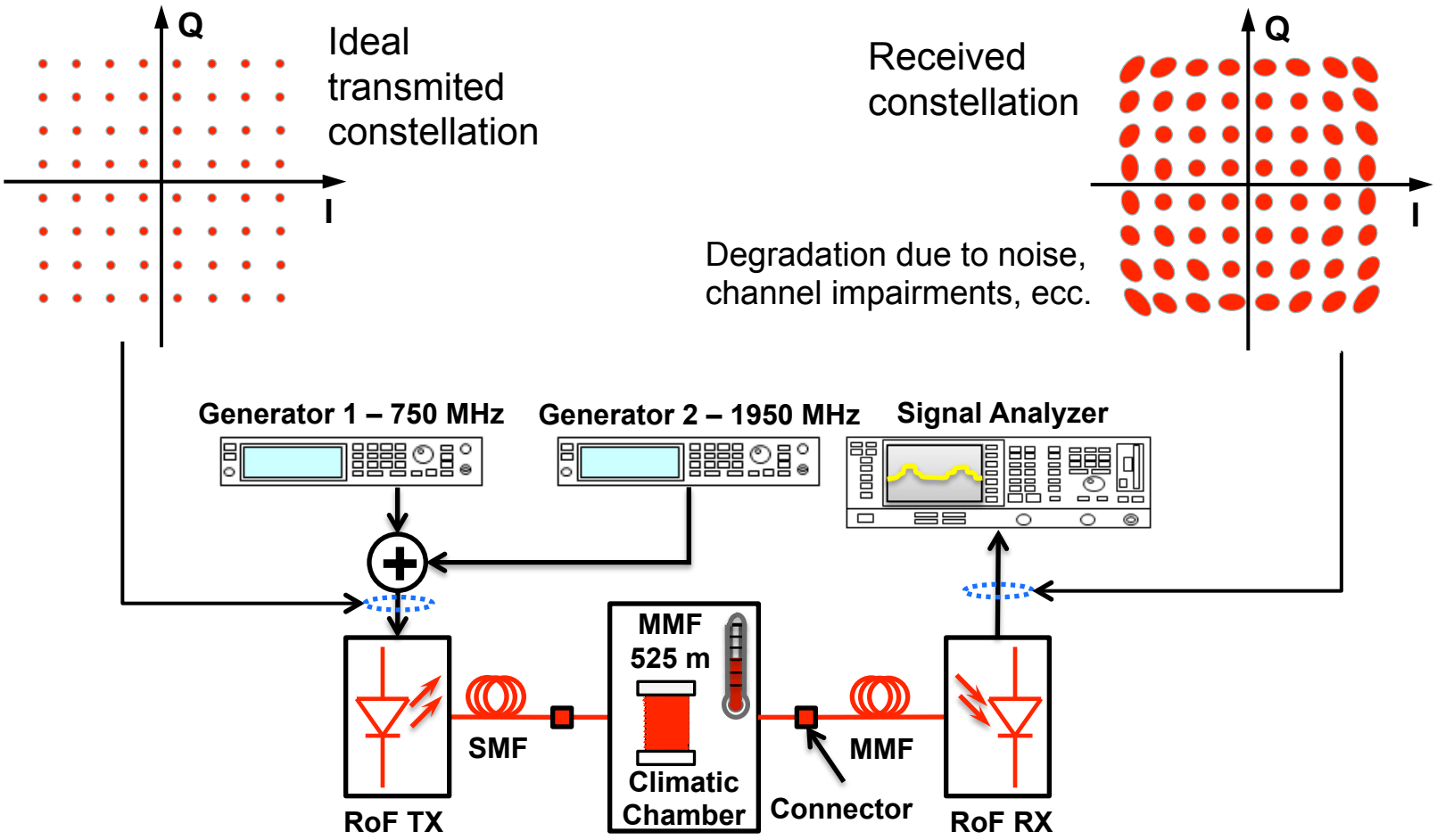
~ 4 dB impact on the mean value

~ 9 dB impact on the worst case value

