Radio over Multimode Fibre Networks

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Outline

- In-home network architecture for integrated broadband services
- Radio-over-MMF using the Optical Frequency Multiplying technique
- OFM system experiments
- Reconfigurable Radio-over-MMF networks
- Concluding remarks

Versatile BB in-home networks

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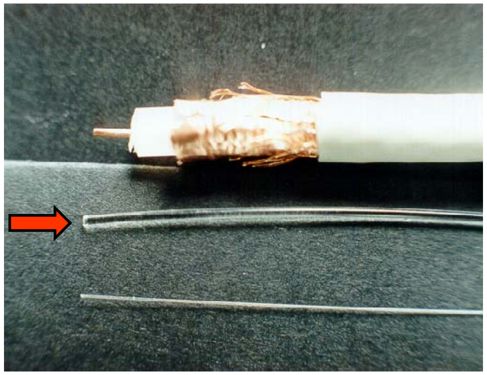
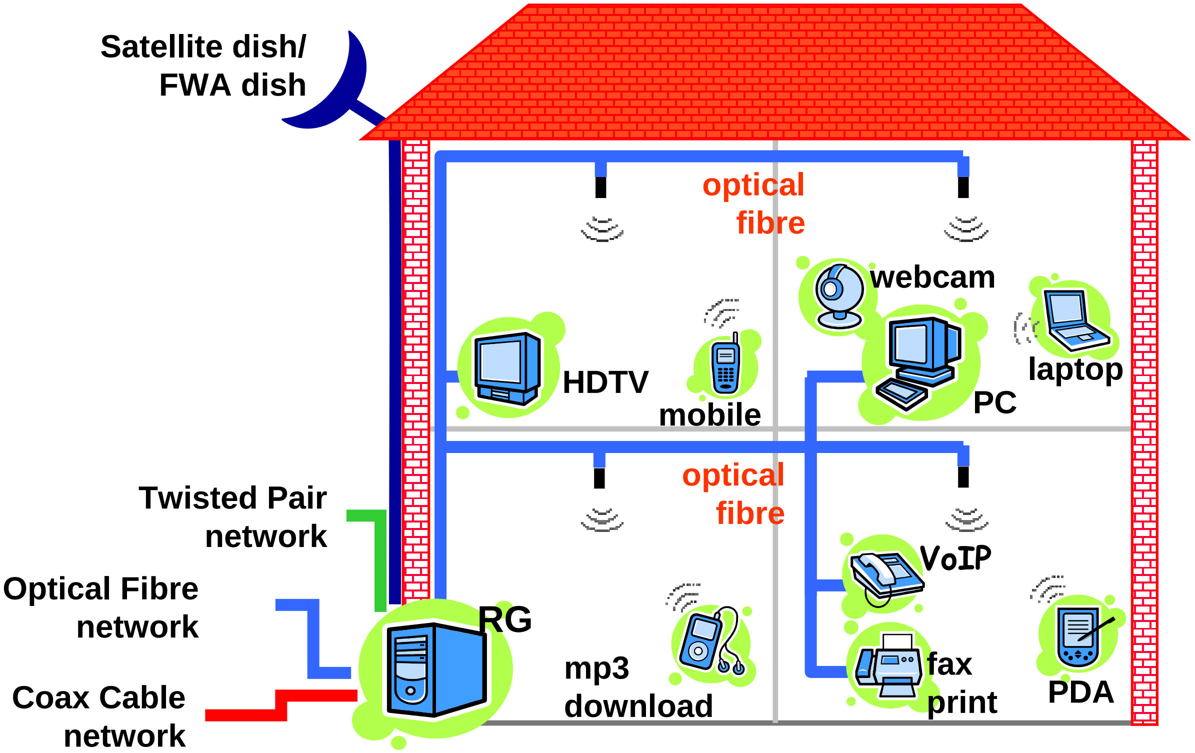
Converged in-home backbone network, integrating wired & wireless services

- reduces installation and maintenance efforts
- eases introduction and upgrading of services



