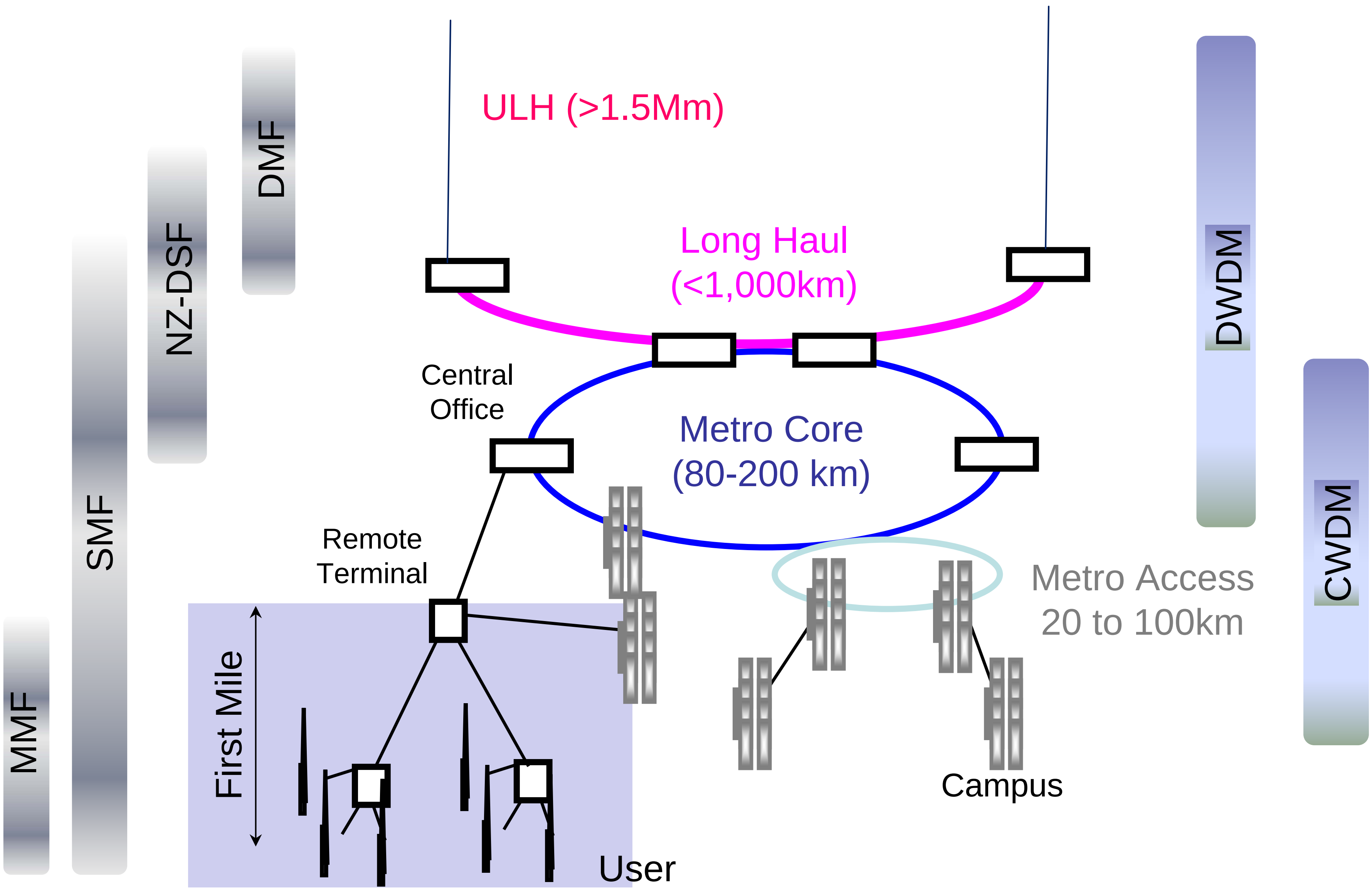
Optical Edge Architectures

Trends and Technology Opportunities

S. Radic

Optical Edge Architectures



(Conventional) Competing Access Technologies:

1) Fiber-in-the-Loop (FITL):

- PON
- FTTH/FTTC/FTTZ

2) xDSL

ADSL ~ 10Mbps, ~3km
VDSL ~ 50Mbps, ~1km

3) Microwave/Millimeter Distribution:

Multipoint Multichannel Distribution Services (MMDS) – 2.5GHz (~200MHz)
Local Multipoint Distribution Services (LMDS) – 28GHz (~1GHz)

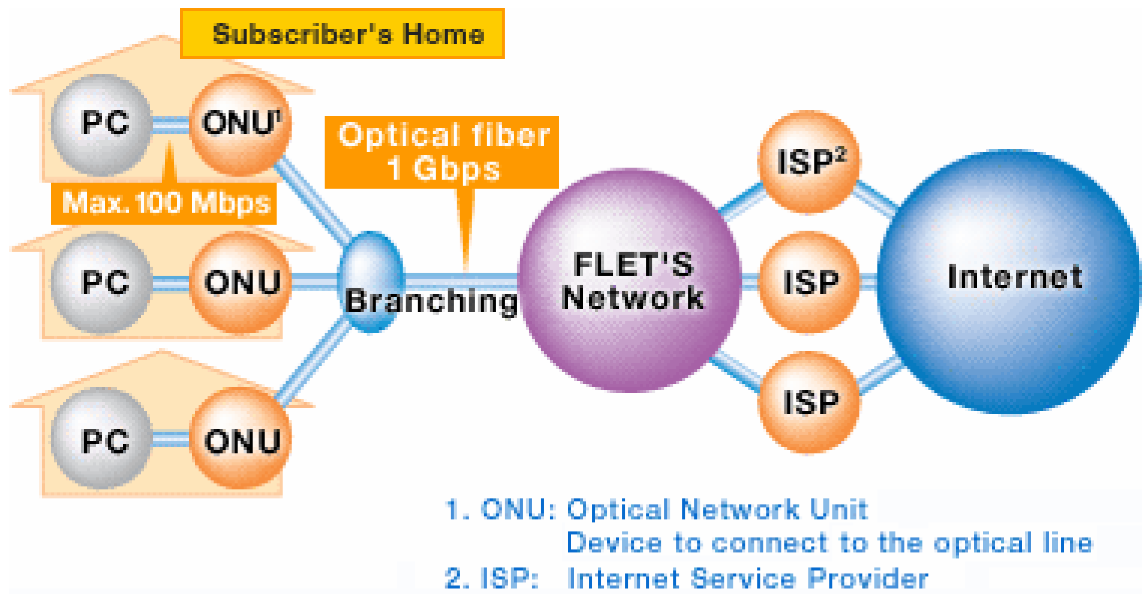
4) Digital Broadcast Satellite (DBS) 300+ Digital Channels

5) Hybrid Fiber Coax (HFC) > 30Mbps/User

Conventional Edge: Bring the fiber to the end user (at cost)

NTT EAST

http://www.ntt-east.co.jp/product_e/05/index.html



Monthly Charge

Service Type		B FLET'S monthly charge	Equipment rental charge		Total
Hyper Family Type		¥4,305	Internal wiring usage charge[2] ¥210	Optical network unit usage charge ¥945	¥5,460
Mansion Type	LAN wiring	¥2,625[1] ~	-		¥2,625 ~
	VDSL	¥2,625[1] ~	¥367.5		¥2,992.5 ~
	Wireless	¥3,675	¥1,365		¥5,040

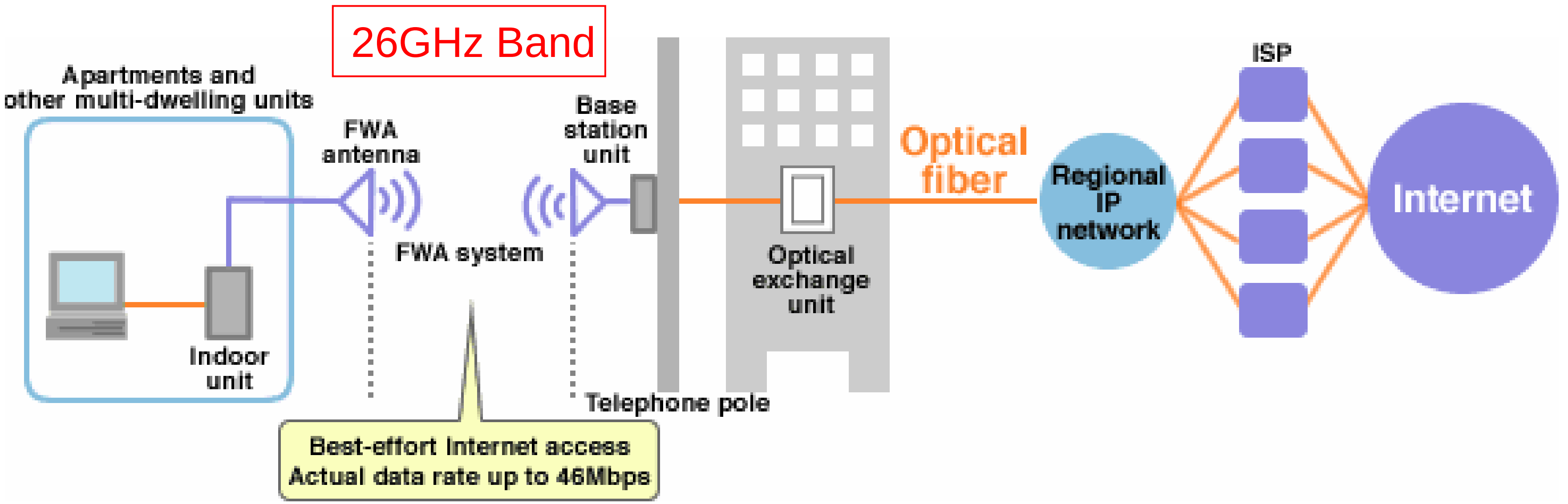
User Forecast

FTTH Subscribers: 6M (March, 2007)

9.5M (March, 2008)

30M (March, 2010)

Conventional Edge: Use RF Link to connect few points only.



http://www.ntt-west.co.jp/service_guide/5great/great02.html

Monthly Charges

Line service charge	Plan 1[2] ¥3,500 (¥3,675 tax included) Plan 2[2] ¥3,000 (¥3,150 tax included)
Optical network unit (ONU) rental charge	¥1,300 (¥1,365 tax included)

1. Internet service provider usage charges will also apply.
2. Applications for Plan 1 can be accepted from one user when eight or more users can be expected to apply.
   Applications for Plan 2 can be accepted from one user when 16 or more users can be expected to apply.

