Coherent Optical Access Networks

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Abstract: Coherent technology is the only viable solution to fulfill requirements regarding data rate, reach and splitting factor for optical access. Cost of optics is compensated by savings in system design to achieve an economic solution.
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1. Introduction

Many operators state that the key requirements for the next generation optical access networks are a high symmetrical sustained data rate per user, long reach of 60 to 100 km and a high splitting factor of up to 1000 [1,2]. As a user data rate of 1 Gbit/s for a splitting factor of 1000 adds up to an un-aggregated data rate of 1 Tbit/s on the access fiber, Time Division Multiplexed (TDM) systems are impractical for the price sensitive access market. A hybrid TDM and Wavelength Division Multiplex (WDM) scheme, although promising, is not practical to meet the requirements either. In our view, a pure WDM system in which each user receives his own wavelength is the only viable solution.

Wavelength selective elements such as Arrayed Waveguide Gratings (AWG) in the optical distribution network are not suitable, as they need to be athermal, require modifications in outside plants where legacy PON systems are deployed, and cannot easily support 1000 ports.

Long reach and high passive splitting factor result in high optical attenuation. To support 1000 wavelengths within the C-band requires tight channel spacing and hence very highly wavelength selective receivers. Coherent reception offers both the needed high sensitivity as well as the wavelength selectivity; therefore, is the only potential means to fulfill the requirements. This paper describes the concept and preliminary implementation results.

2. System description

Figure 1 shows the high level system concept. The long distance office is connected to the optical core network and interfaces towards the access side. The Optical Line Terminal (OLT) provides up to 1000 wavelengths in an ultra dense wavelength grid in the C-Band. Standard passive, non-WDM, splitters distribute all downstream wavelengths to all Optical Network Units (ONUs) where the assigned wavelength is selected by coherent detection. A tunable laser in the ONU provides the upstream signal which is locked on to the downstream with a small frequency offset. Additional details can be found in [3,4].

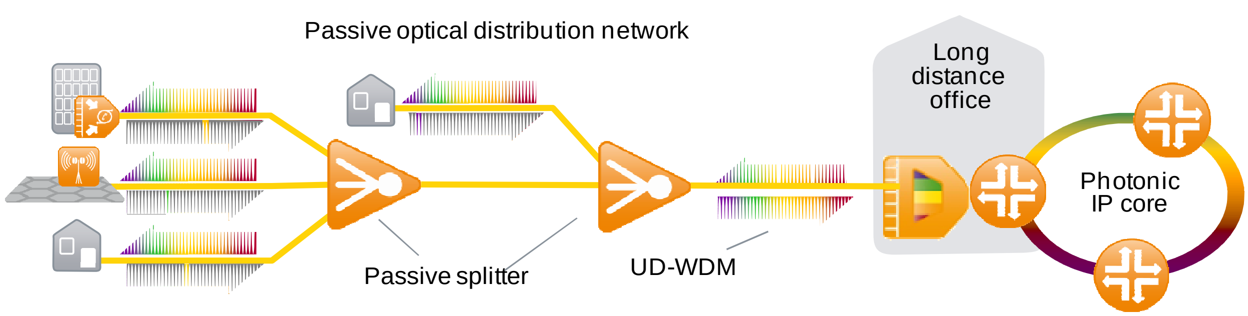

Figure 1: High level system concept

3. Implementation and results

The system is based on three main technological ingredients: 1) *coherent detection* to enable high sensitivity, thus long reach and high split, 2) *electronic signal processing* to mitigate for distortions due to cost optimized components and 3) *photonic integrated circuits* to bring the relatively complex optics into a cost position suitable for the access market.

Figure 2 shows the block diagrams of ONU and OLT. In the OLT, 8 wavelengths are generated from a single laser source by means of multiple subcarrier modulation with an IQ modulator. The multiple electrical subcarriers are generated digitally out of 8 discrete 1.25 Gbit/s data inputs. The same laser which is used for downstream transmission also serves as the local oscillator for the coherent reception of the upstream signals. A wideband photodiode receives the 8 upstream wavelengths which are generated by ONUs corresponding to the downstream wavelengths. After analog to digital conversion, an FPGA then digitally down converts and decodes the optical signals to recover the upstream data. Up to 128 of such 8-wavelengths groups are then combined onto the fiber to form a 1024 wavelength system.