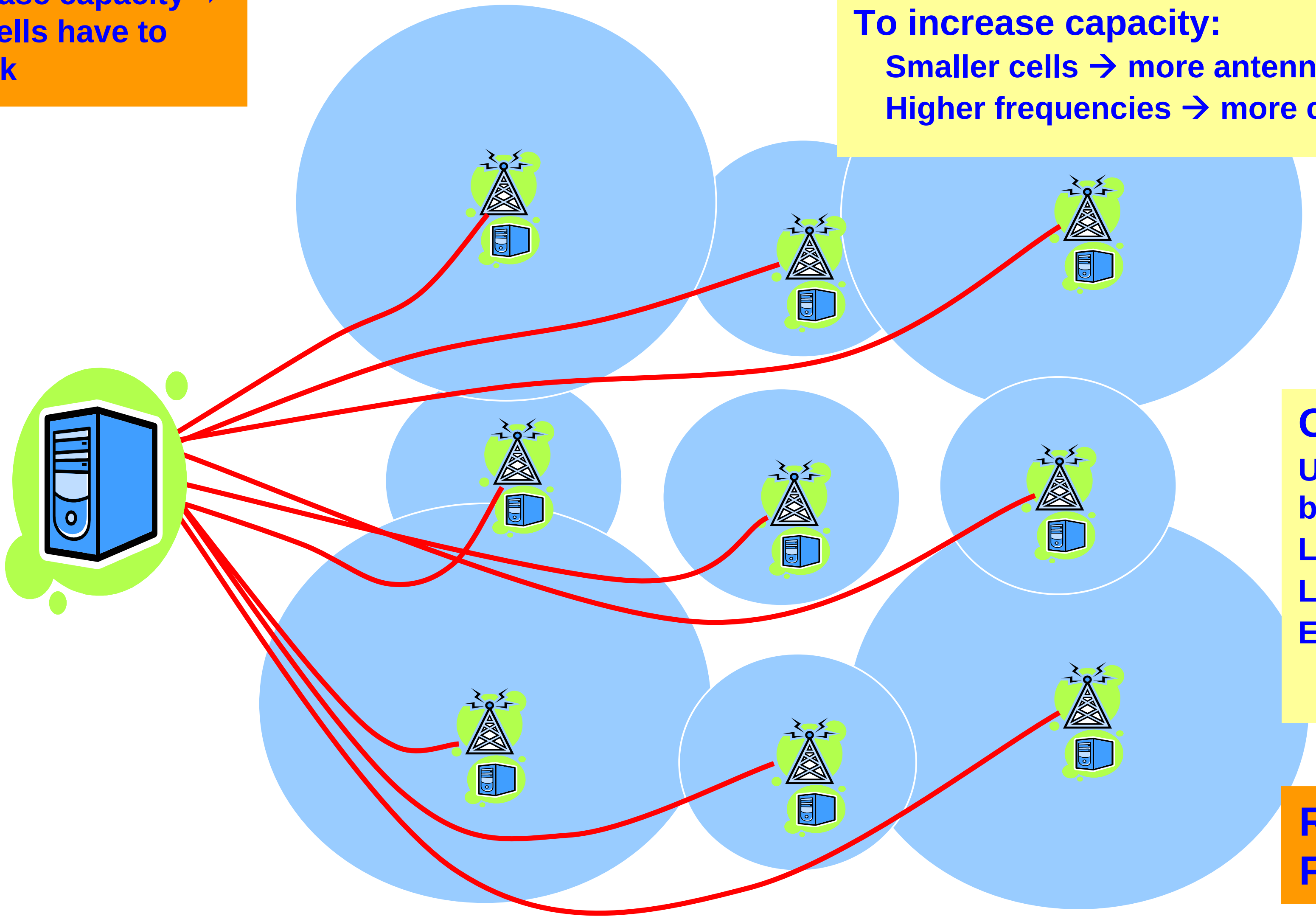


→ converged in-home network on POF

IOP

Radio over Fibre

increase capacity ⇨ big cells have to shrink



To increase capacity:

- **Smaller cells → more antenna sites**
- **Higher frequencies → more complexity**

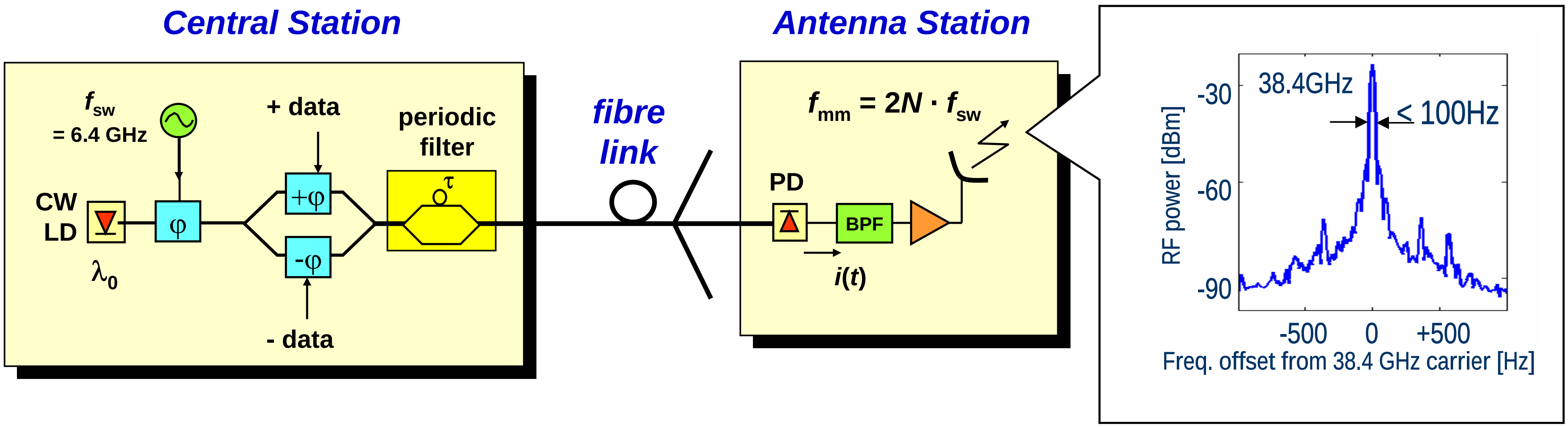
Optical Fibre

Unlimited bandwidth
Low loss
Light weight
EM immunity

⇩

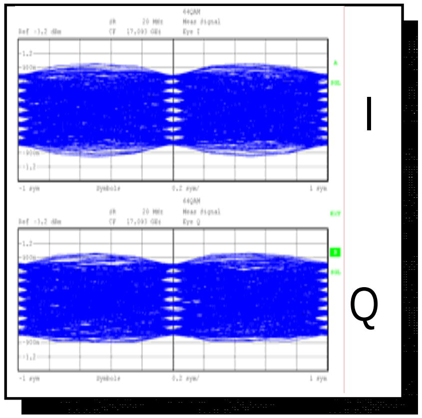
Radio over Fibre

Radio over multimode fibre



"Optical Frequency Multiplying"

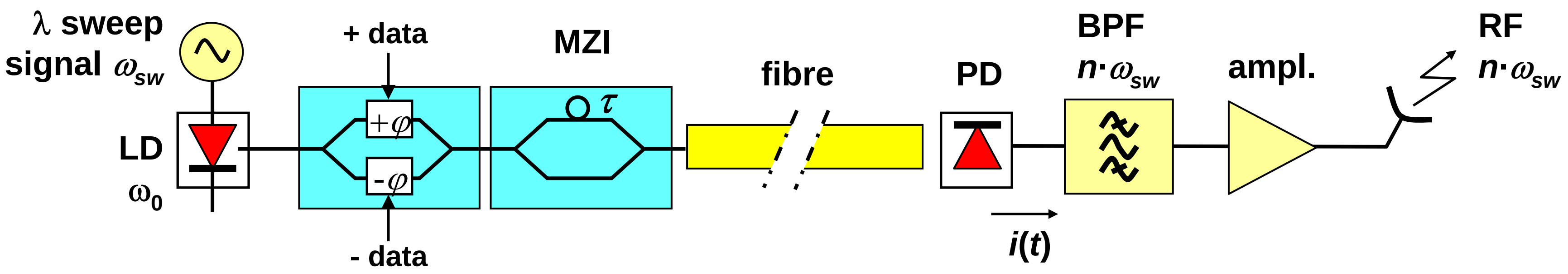
- low-cost technology
- simple antenna stations
- very pure microwave → high wireless capacity
- dispersion-tolerant → for SMF <u>and</u> MMF



120 Mbit/s
64 QAM
@ 17.2 GHz
after 4.4 km
silica MMF

[A.M.J. Koonen, Patent NL 1019047]
[M. Garcia Larrode et al., EL 2006]