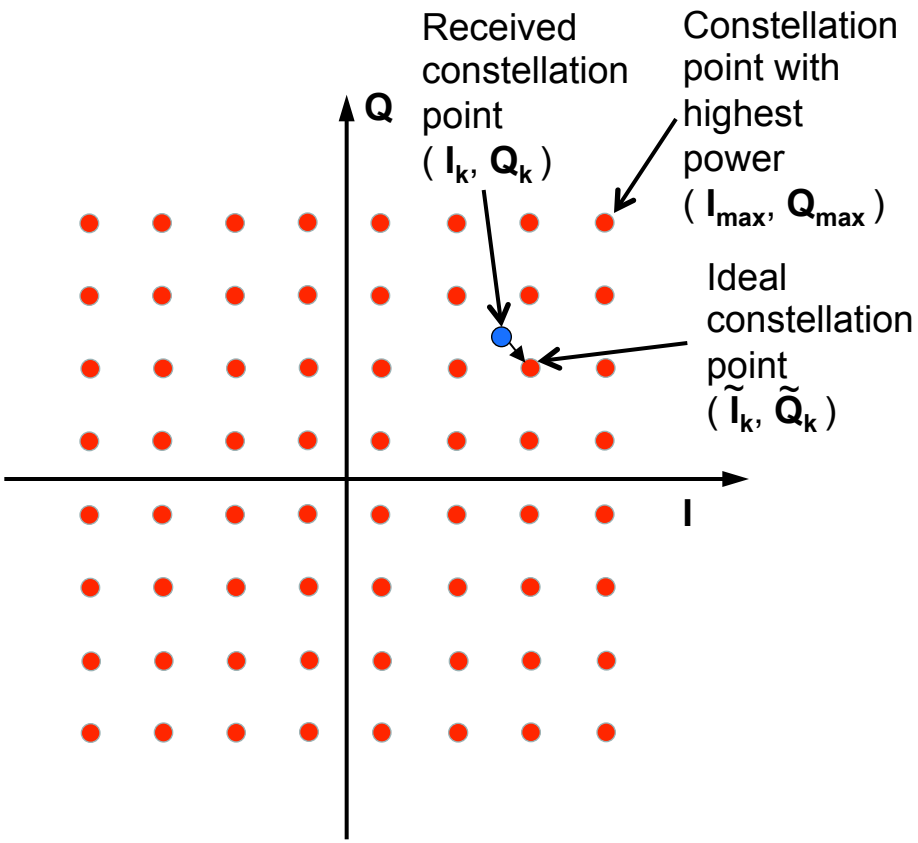


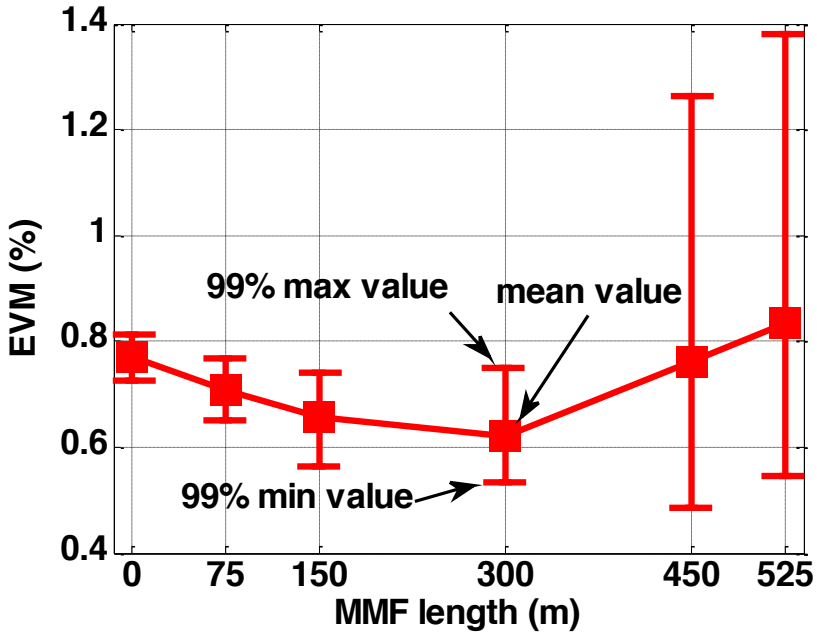
# Error Vector Magnitude (EVM) test: meaning