Start-Up Costs

Contract fee	¥800 (¥840 tax included)
Installation charge (may differ)	¥20,000 (¥21,000 tax included)*

Infrastructure:

Multi Mode Fiber (MMF)

- Interconnect/Ethernet Deployed
- Connectorization/Coupling
- Non-Glass Fabrication Possible

Single Mode Fiber (SMF)

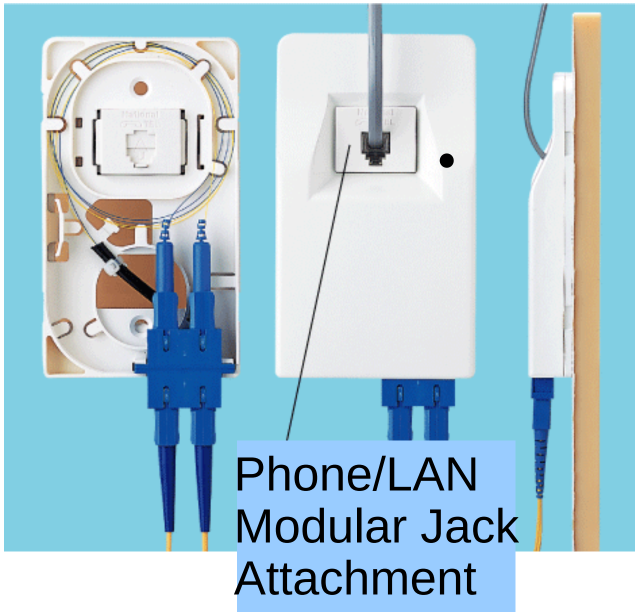
-Standard backbone deployment

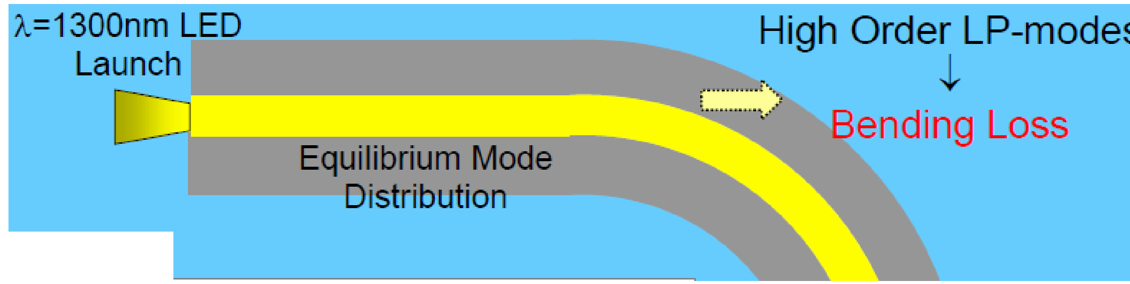
-Vanishing cost differential with MMF

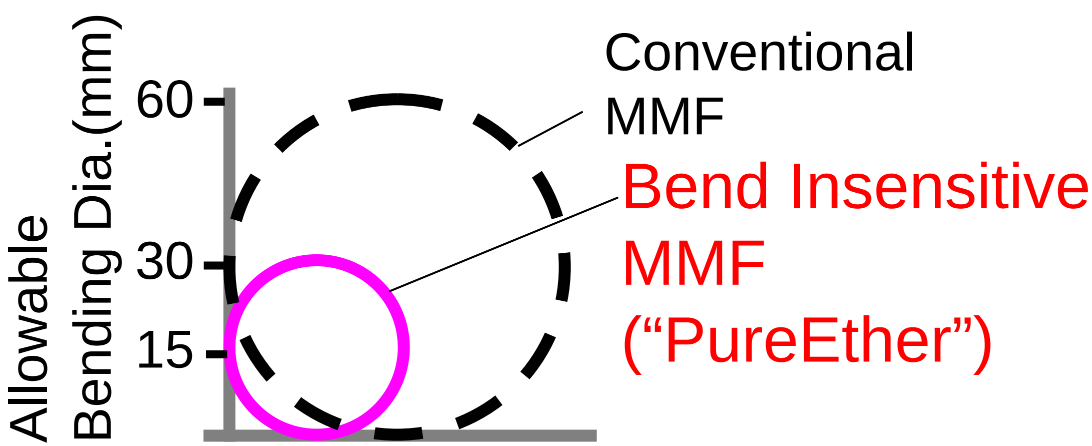
- Connectorization/Coupling still not cheap

Growing realization that copper will be phased out.

MMF has advanced as viable SMF alternative







Courtesy of Sumitomo Electric Industries Ltd.

MMF has advanced as viable SMF alternative

Standard	Name	Specification	MMF Type	Bandwidth (MHz・km)	Distance (m)
IEEE802.3	Gigabit Ethernet	1000BASE-SX (λ: 850nm)	50μm	≥ 500	≤ 550
			62.5μm	≥ 200	≤ 275
		1000BASE-LX (λ: 1300nm)	50μm	≥ 500	≤ 550
			62.5μm	≥ 500	≤ 550
IEEE802.3 ae.	10 Gigabit Ethernet	1000BASE-SR/SW (λ: 850nm)	50μm	≥ 500	≤ 82
				≥ 2000	≤ 300
			62.5μm	≥ 200	≤ 33
		1000BASE-LX4	50μm	≥ 500	≤ 220

2002 Standardization of 850nm Laser Optimized MMF

- High Bandwidth (≥ 2000 MHz・km)
- Cost Effectiveness (850nmVCSEL Laser)
- Full Compatibility with Traditional Systems

Present and Future Rationale

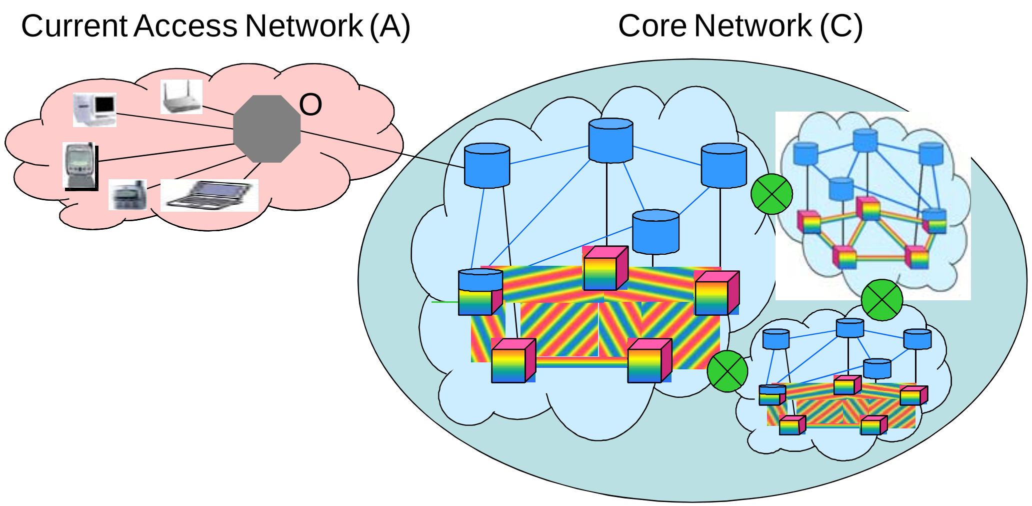
Trends to be supported:

1) Scalable increase in capacity

2) Increase in diversity of services

Latency
Security
Reliability
Elasticity

Not necessarily compatible with Core/Metro requirements



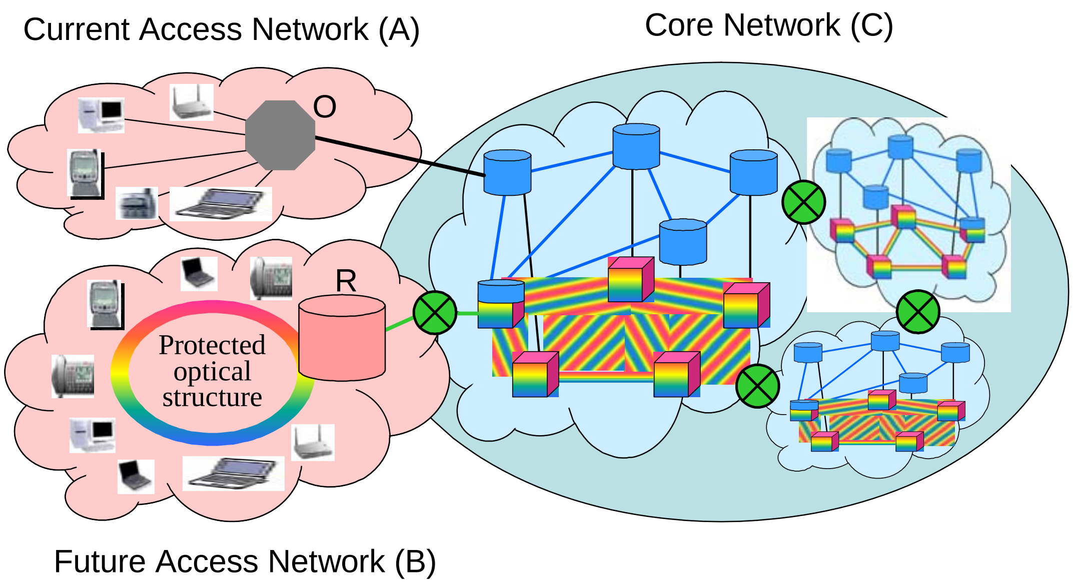
Currently:

- Star topology connects the user to the central office
- Access star interfaced with Core at single node

Issues:

- Connections generally unprotected
- Cost sharing of the infrastructure non-existent
- Data rates are not passed from the core to the access user
- Access lines are service-specific

Present and Future Rationale



1) Future network still needs to accommodate heterogeneous service needs

2) Unrealistic to expect single network architecture to support all possible services without increased resources

3) Heterogeneous service handled at the edge access points

4) Edge nodes will aggregate data and map service-specific service to/from Core

(Some) of the technology opportunities:

1) Extended Reach PON

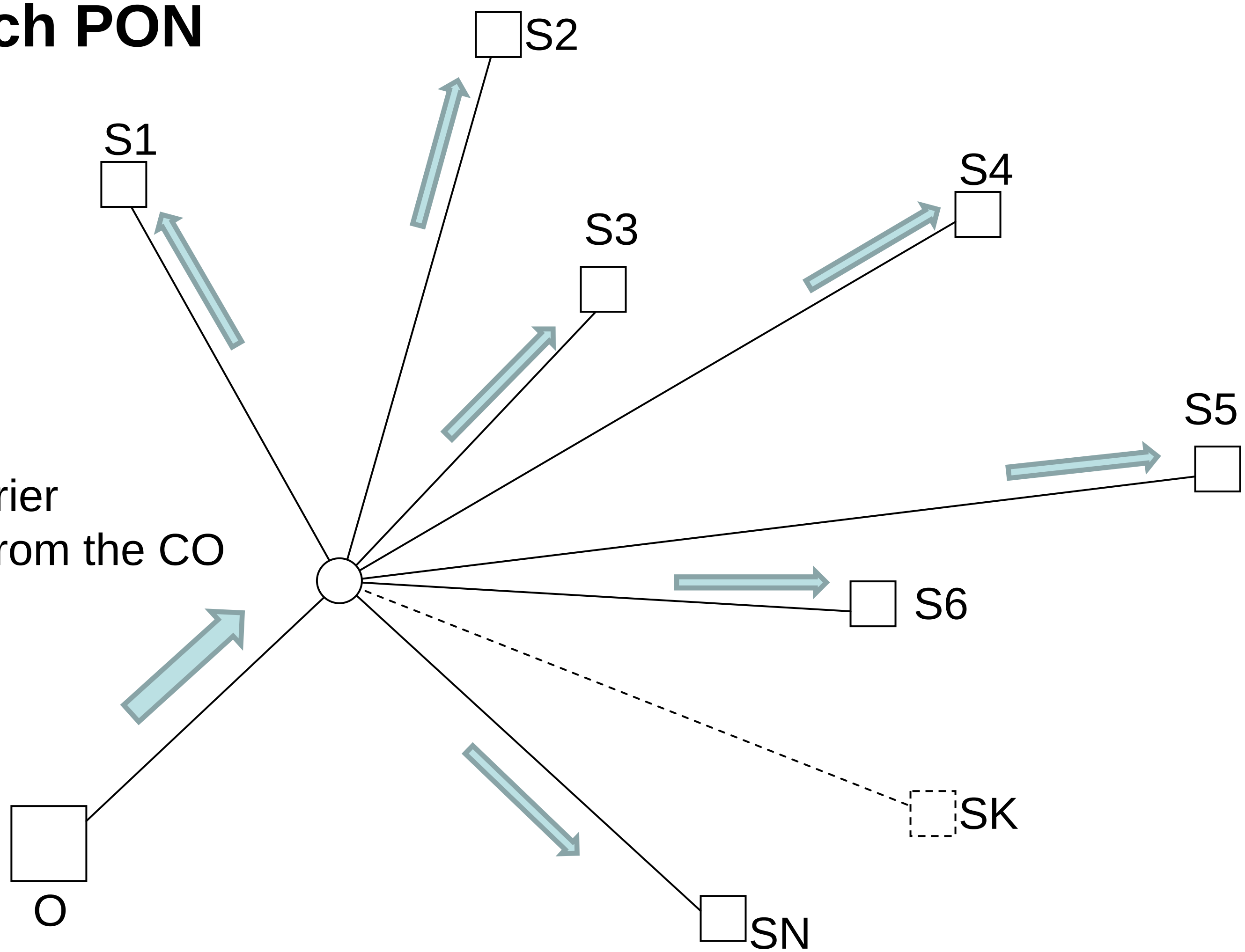
2) Scalable Data Rate over Fixed (Low-Grade) Infrastructure

3) Scalable Multicasting and Band Mapping

4) Wireless Support

1) Extended Reach PON

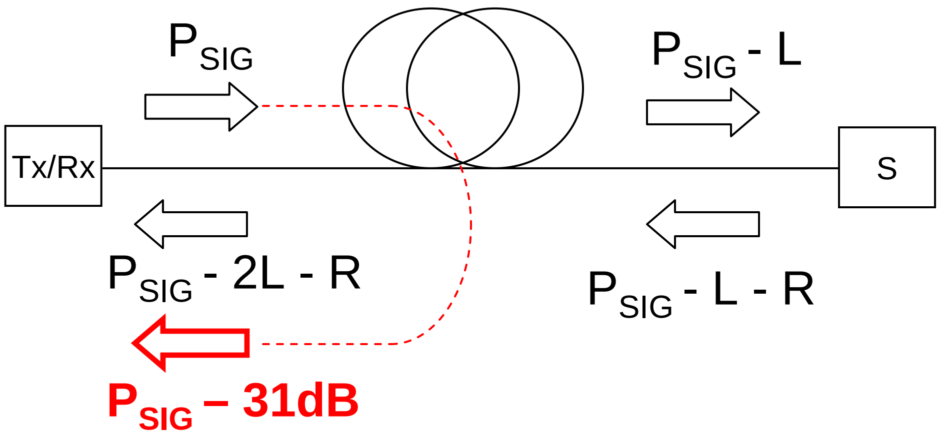
End user (S):



1) Passive
- Low cost
- Uses distributed carrier
- Limited in distance from the CO

2) Active Node
- Higher Cost
- Can use its own carrier
- Not limited in distance from CO

How far in Passive PON?



Example:

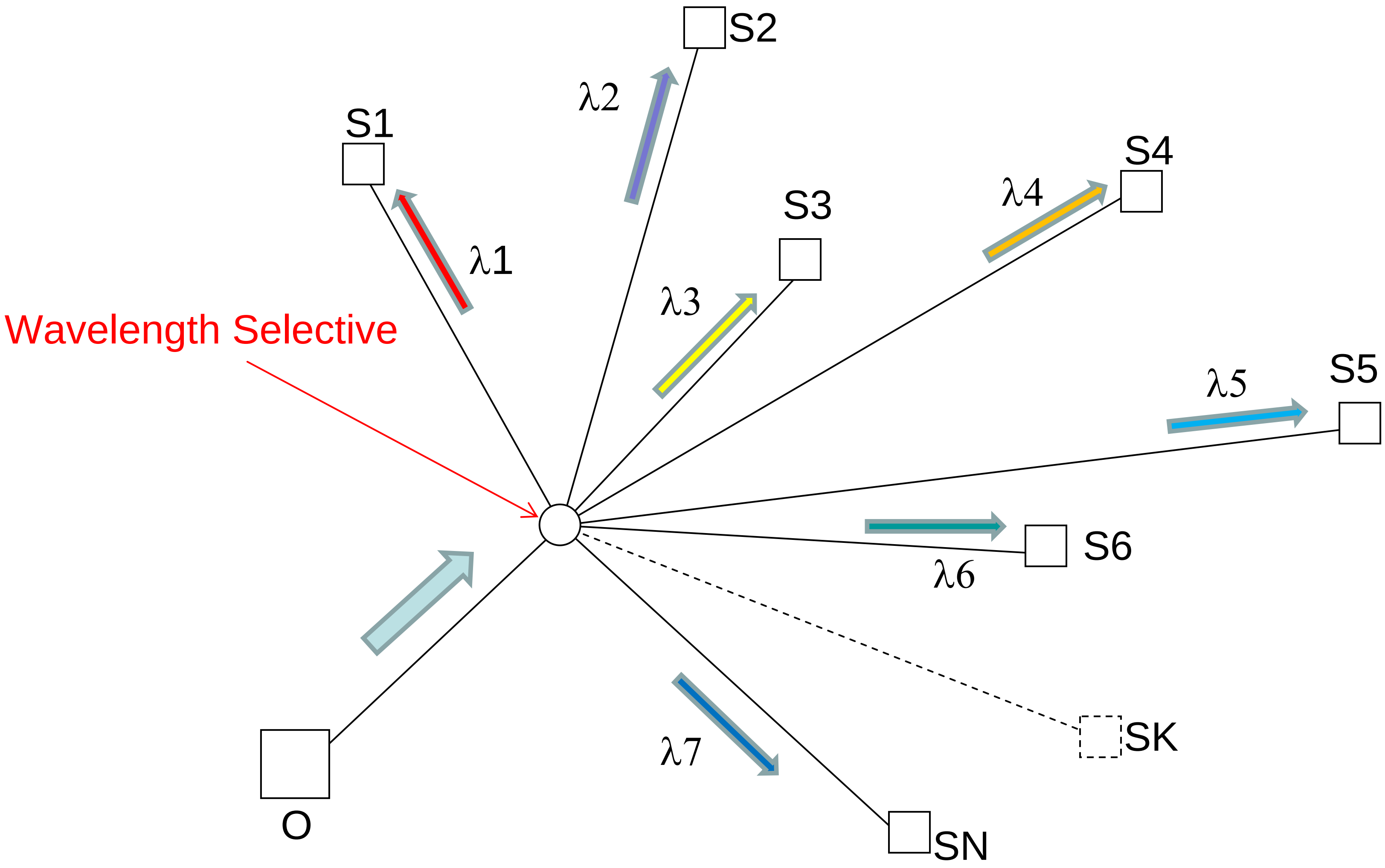
Launch: 10dBm

Required OSNR: 20dB

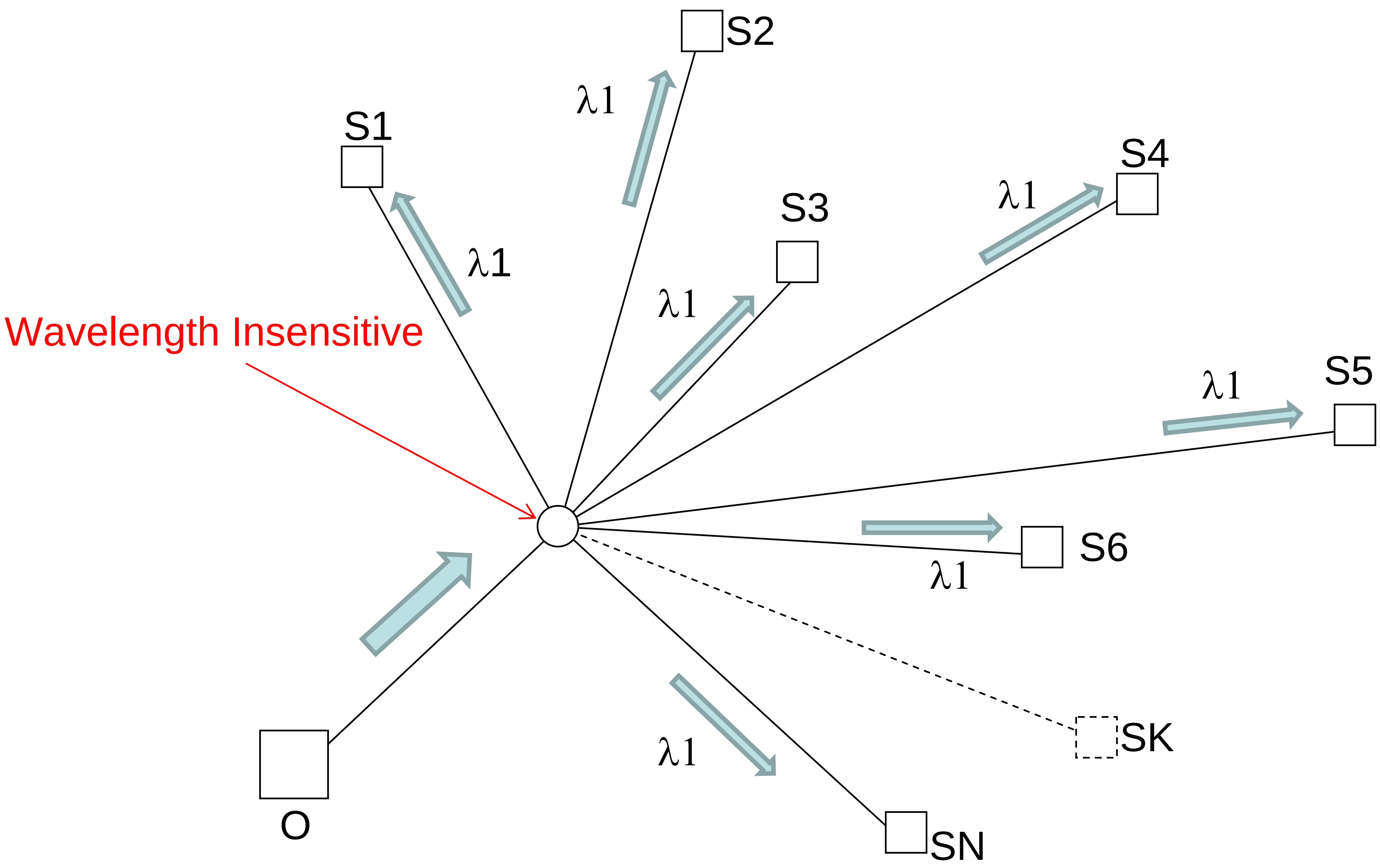
Loss: 0.25dB/km, R~5dB

Reach < 10km

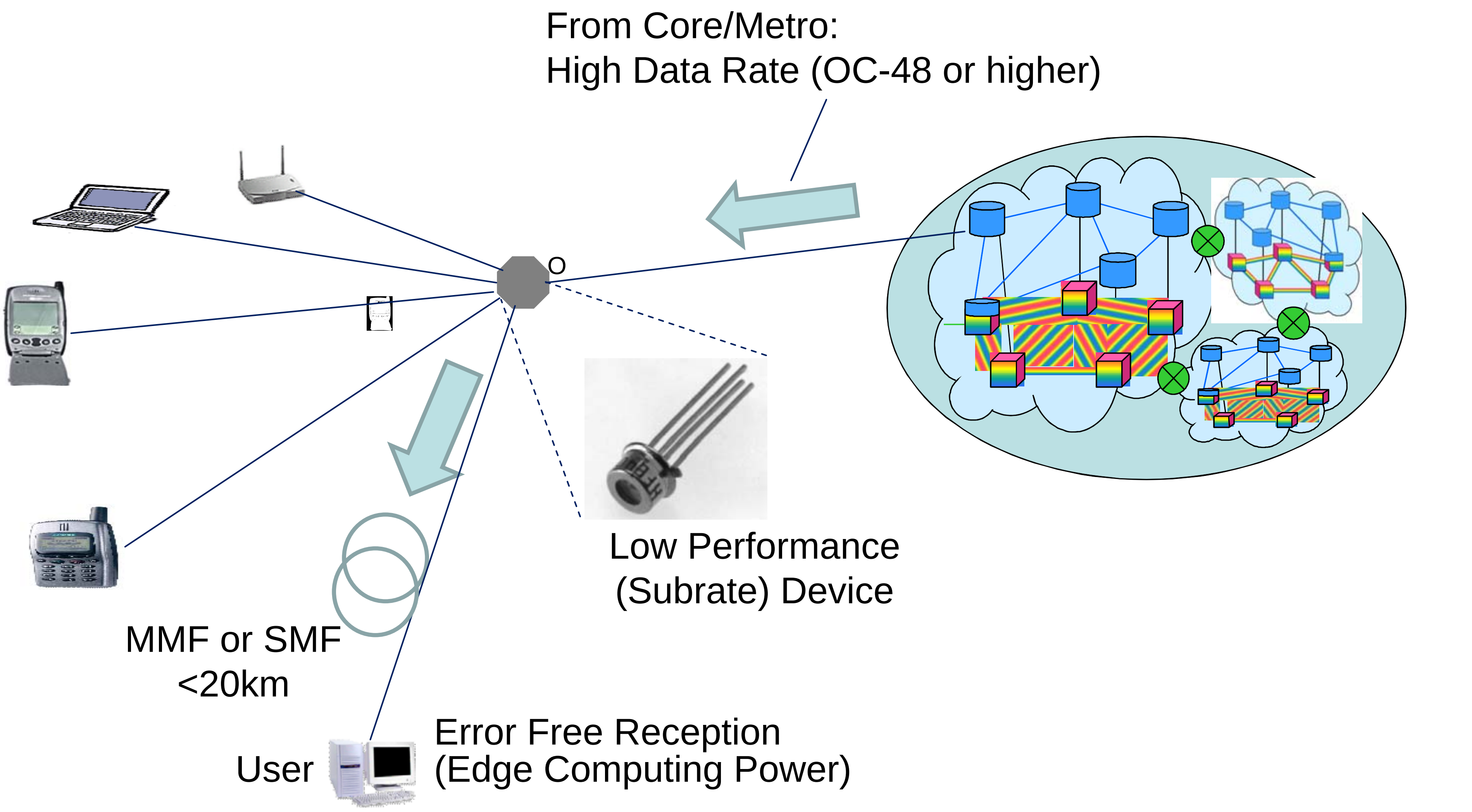
Option 1: Wavelength Diversity



Option 2: Monochromatic

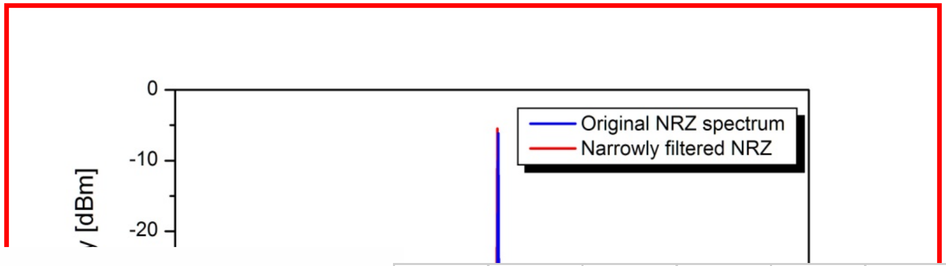


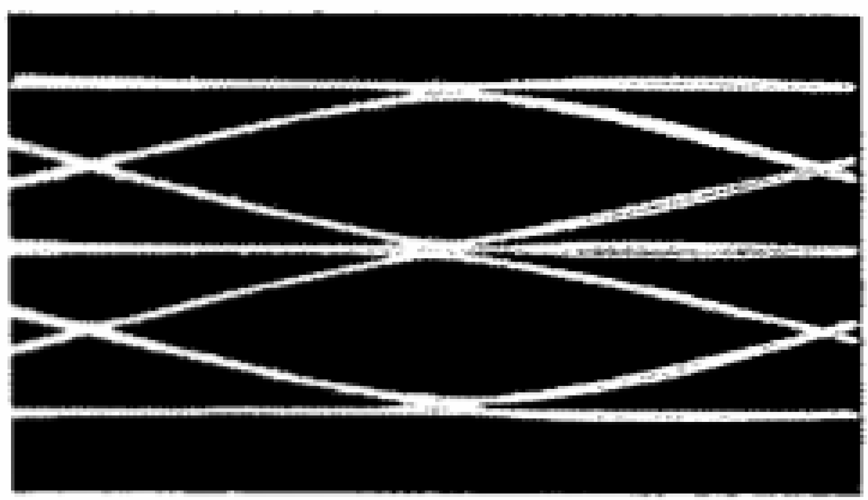
2) Scalable Data Rate over Access (Low-Grade) Infrastructure



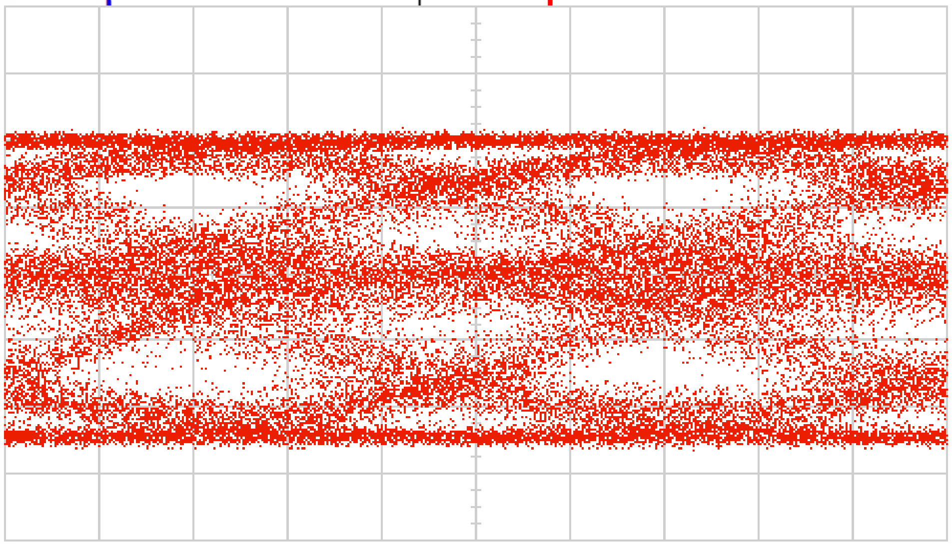
Principle:

Compress the Spectrum and Any Infrastructure is OK





b = 3



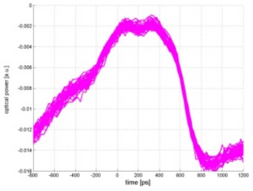
Correlative Digital Communication Techniques
Lender, A.;
Communications, IEEE Transactions on [legacy, pre - 1988]
Volume 12, Issue 4, Dec 1964 Page(s):128 - 135

Price is paid by computational resource at the end user.