OFM system analysis



- Monochromatic laser, optical frequency ω_0 sinusoidally swept over range $2\beta\cdot\omega_{sw}$ with sweep freq. ω_{sw}
- Periodic bandpass filtering before the fibre (is equivalent to filtering after the fibre)
- MZI with Free Spectral Range $\Delta\Omega_{FSR} = 2\pi / \tau$, <u>locked</u> to laser freq. ω_0
- Neglecting fibre dispersion, photodiode output signal

$$i(t) = I_0 \cdot \left\{ 1 + \cos\left[2\beta \cdot \sin\left(\tfrac{1}{2}\omega_{sw}\tau\right) \cdot \cos\left(\omega_{sw}(t - \tfrac{1}{2}\tau)\right) + \omega_0\tau \right] \right\}$$

containing <u>even harmonic frequency components</u> at $2k\cdot\omega_{sw}$ with relative amplitude

$$\cos(\omega_0\tau) \cdot J_{2k}\left(2\beta \cdot \sin(\tfrac{1}{2}\omega_{sw}\tau)\right)$$

and <u>odd harmonic frequency components</u> at $(2k+1)\cdot\omega_{sw}$ with relative amplitude

$$\sin(\omega_0\tau) \cdot J_{2k-1}\left(2\beta \cdot \sin(\tfrac{1}{2}\omega_{sw}\tau)\right)$$

OFM generated microwave harmonics

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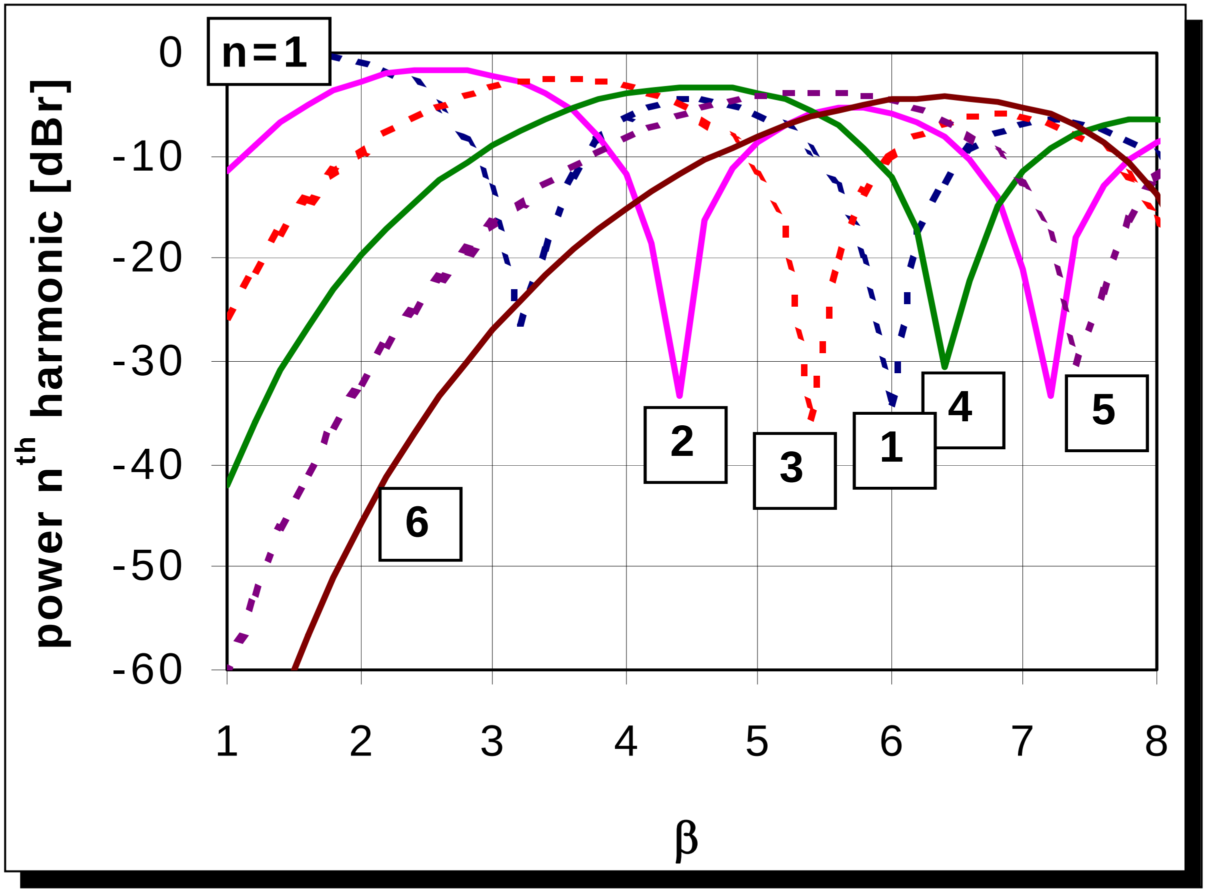

- *Assumptions*:
  - sweep freq. f_{sw}=2 GHz
  - MZI FSR $\Delta\nu_{FSR}$ =10 GHz
  - at each harmonic, $\omega_0\,\tau$ is optimised for max. power

- Optical FM modulation index β to be optimised for max. power in preferred harmonic (e.g., $\beta_{opt} \approx 6.3$ for n=6, so for the 12 GHz harmonic)

Impact of laser linewidth

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- Output signal of photodiode, assuming laser linewidth $\sqrt{\overline{(\delta\omega)^2}}$, and neglecting fibre dispersion

$$i(t) = I_0 \cdot \left\{ 1 + \cos\left[2\beta \cdot \sin\left(\tfrac{1}{2}\omega_{sw}\tau\right) \cdot \cos\left(\omega_{sw}(t - \tfrac{1}{2}\tau)\right) + \omega_0\tau + \delta\omega \cdot \tau \right] \right\}$$

→ OFM effectively suppresses laser phase noise, provided that $\delta\omega_{rms} \cdot \tau << \pi/2$ i.e. laser linewidth is much smaller than a quarter of the FSR of the MZI $\Delta\omega_{FSR} = \pi / 2\tau$

➔ OFM generates very pure microwave carriers

Impact of MMF modal dispersion

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- **MMF small signal intensity modulation transfer function** due to modal dispersion, neglecting chromatic dispersion