# EVM test: results

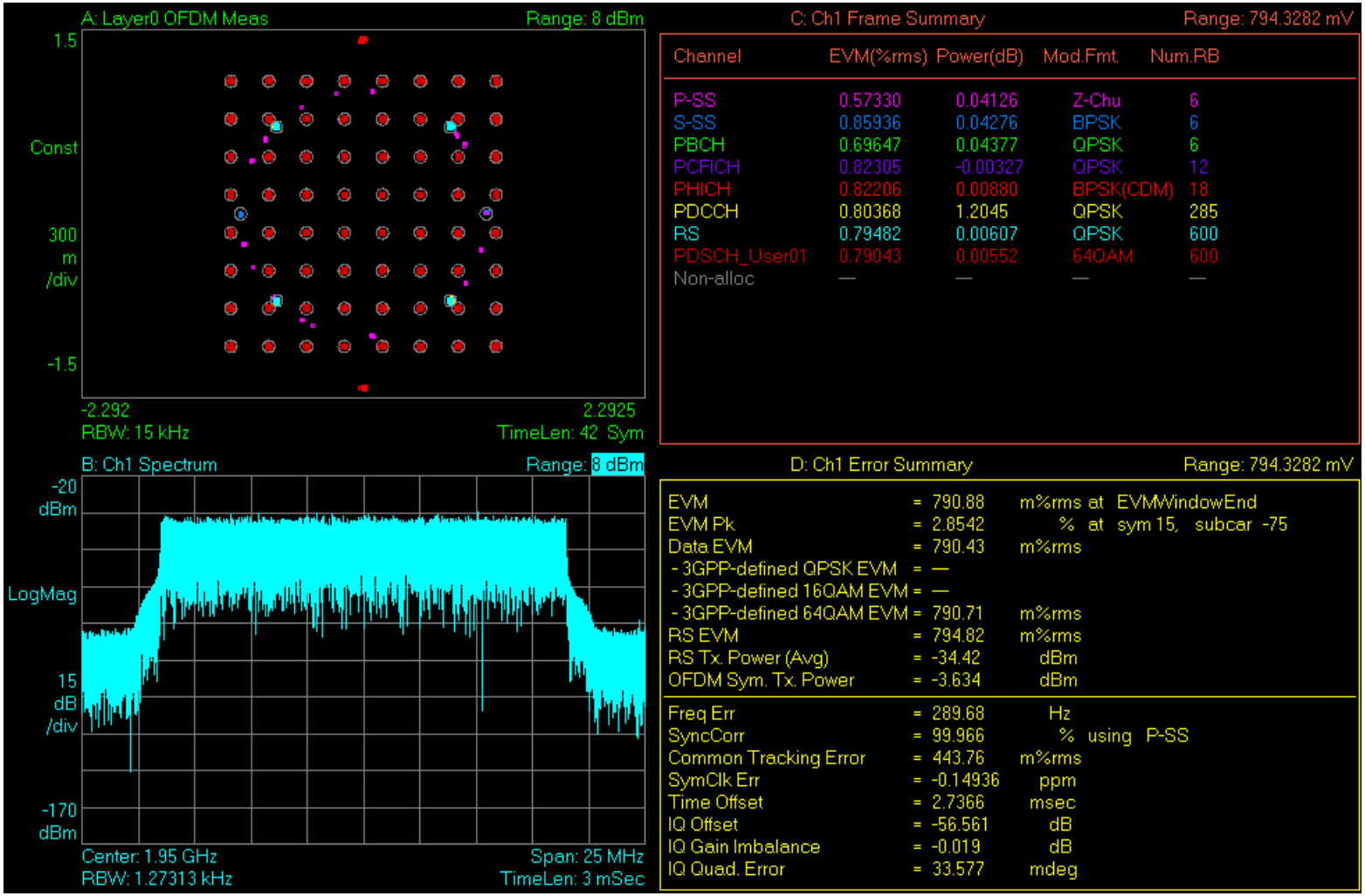



$$EVM(\%) = \frac{\sqrt{\frac{1}{N}\sum_{k=1}^{N}\left[\left(I_k - \tilde{I}_k\right)^2 + \left(Q_k - \tilde{Q}_k\right)^2\right]}}{\sqrt{I_{max}^2 + Q_{max}^2}}$$




No impact on mean value.
Small impact on maximum and minimum values at 99% level

# EVM test: example



# Conclusions

- The thesis investigates fiber-optic solutions based on silica and plastic optical fibers to transport wired and wireless services in an indoor scenario

- In this presentation, particular attention has been given to the research activity of the third year of my Ph.D.:
  - Theoretical and experimental activities have been carried out to investigate the linear and non-linear performance of a RoMMF link
  - Based on this activities, optimum optical components were identified
  - A prototype for a point-to-point link of an in-building DAS using MMF has been designed
  - Experimental characterization of the link in terms of ACLR and EVM in a dual-band LTE transmission has been performed
  - The performance are complying with standard requirements for successful transmission