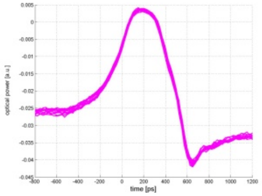
VCSEL/MMF Access

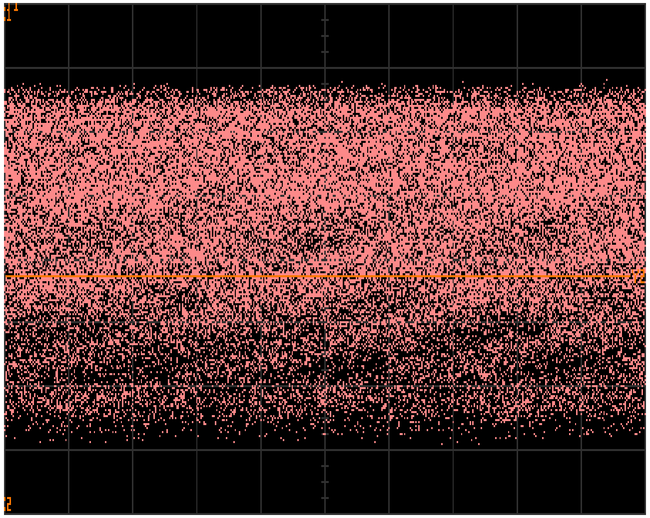
Directly modulated laser diode and propagation in multi-mode fiber (MMF)

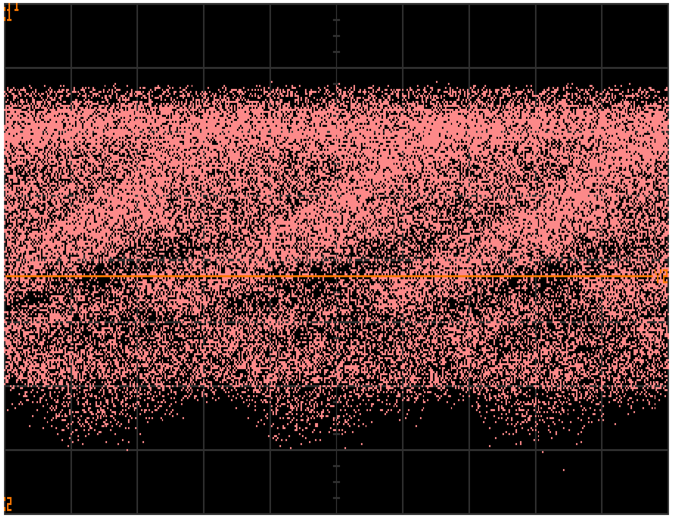
Bit-by-bit BER ~0.1



Eye diagrams after 400 m of legacy 62.5 μm MMF for 2 launch conditions







Processed BER < 10^{-7}

Processed BER ~ $5*10^{-6}$

N. Alic et al, "Sequence Estimation with Run-Length Coding for VCSEL-Based Multimode Fiber Links," in Proc. CLEO 2005, Paper CWG7, Baltimore, MD (2005).

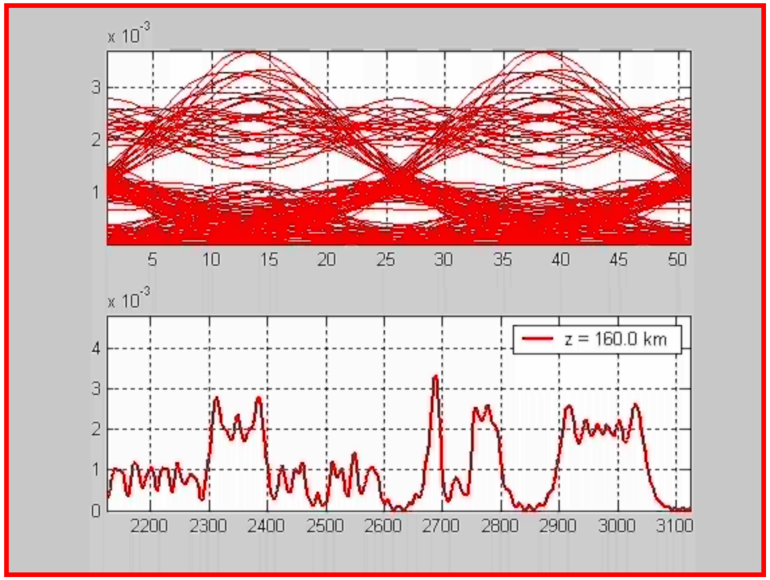
MMF/VCSEL Access

- Of particular interest is the ability to equalize both the laser/driver (VCSEL) and MMF response at the same time
  - Laser diode frequency response depends on the biasing current (higher biasing current is needed for higher frequency response)
  - Laser diode life-time and reliability are inversely proportional to the square of the biasing current.
  - Hence, the life time and reliability can be significantly extended by biasing the laser diodes below their specified value. (this, however produces ISI, which in turn can be taken out by equalization).

Equalization vs. Compensation

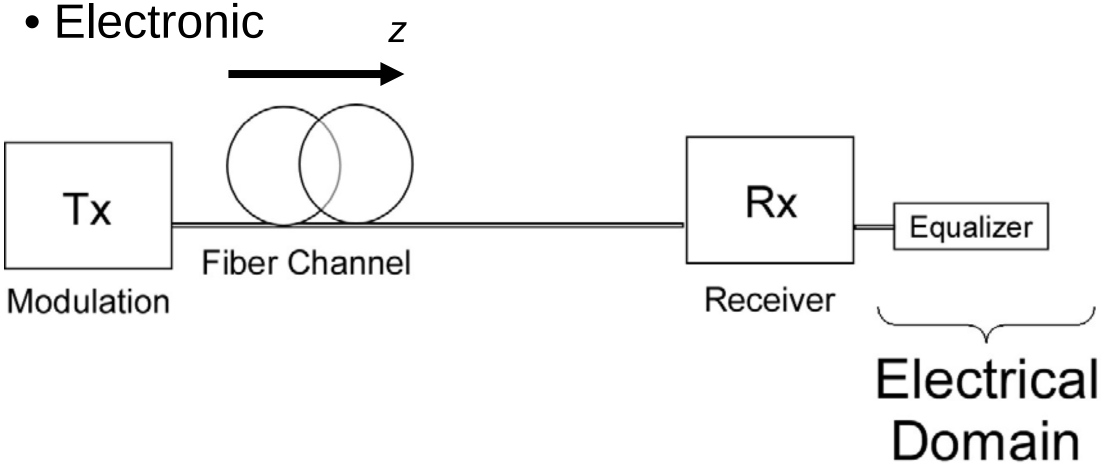
- Chromatic dispersion (CD, GVD)
- Polarization mode dispersion (PMD)
- **Multimode fiber dispersion (data-comm.)**
- **Use of lower rate electronics**
- **Imperfect components**

Eye diagram



Bit-stream

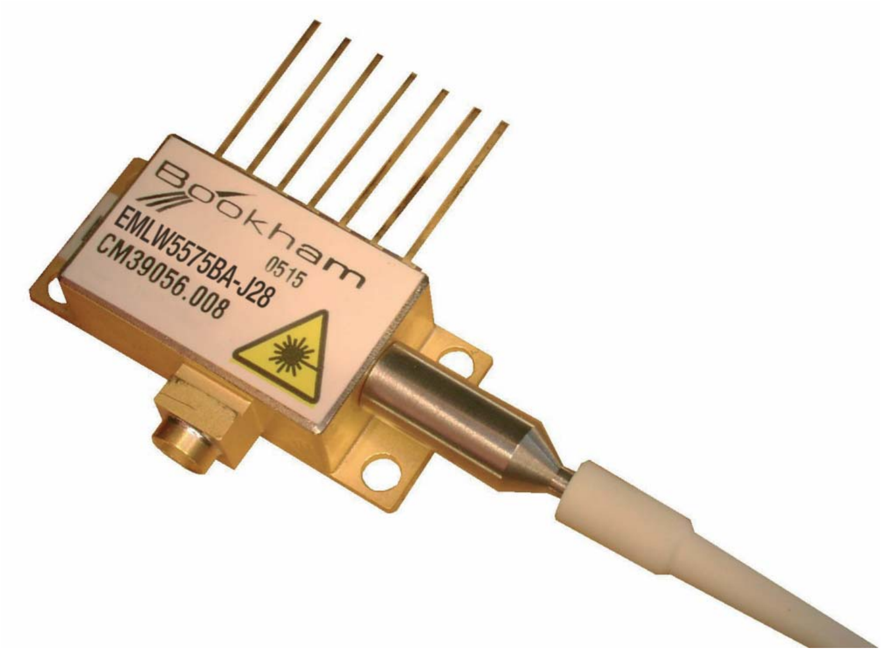
Impairments mitigation:
- Optical
- Electronic

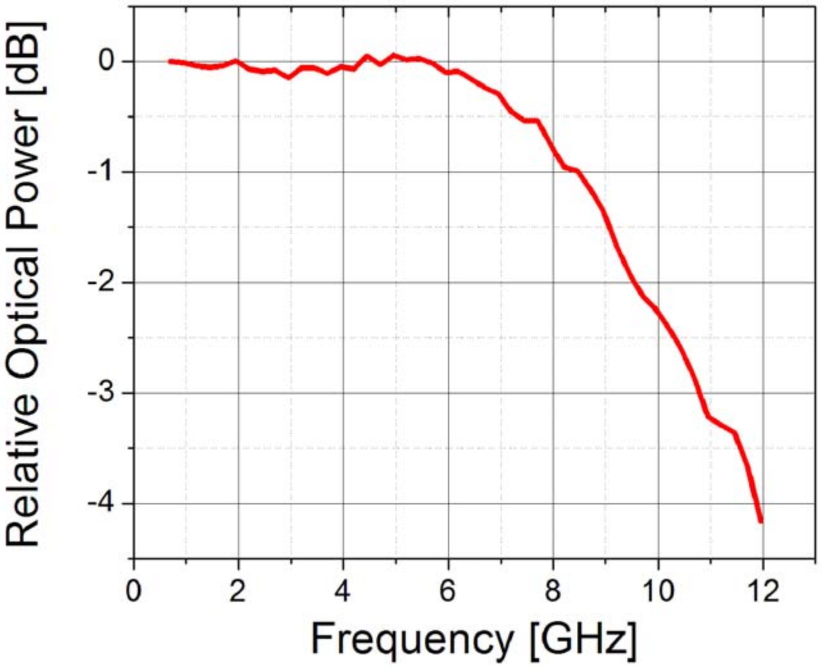


Equalizers:

- Adaptive
- Low cost

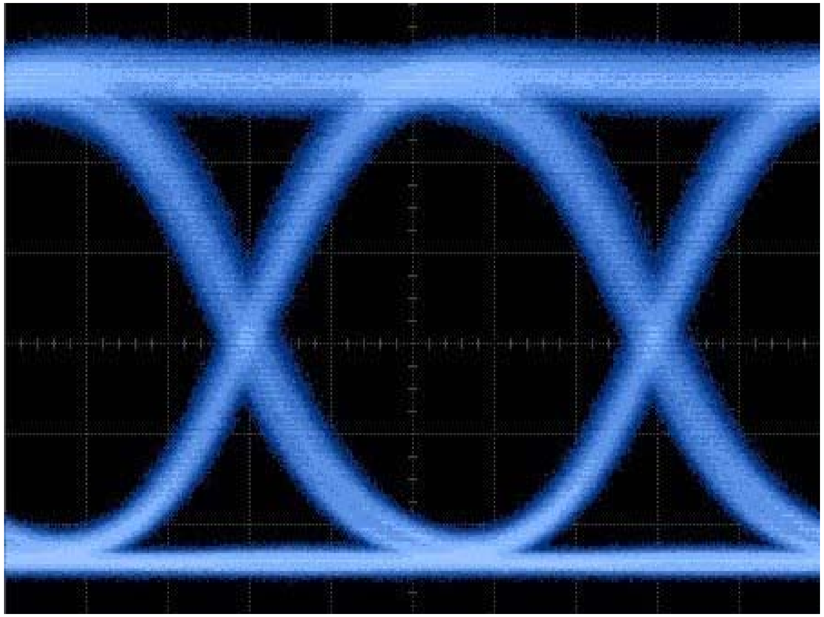
Sub-OC-192 EML for OC-768 Access



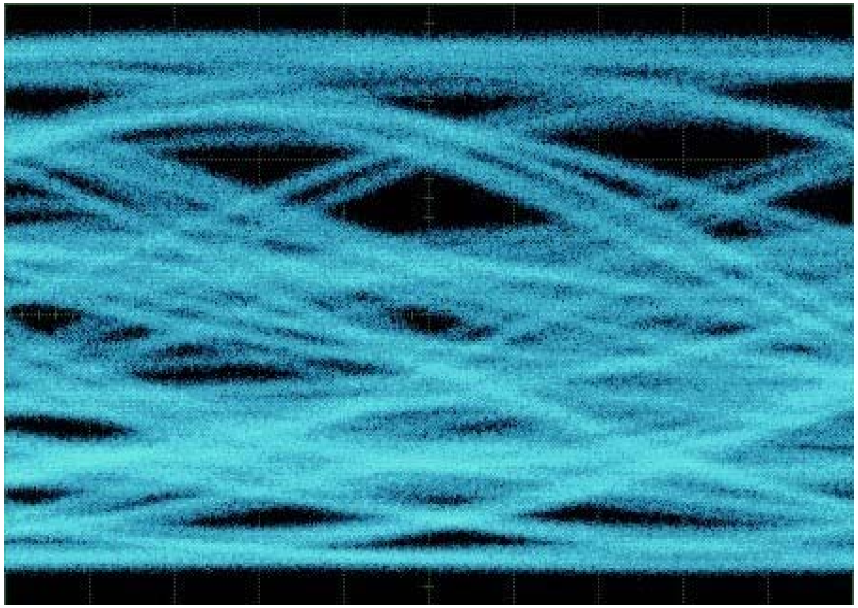


Sub-OC-192 EML for OC-768 Acces

EML modulated at 10Gbps

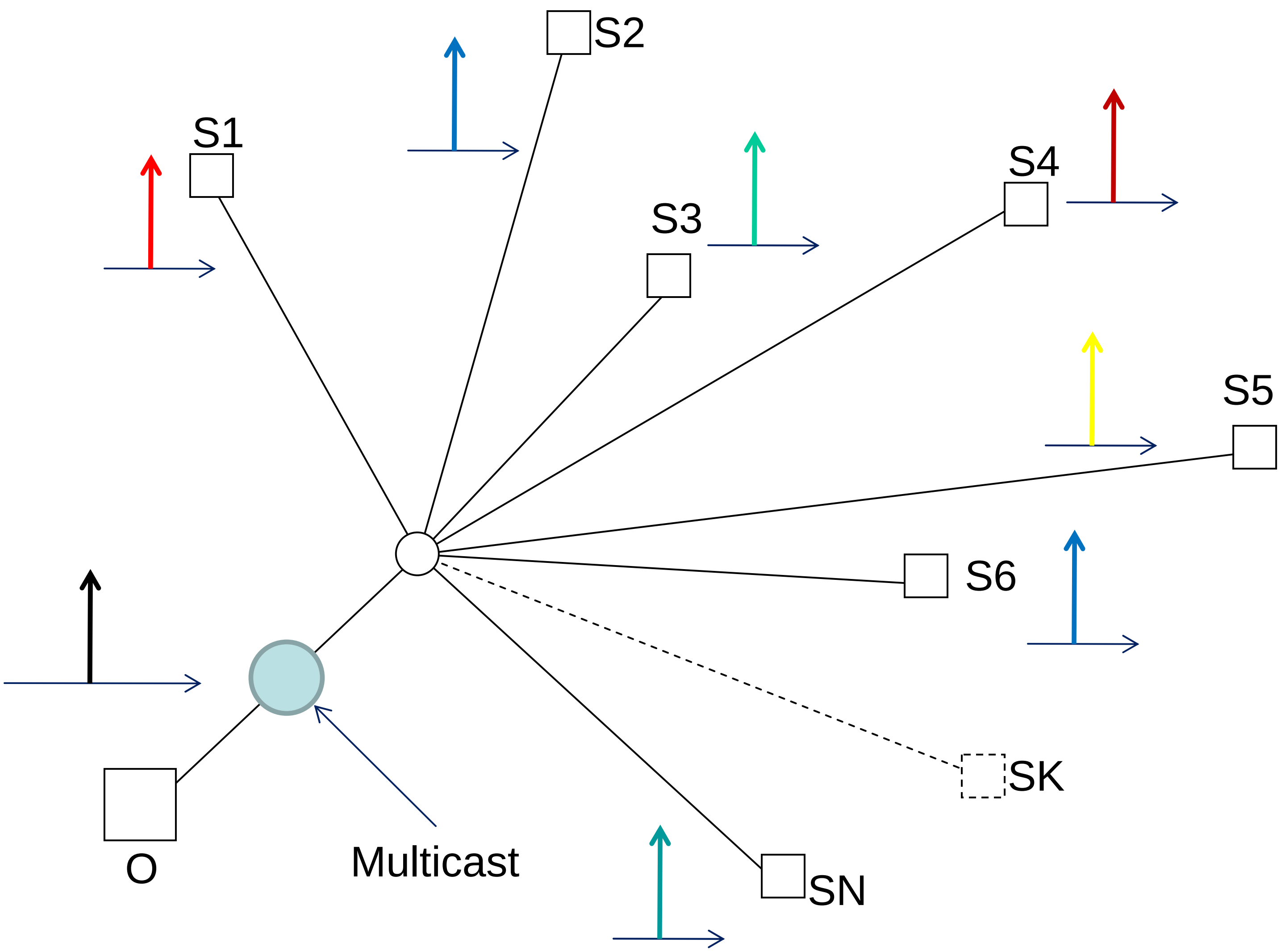


EML modulated at 40Gps

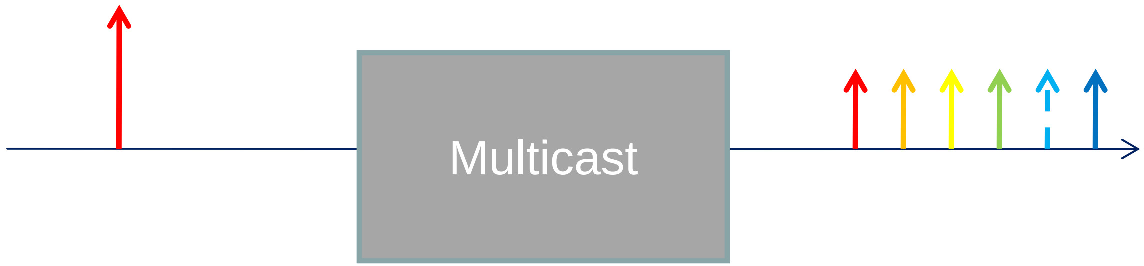


Readily transportable over any access scale (<20km), ECOC 2007.

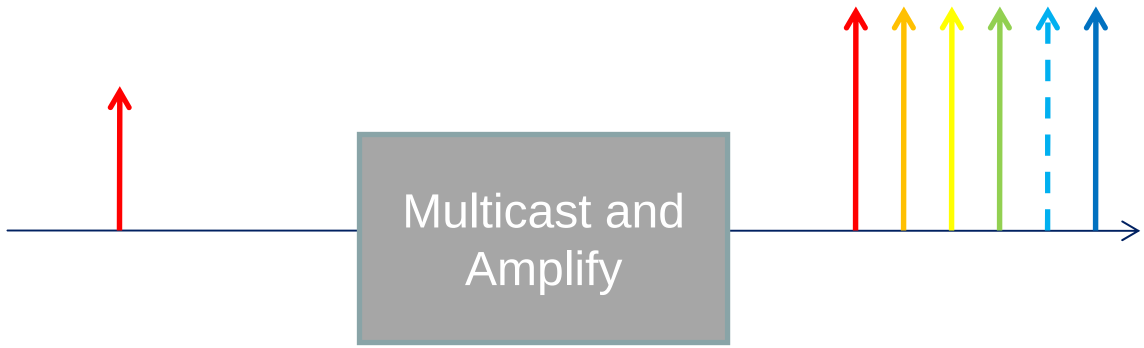
3) Scalable Multicasting and Band Mapping



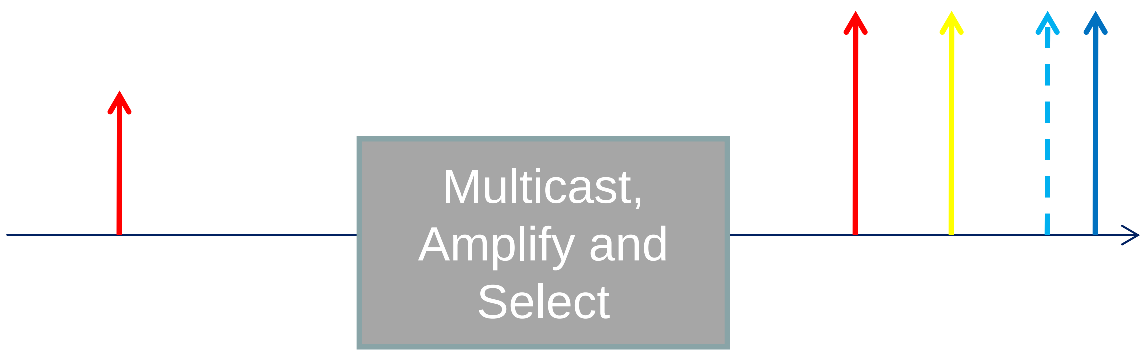
Multicast 1



Multicast 2



Multicast 3



Candidate Technologies:

FPM

1) SOA
2) Si
3) Fiber
4) NL

Receive-and-Multicast

4) Wireless Support

The future user:

1) Wants to be untethered

2) Demands High Bandwidth

3) Is not concerned with statistical, but instantaneous capacity

4) Wants to move freely on local and global scale

5) Cannot predict the nature of services needed in near-term

Assumption:

1) The wireless user will drive the optical access

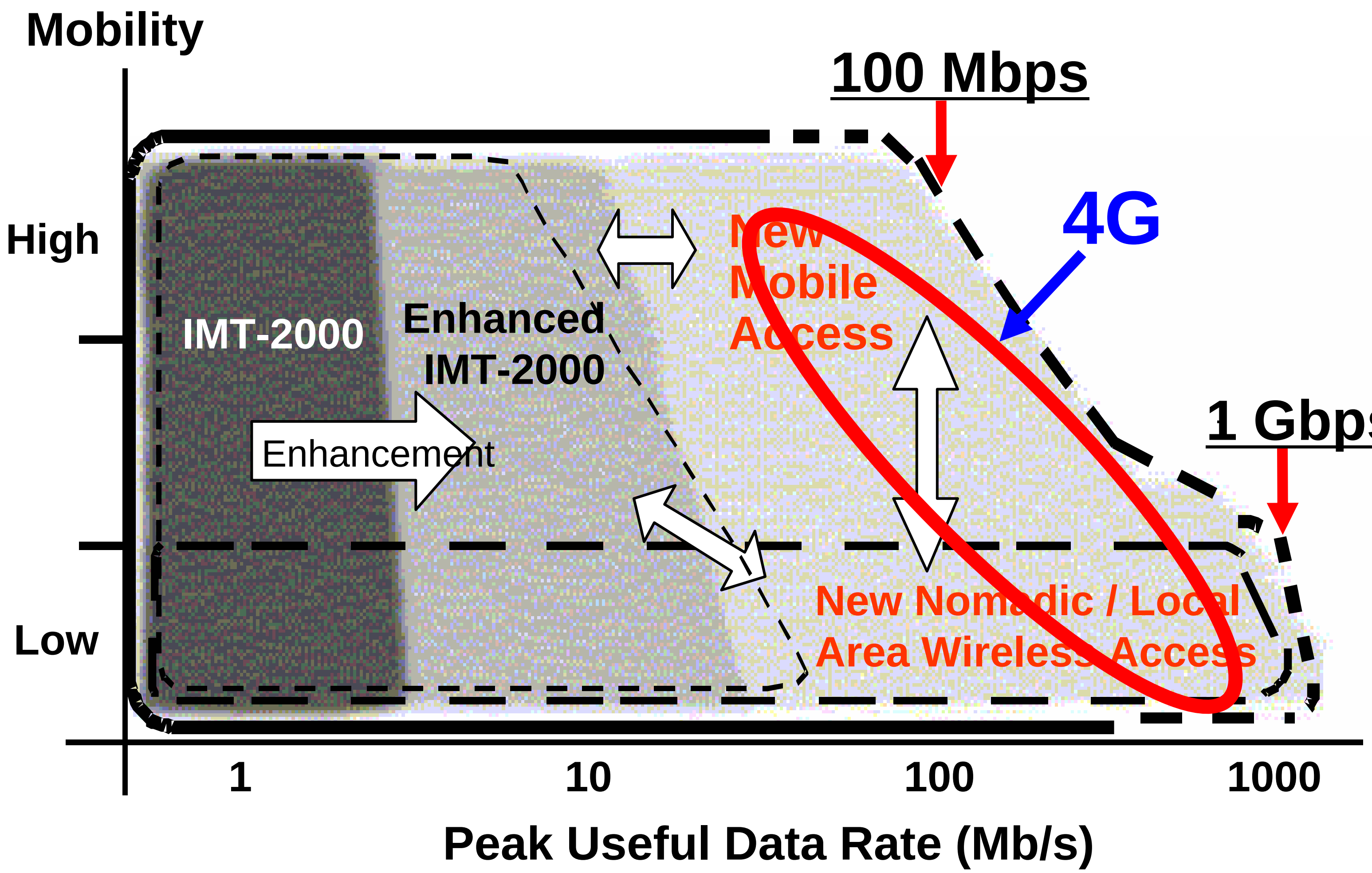
2) Segmentation into fixed, mobile and quasistationary

Targets:

- >100 MBps High Mobility

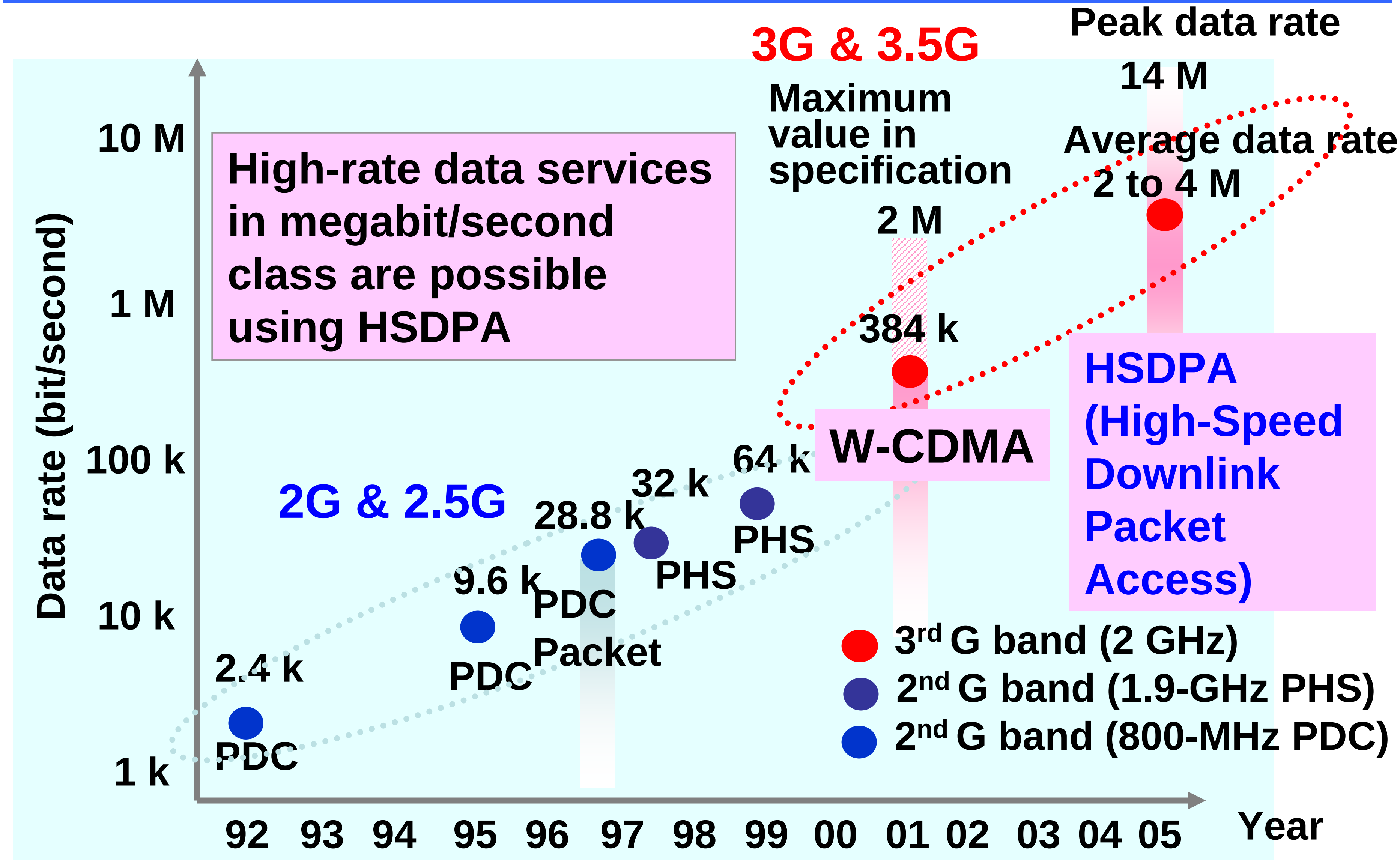
- >1 GBPs Low Mobility

- >10 GBPS Quasistationary

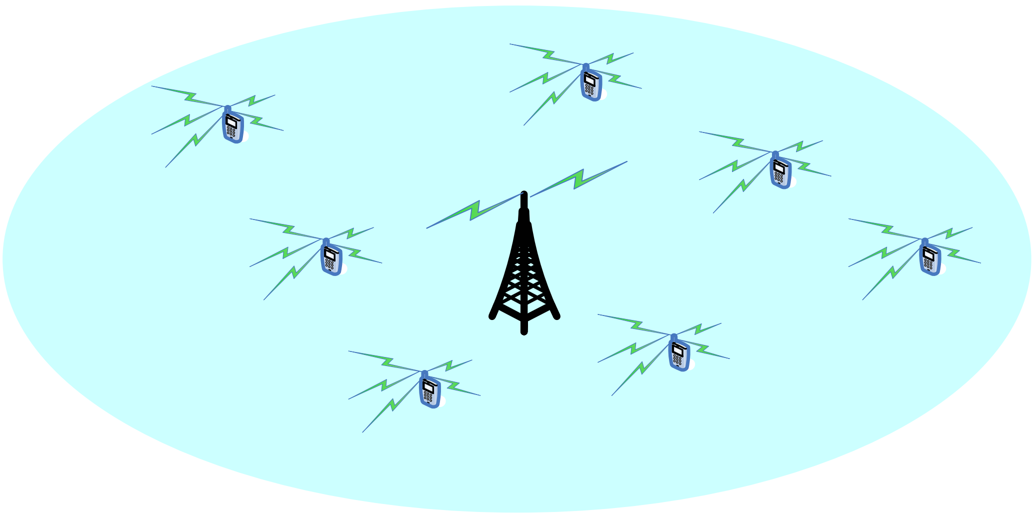


Extracted from ITU-R Recommendation M.1645

Achievable Data Rate in Cellular Systems in Japan



What we have mastered

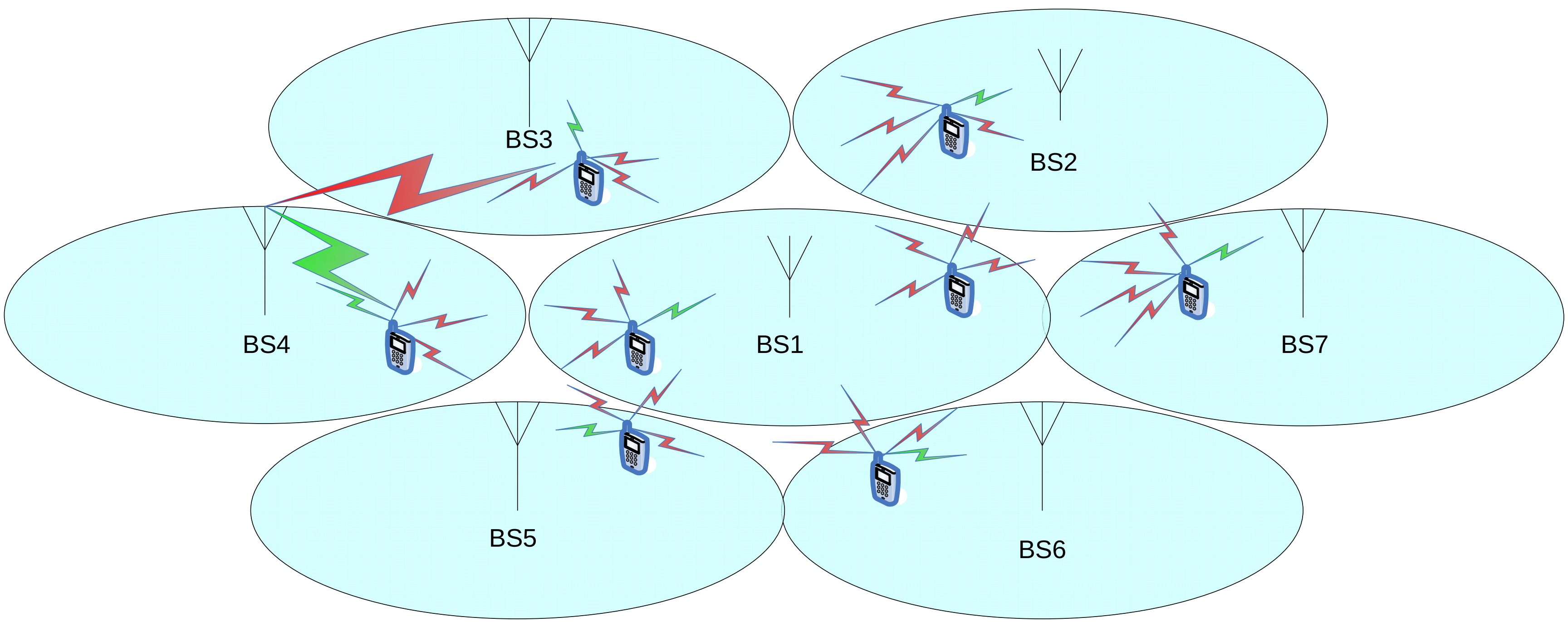


Single-cell Multiple Access Wireless System

- **Capacity achieving techniques are being implemented, e.g. Interference Cancellation (IC) at the BS**
- **Fading is being exploited rather than fought**
  - » **Opportunistic Transmissions, e.g. Multiuser Diversity**
  - » **MIMO**