  $| H_{IM}(\omega) | = \Phi_{out}(\omega) / \Phi_{in}(\omega)$

  where $\Phi_{out}(\omega)$ is the Fourier transform of the output power signal $P_{out}(t)$ of the MMF, and $\Phi_{in}(\omega)$ of the input power signal $P_{in}(t)$

- neglecting chromatic dispersion, the impulse response of an MMF is a series of delayed impulses from the individual modes

  → frequency response $| H_{IM}(\omega) |$ shows multiple lobes

- without mode coupling: amplitudes of OFM generated harmonics can be shown to scale linearly with $| H_{IM}(\omega) |$

  → deploy the extended frequency response lobes of MMF

  (or the wide frequency response of a well-equalised graded-index MMF)

- with mode coupling: the MMF itself also contributes to the OFM process;

  → the MZI contribution dominates as long as its delay τ exceeds the MMF's differential mode delays

[A.M.J. Koonen, A. Ng'oma, Wiley 2006]
[M. Garcia Larrode, A.M.J. Koonen, JLT 2008]

Higher-order transmission lobes in GI-MMF

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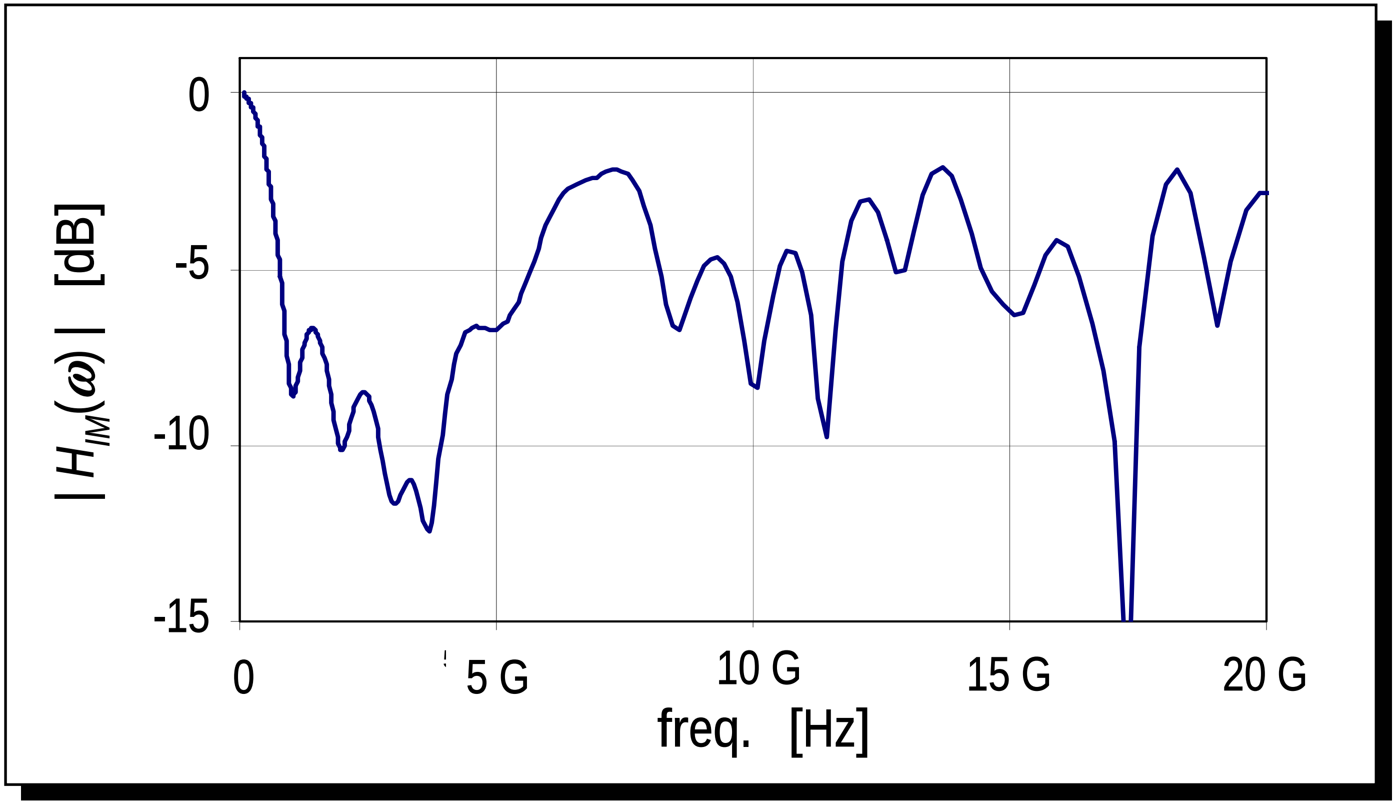