# List of publications



## Journal papers:


1. D. Visani, G. Tartarini, L. Tarlazzi, P. Faccin, “Transmission of UMTS and WIMAX Signals Over Cost-Effective Radio Over Fiber Systems,” *IEEE Microwave and Wireless Components Letters*, vol. 19, no. 12, pp. 831-833, Dec. **2009**.
2. D. Visani, G. Tartarini, M. N. Petersen, P. Faccin, L. Tarlazzi, “Effects of laser frequency chirp on modal noise in short-range radio over multimode fiber links,” *OSA Applied Optics*, vol. 49, no. 6, pp. 1032-1040, Feb. **2010**.
3. D. Visani, G. Tartarini, M. N. Petersen, L. Tarlazzi, P. Faccin, “Link Design Rules for Cost-Effective Short-Range Radio Over Multimode Fiber Systems,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 58, no. 11, pp. 3144-3153, Nov. **2010**.
4. C. M. Okonkwo, E. Tangdiongga, H. Yang, D. Visani, S. Loquai, R. Kruglov, B. Charbonnier, M. Ouzzif, I. Greiss, O. Ziemann, R. Gaudino, A. M. J. Koonen, “Recent Results From the EU POF-PLUS Project: Multi-Gigabit Transmission Over 1 mm Core Diameter Plastic Optical Fibers,” *IEEE/OSA Journal of Lightwave Technology*, vol. 29, no. 2, pp. 186-193, Jan. **2011**.
5. D. Visani, Y. Shi, C. M. Okonkwo, H. Yang, H. P. A. van den Boom, G. Tartarini, E. Tangdiongga, A.M.J. Koonen, “Wired and wireless multi-service transmission over 1mm-core GI-POF for in-home networks,” *IET Electronics Letters*, vol. 47, no. 3, pp. 203-205, Feb. **2011**.
6. D. Visani, C. M. Okonkwo, S. Loquai, H. Yang, Y. Shi, H. P. A. van den Boom, T. Ditewig, G. Tartarini, S. C. J. Lee, A. M. J. Koonen, E. Tangdiongga, “Beyond 1 Gbit/s Transmission Over 1 mm Diameter Plastic Optical Fiber Employing DMT for In-Home Communication Systems,” *IEEE/OSA Journal of Lightwave Technology*, vol. 29, no. 4, pp. 622-628, Feb. **2011**.
7. M. N. Petersen, G. Tartarini, D. Visani, P. Faccin, L. Tarlazzi, “Influence of transmitter chirp and receiver imperfections on RF gain in short-range ROMMF systems,” *Microwave and Optical Technology Letters*, vol. 53, no. 4, pp. 822-824, Apr. **2011**.
8. S. T. Abraha, C. M. Okonkwo, H. Yang, D. Visani, Y. Shi, H.-D. Jung, E. Tangdiongga, A. M. J. Koonen, "Performance Evaluation of IR-UWB in Short-Range Fiber Communication Using Linear Combination of Monocycles," *IEEE/OSA Journal of Lightwave Technology*, vol. 29, no. 8, pp. 1143-1151, Apr. **2011**.
9. D. Visani, G. Tartarini, P. Faccin, L. Tarlazzi, “Cost-effective radio over fiber system for multi service wireless signal,” *Optics Communications*, vol. 284, no. 12, pp. 2751-2754, June **2011**.
10. D. Visani, C. M. Okonkwo, Y. Shi, H. Yang, H. P. A. van den Boom, G. Tartarini, E. Tangdiongga, A. M. J. Koonen, “$3\times2^{N}$-QAM Constellation Formats for DMT Over 1-mm Core Diameter Plastic Optical Fiber,” *IEEE Photonics Technology Letters*, vol. 23, no. 12, pp. 768-770, June **2011**.

# List of publications



11. G. Alcaro, D. Visani, L. Tarlazzi, P. Faccin, G. Tartarini, “Distortion Mechanisms Originating from Modal Noise in Radio over Multimode Fiber Links,” *IEEE Transactions on Microwave Theory and Techniques*, vol. 60, no. 1, pp. 185-194, Jan. **2012**.
12. Y. Shi, C. M. Okonkwo, D. Visani, H. Yang, H. P.A. can den Boom, G. Tartarini, E. Tangdiongga, A. M. J. Koonen, “Ultra-Wideband Signal Distribution over Large-Core POF for In-Home Networks,” submitted to *IEEE/OSA Journal of Ligthwave Technology*.

## Conference papers:

1.D. Visani, G. Tartarini, L. Tarlazzi, P. Faccin, “Accurate and efficient transmission evaluation of wireless signals on radio over fiber links,” IEEE International Topical Meeting on Microwave Photonics (MWP) 2009, paper Th4.17, 14-16 Sep. **2009**, Valencia, Spain.

2.D. Visani, G. Tartarini, M. N. Petersen, L. Tarlazzi, P. Faccin, “Reducing Modal Noise in Short-Range Radio over Multimode Fibre Links,” OSA Optical Fiber Communication Conference (OFC) 2010, paper JWA56, 21-15 Mar. **2010**, San Diego, CA, USA.