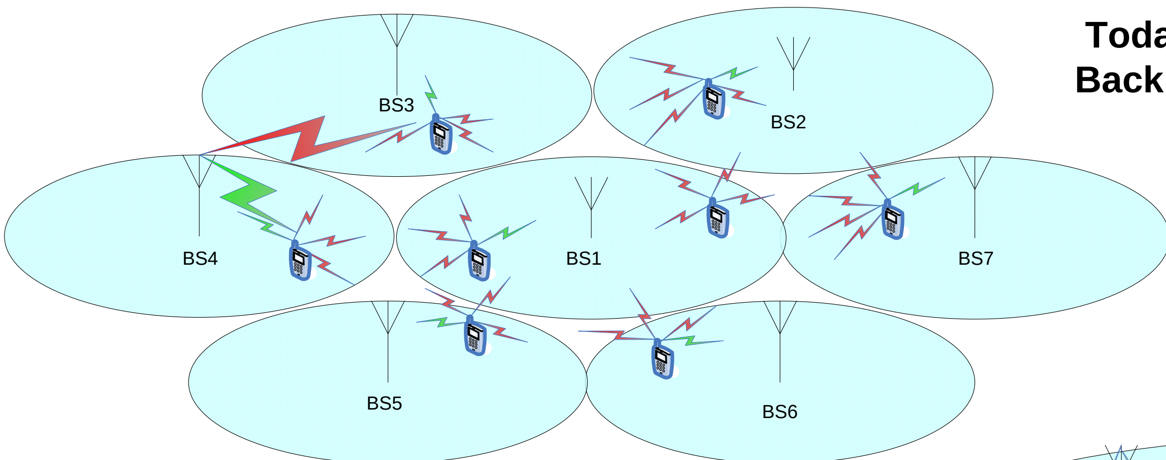
What we have not quite mastered

- **Other-cell (or inter-cell) interference**
- **It is either avoided (minimized) through frequency reuse and costly degrees of freedom are lost**
- **Or it is treated as noise and we live with it**
- **But if I can cancel interference within one cell, can't I do the same for inter-cell ? With access to the right information, yes.**

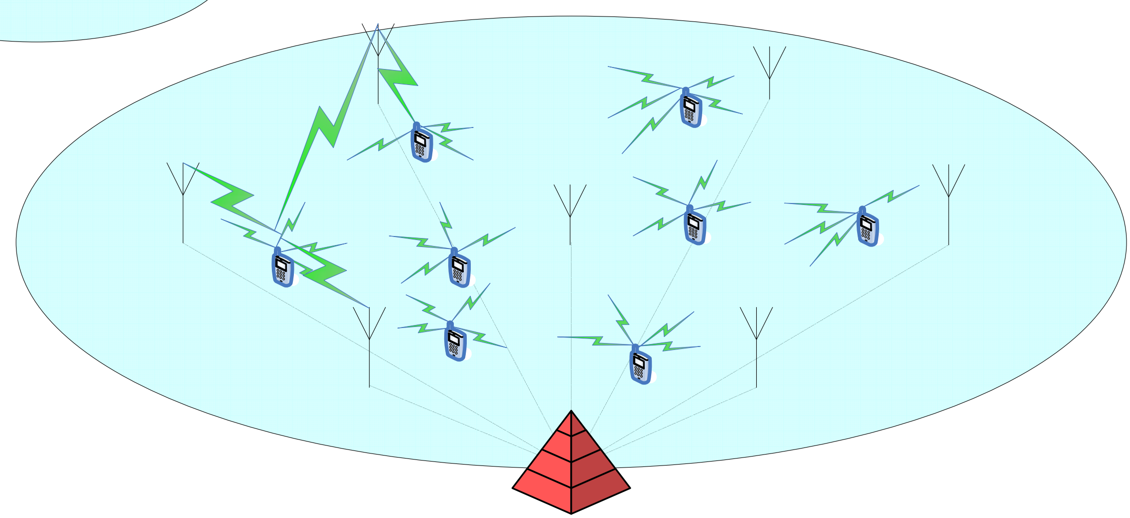


The question(s)

- **What are the uplink and downlink capacities of a system where the BS's operate as remote antennas of a centralized processing site?**
- **What are the capacity achieving strategies?**
- **How do they compare to the conventional approach ?**



Today: Distributed processing at each cell. Backhaul carries decoded information bits.



Tomorrow(?): Centralized processing. Backhaul must carry a lot more!

Optical Edge Architectures

- Conventional (super)cell architecture at the limit – no major increase by more complex coding expected
- Present status: cell multiplicity addressed (cancellation of interference) but not exploited
- End user demands to be **qualitatively** higher (10x-100x) bandwidth
- Cells seen as a collective in the future – not an isolated or autonomous constructs
- Size of the supercell fundamentally defined by the latency:
  few hundreds of microseconds acceptable; a millisecond excessive
- Physical size of the supercell distribution ~10-20km

Key Questions:

Uplink/Downlink Capacities from remote antenna to a central processing site

Supercell size that allows:

- Maximized capacity
- Interference Cancellation

Uplink Capacities: RF- or Optical backbone?

To digitize or not to digitize at the remote antenna?

Speed and complexity of remote ADC?

Carrier frequencies: sub-GHz, ~3GHz or 60GHz?

Analog transport: what is the system gain?

Coordinated samples to centralized processor: To Digitize or Not

ADC RF Signal – then transport over optical link

Governed by ADC status:

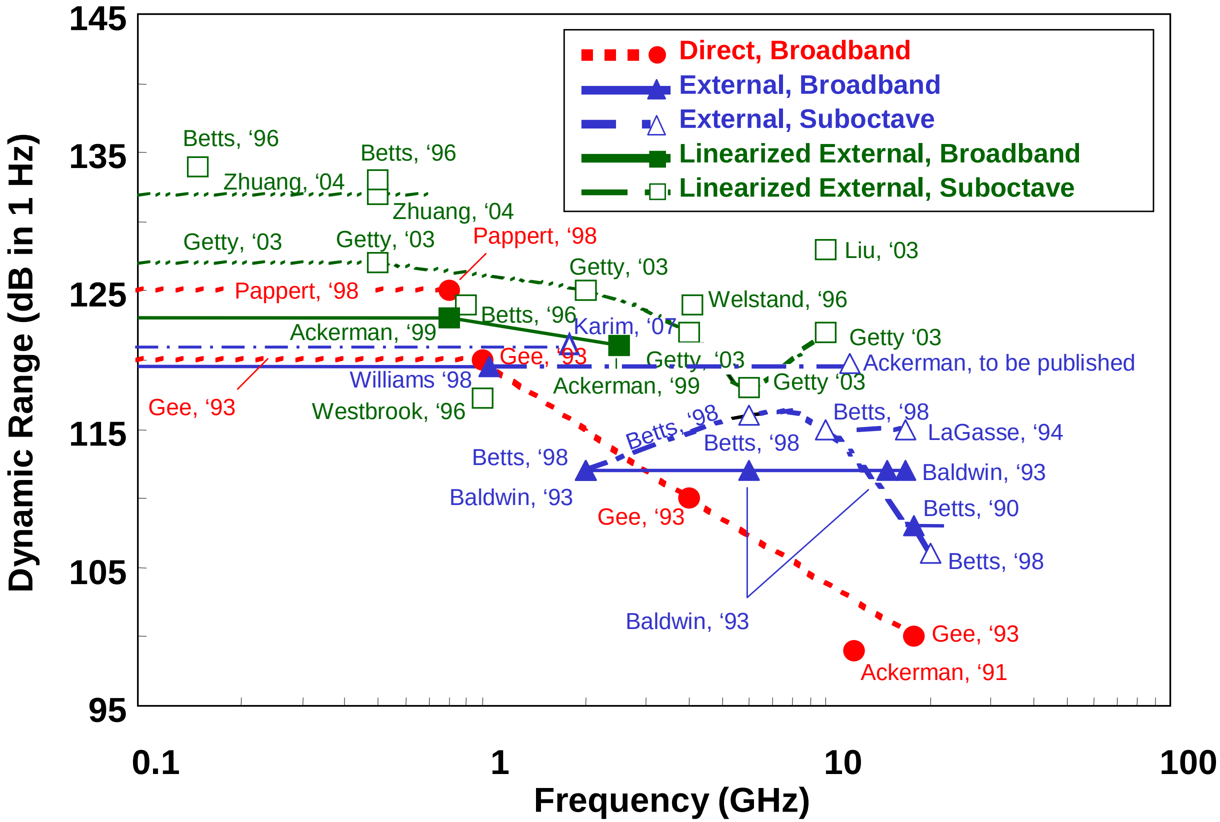
- Few Gbps rate now, coarse resolution (<6bit)
- ~5Gbps, 8-bit in few years
- Is advanced ADC "fieldable" at the remote antenna?
- Latency penalty from remote ADC/processing? (Estimate >100microsecond)

Digital transport:

- Fiber – no capacity limits
- RF-line-of-sight-hops (60-80GHz carrier) <500m
- Hybrid: Fiber for non-line-of sight and fat pipelines; RF-links
- For line-of-sight, limited to Gbps rate

To Digitize or NOT - Analog Links:

Very high rate backbone
Eliminates the need for ADC
Compatible with ~10km transport



Intel 24 GHz Base-Station 1 Gbps System