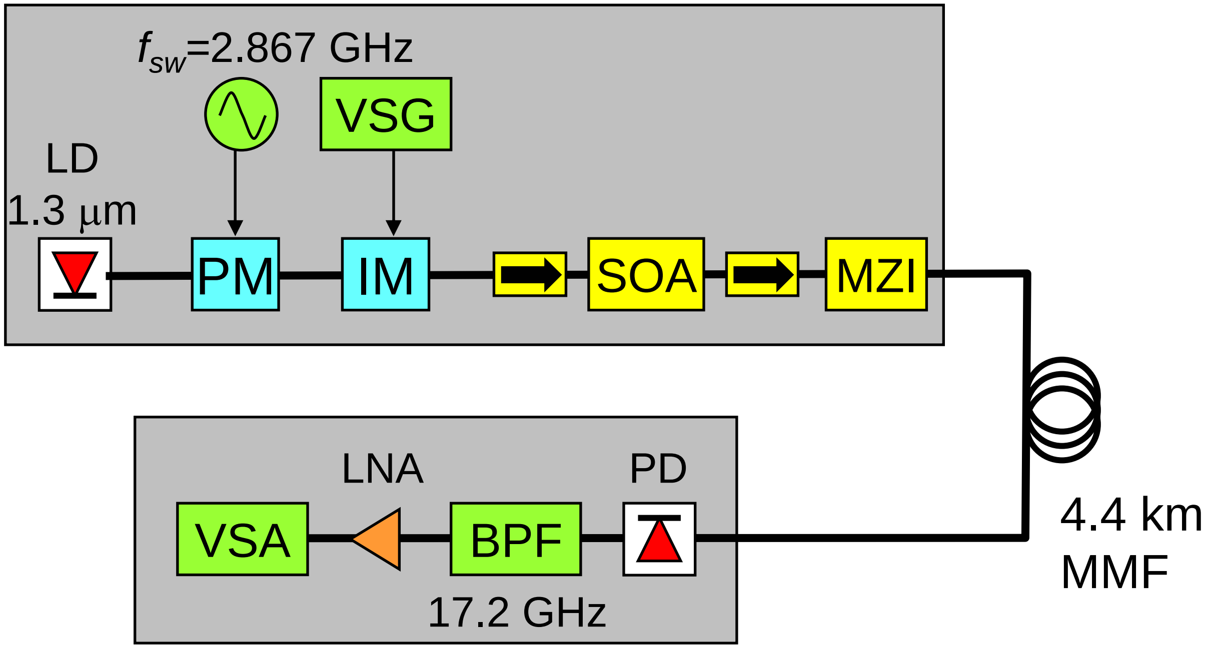
simulation

MMF length L=5 km
parabolic refr. index
core dia. 50 μm

full NA launching, NA=0.2
negligible mode mixing

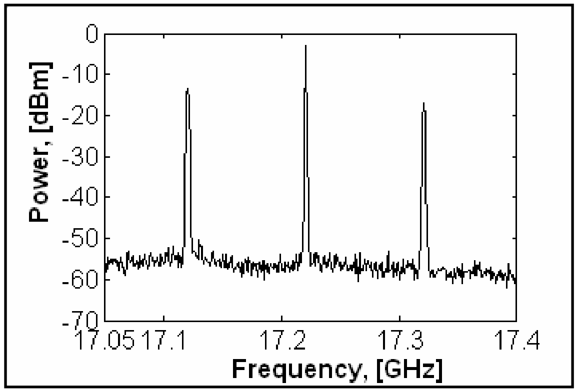
monochromatic source
λ=1.3 μm

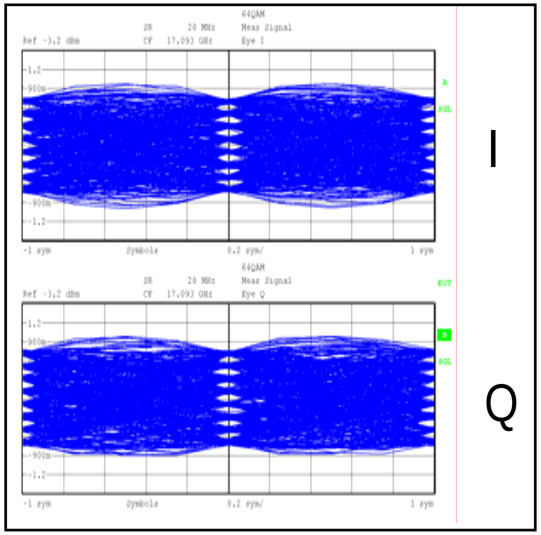
64-QAM experiment over silica GI-MMF



- μ-wave carrier freq. 17.2 GHz
- 64-QAM on subcarrier freq. 127 MHz
- symbol rate 20 MBaud → 120 Mbit/s
- over 4.4 km silica GI-MMF
- also over 25 km SMF @ 39.9 GHz
- multi-tone (up to 10 tones) 64-QAM operation at 18.3 GHz over the GI-MMF link shown

VSG = Vector Signal Generator
VSA = Vector Signal Analyzer

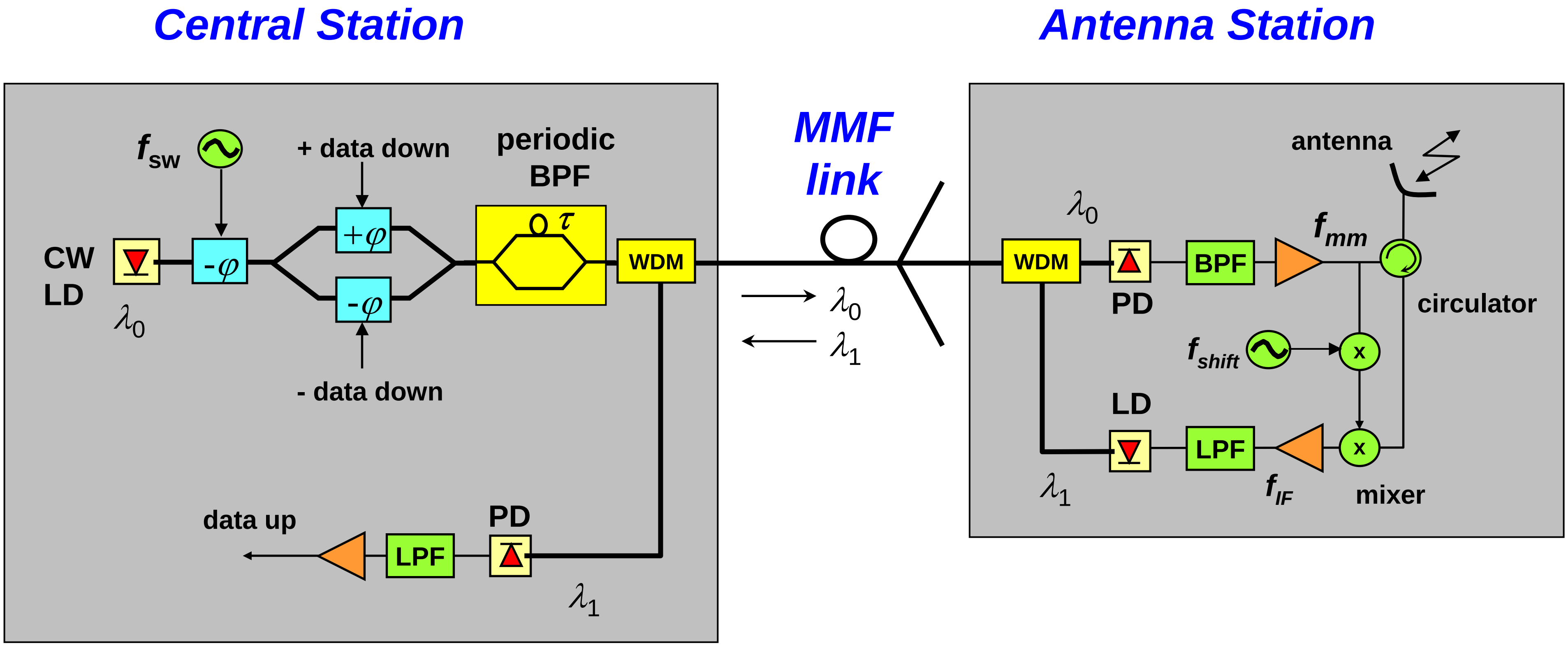




EVM = 4.8 % (< 5.6 % req.)