3.D. Visani, C. M. Okonkwo, S. Loquai, H. Yang, Y. Shi, H. P. van den Boom, T. Ditewig, G. Tartarini, B. Schmauss, S. Randel, T. Koonen, E. Tangdiongga, “Record 5.3 Gbit/s Transmission over 50m 1mm Core Diameter Graded-Index Plastic Optical Fiber,” OSA Optical Fiber Communication Conference (OFC) 2010, paper PDPA3, 21-15 Mar. **2010**, San Diego, CA, USA.

4.C. Raffaelli, M. Savi, G. Tartarini, D. Visani, “Physical path analysis in photonic switches with shared wavelength converters,” 12th International Conference on Transparent Optical Networks (ICTON) 2010, paper Mo.C1.5, June 27–July 1 **2010**, Munich, Germany.

5.G. Alcaro, D. Visani, G. Tartarini, L. Tarlazzi, P. Faccin, “Controlling the impact of Modal Noise on Harmonic and Intermodulation distortions in Radio over Multimode Fiber links,” 36th European Conference and Exhibition on Optical Communication (ECOC) 2010, paper We.7.B.5, 19-23 Sep. **2010**, Torino, Italy.

6.Y. Shi, H. Yang, D. Visani, C. M. Okonkwo, H. P. A. van den Boom, H. Kragl, G. Tartarini, S. Randel, E. Tangdiongga, A.M.J. Koonen, “First demonstration of broadcasting high capacity data in large-core POF-based in-home networks,” 36th European Conference and Exhibition on Optical Communication (ECOC) 2010, paper We.6.B.2, 19-23 Sep. **2010**, Torino, Italy.

7.H. Yang, D. Visani, C. M. Okonkwo, Y. Shi, G. Tartarini, E. Tangdiongga, A. M. J. Koonen, “Multi-standard transmission of converged wired and wireless services over 100m plastic optical fibre,” 36th European Conference and Exhibition on Optical Communication (ECOC) 2010, paper We.7.B.3, 19-23 Sep. **2010**, Torino, Italy.

# List of publications




8. Y. Shi, H. Yang, C. M. Okonkwo, D. Visani, G. Tartarini, E. Tangdiongga, A. M. J. Koonen, “Multimode fiber transmission of up-converted MB-OFDM UWB employing optical frequency multiplication,” IEEE International Topical Meeting on Microwave Photonics (MWP) 2010, paper Th4.32, 5-9 Oct. **2010**, Montreal, Canada.
9. D. Visani, G. Tartarini, Y. Shi, H. Yang, C. M. Okonkwo, E. Tangdiongga, A. M. J. Koonen, “Towards converged broadband wired and wireless in-home optical networks,” 15th International Conference on Optical Network Design and Modeling (ONDM) 2011, paper S4.2, 8-10 Feb. **2011**, Bologna, Italy.
10. Y. Shi, D. Visani, C. M. Okonkwo, H. Yang, H. P. A. van den Boom, G. Tartarini, E. Tangdiongga, A. M. J. Koonen, “First demonstration of HD video distribution over large-core POF employing UWB for in-home networks,” OSA Optical Fiber Communication Conference (OFC) 2011, paper OWB5, 6-10 Mar. **2011**, Los Angeles, CA, USA.
11. E. Tangdiongga, C. M. Okonkwo, Y. Shi, D. Visani, H. Yang, H. P. A. van den Boom, A. M. J. Koonen, “High-Speed Short-Range Transmission over POF,” OSA Optical Fiber Communication Conference (OFC) 2011, paper OWS5, 6-10 Mar. **2011**, Los Angeles, CA, USA.
12. E. Tangdiongga, D. Visani, H. Yang, Y. Shi, C. M. Okonkwo, H. P. A. van den Boom, G. Tartarini, and A. M. J. Koonen, "Converged In-home Networks using 1-mm Core Size Plastic Optical Fiber," OSA Access Networks and In-house Communications (ANIC) 2011, paper ATuC2, 12-14 June **2011**, Toronto, Canada.
13. Y. Shi, D. Visani, C. M. Okonkwo, H. van den Boom, G. Tartarini, E. Tangdiongga, A.M.J. Koonen, “Simultaneous Transmission of Wired and Wireless Services over Large Core POF for In-Home Networks,” 37th European Conference and Exhibition on Optical Communication (ECOC) 2011, paper Tu.3.C.5, 18-22 Sep. **2011**, Geneva, Switzerland.