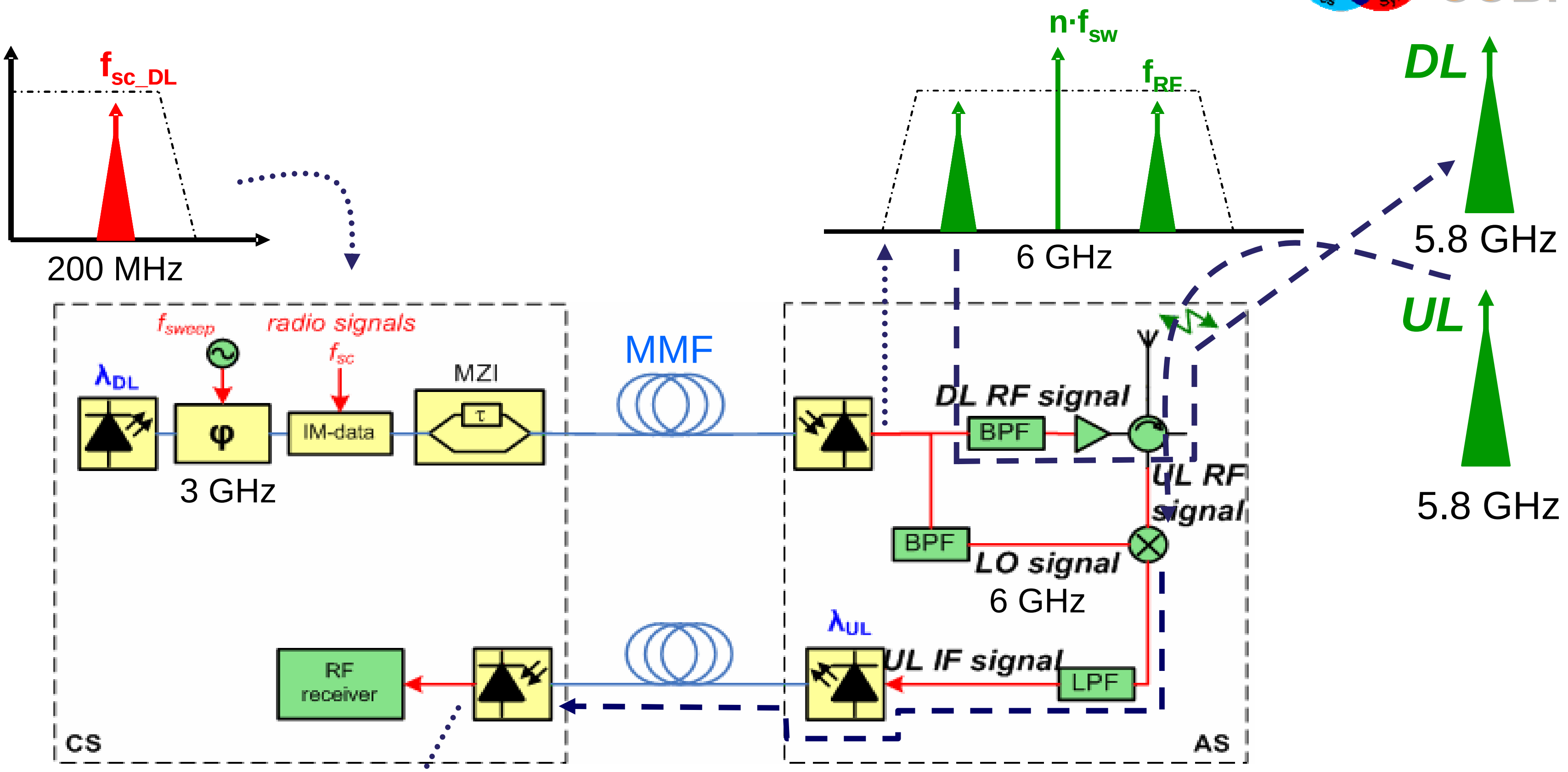
[A. Ng'oma et al., OFC2005]

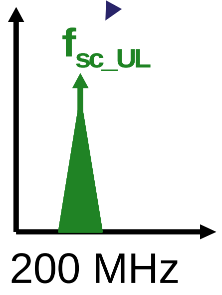
Bi-directional system



- freq.-division duplex
- upstream: TDMA, or SCMA, incl. MAC protocol

Bi-directional OFM link



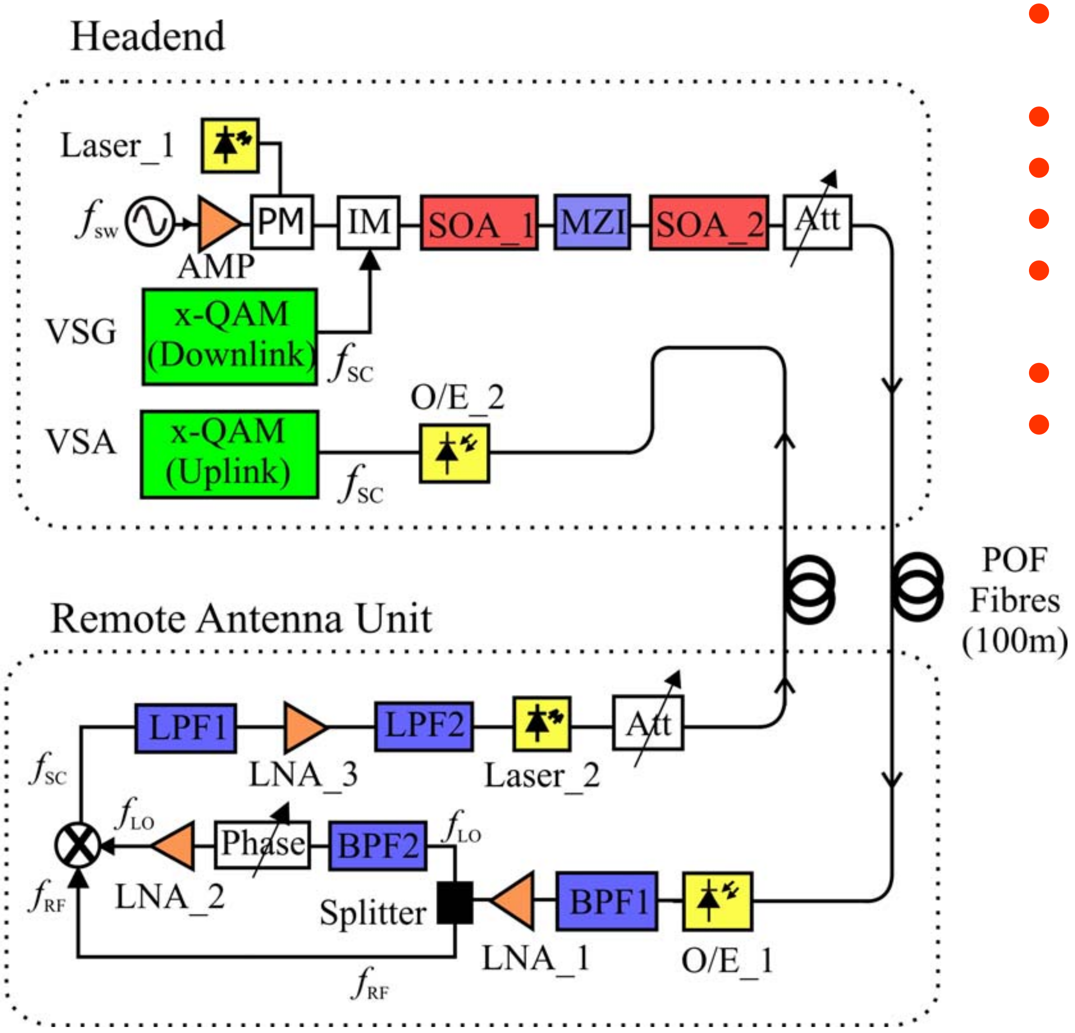


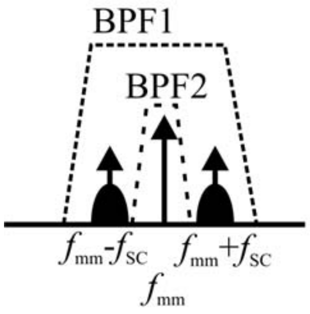
- **Remote LO delivery**
- **Low cost uplink**

DL: 64-QAM, 24Mbit/s, at 5.8 GHz; f_{sc_DL}=200MHz
f_{LO}=6 GHz
4.4 km silica GI-MMF
UL: 64-QAM, 24Mbit/s, at f_{IF_UL}=200MHz

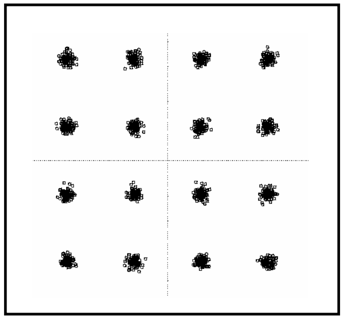
[M. Garcia Larrode et al, IEEE PTL 2006]

Bi-dir. 16-QAM experiment over GI-POF





- downstream and upstream link: 100m 50µm core GI-POF
- PD BW=25 GHz, 50µm core MMF
- λ_{down} = 1316 nm
- sweep freq. f_{sw} = 2.867 GHz
- µ-wave carrier freq. 17.2 GHz (6th harmonic)
- subcarrier freq. 300 MHz
- symbol rate 25 MBaud → 100 Mbit/s

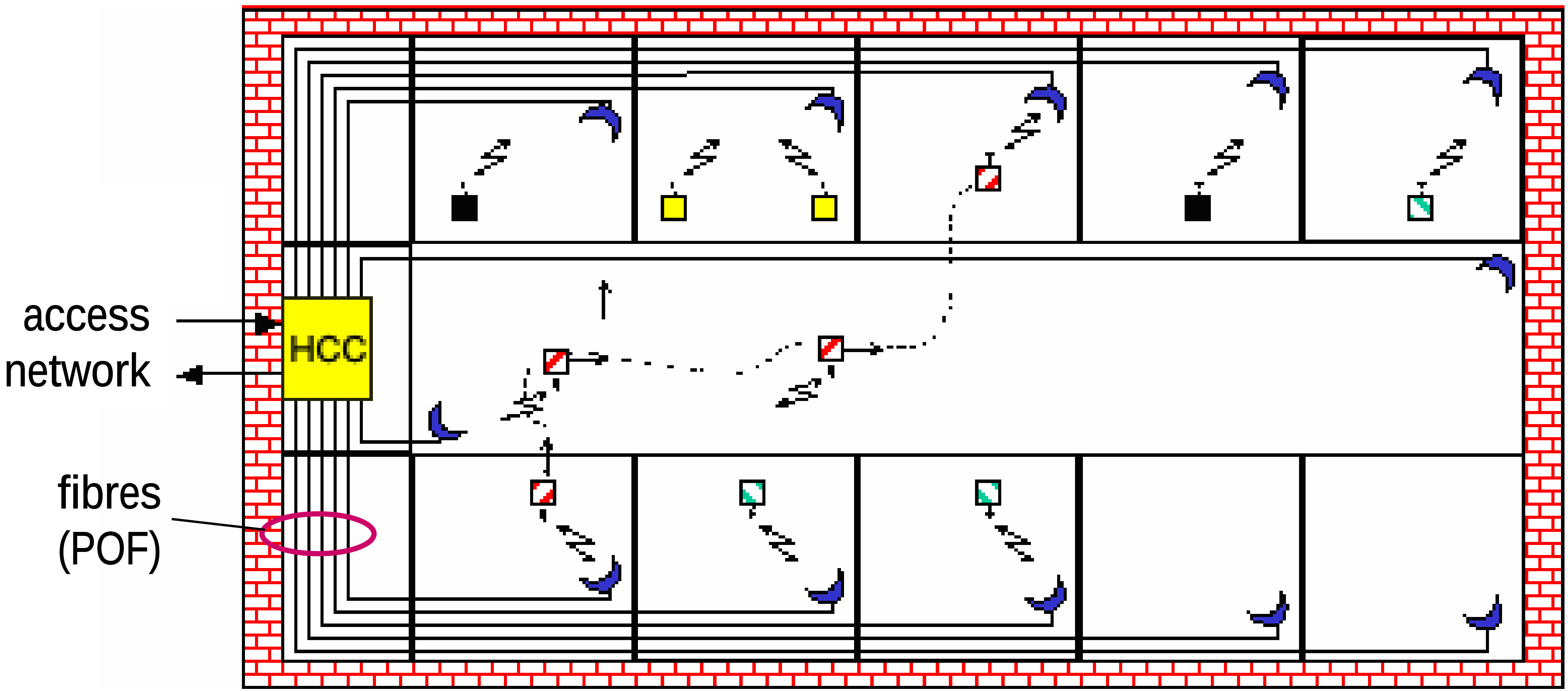


Constellation diagram

EVM=4.8% (<5.6%)

[A. Ng'oma et al., AP-MWP 2007]

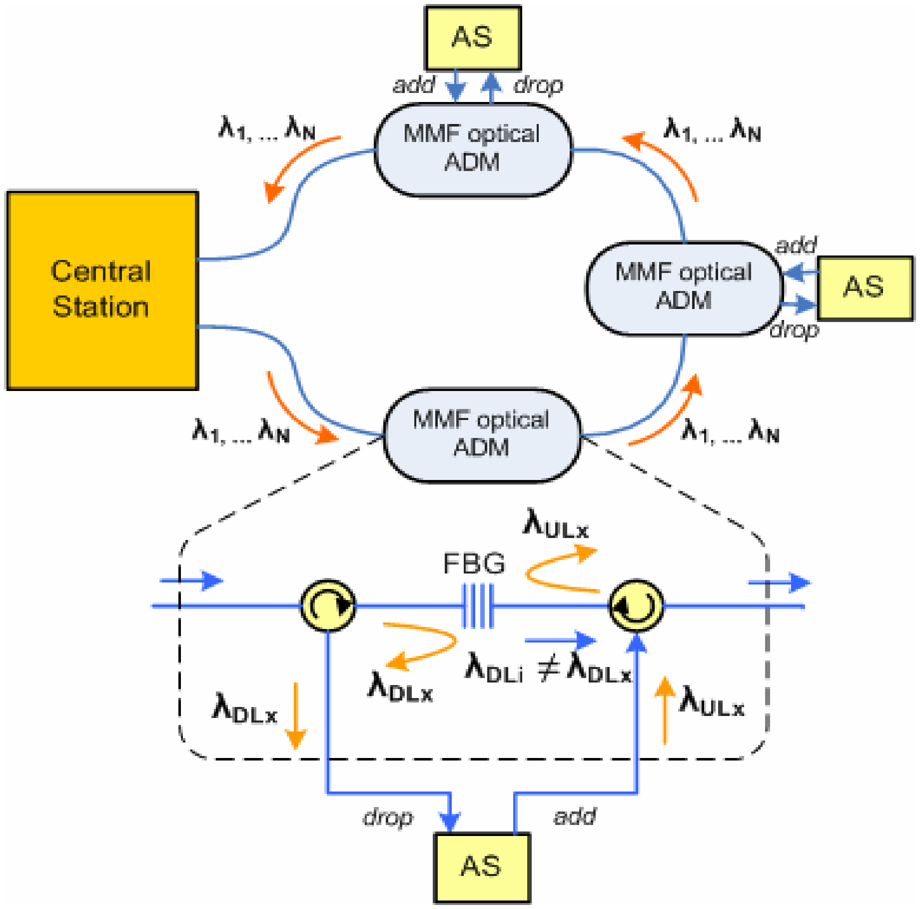
Inter-room μ-wave wireless communication

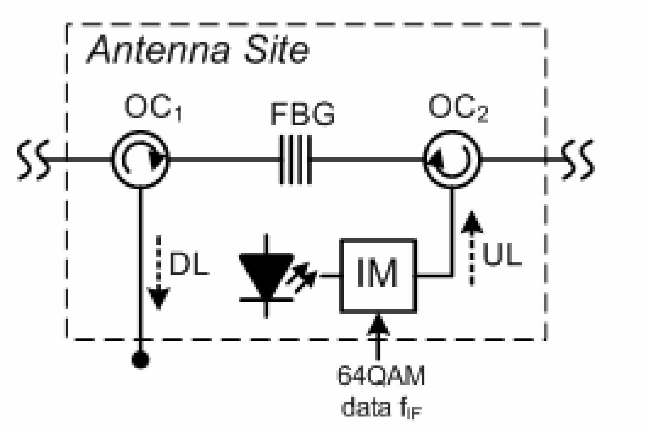


HCC: Home Communication Controller

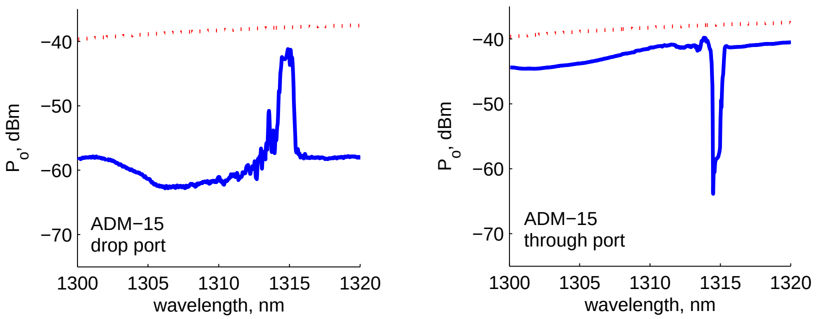
- transparent for any wireless signal format
- any-to-any room communication
- multi-casting

Wavelength-routed RoMMF network





- **RoMMF add/drop node**
  (MMF FBG with BW=100 GHz)



- **drop and through ports**

- Downlink: 120 Mbit/s 64-QAM, at 23.7 GHz
- Uplink: 64-QAM, at f_{IF}=300 MHz, with IM/DD
- λ_1=1303.8 nm, λ_2=1310.1 nm, λ_3=1314.8 nm

[M. Garcia Larrode, A.M.J. Koonen, Trans. MTT 2008]

Concluding remarks

- Future-proof, versatile and high-capacity service provisioning of multiple services in in-home networks can efficiently be done using *silica or polymer multimode fibre*.
- *Radio-over-fibre* facilitates the overlay of wireless communication services in a wired infrastructure, and the convergence of wirebound and wireless services in In-Home networks.
- With the *Optical Frequency Multiplying technique* microwave radio signals with high spectral purity and high capacity can be generated, and transported over dispersive multimode (and single-mode) fibre links.
- In combination with flexible wavelength routing, *reconfigurable multi-standard wireless pico-cell LANs* can be created.

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  FP6 Network of Excellence *ISIS,*

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  Future Home Networks

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