In the ONU, a tunable laser serves as a local oscillator source for the coherent receiver. Heterodyne reception with an Intermediate Frequency (IF) of approximately 1 GHz is used and therefore no optical 90° hybrid is needed. The IF signal is digitized and a real time processor recovers the received data. The same tunable laser is used for the upstream transmission as well. Its light is modulated in a DQPSK modulator and sent upstream. As the downstream reception uses a heterodyne scheme with an IF of 1 GHz and the upstream signal is derived out of the laser directly, downstream and upstream wavelengths are interleaved.

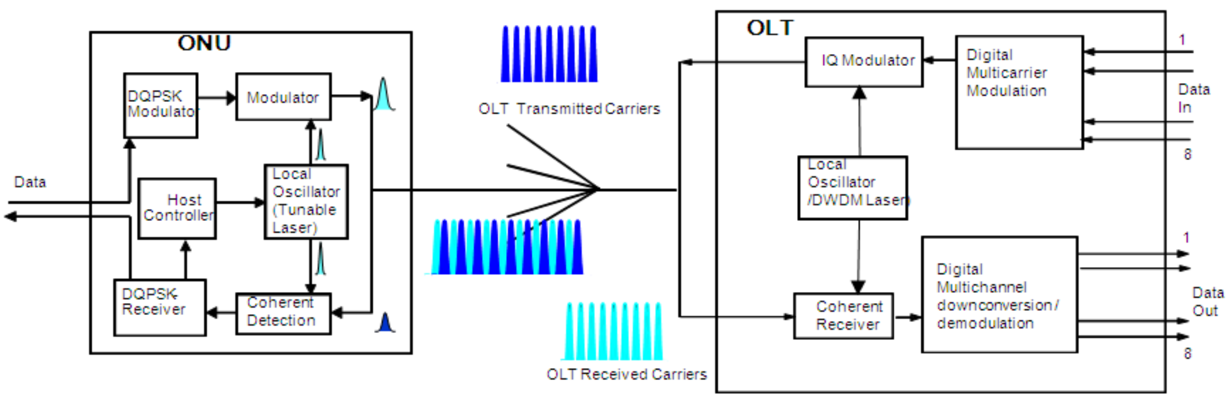

Figure 2: Block diagrams of the OLT and ONU

The detailed wavelength scheme is shown in Figure 3. Part a) shows the upstream and downstream channel spectrum in the ODN. The blue bars depict the downstream wavelengths and their frequency offset relative to the source laser. The basic unit of the wavelength offset is represented by Δ which is approximately 1 GHz. The first two channels are offset by ±2Δ from the source laser. The subsequent channels are separated by a spectral distance of 3Δ. The resulting frequency offsets with regard to the laser source are depicted in the lower part of Figure 3 a).

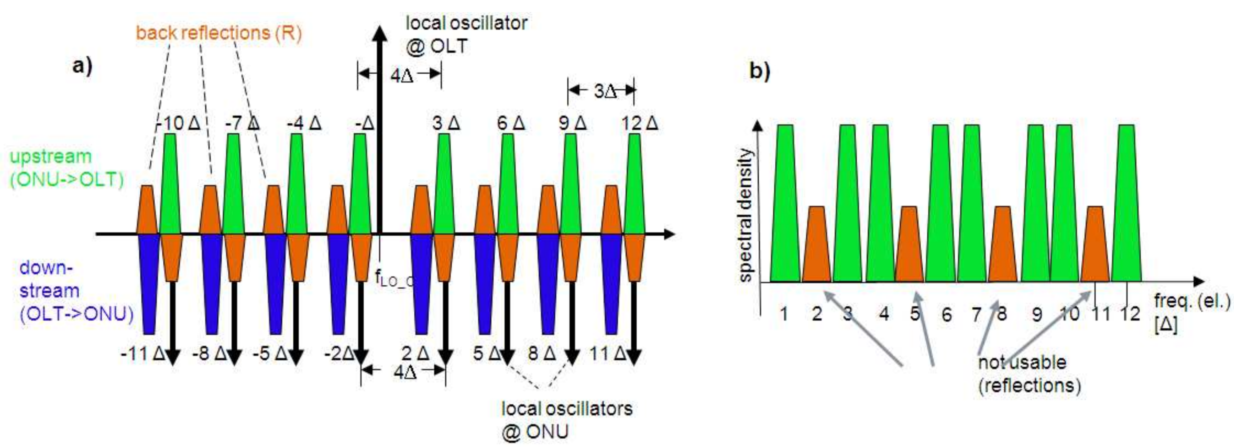

Figure 3: wavelength plan. a) Optical spectrum on the fiber, b) electrical spectrum at OLT receiver

In the upstream direction, the ONU tunes its local oscillator tunable laser to a fixed frequency offset of +Δ with regard to the downstream wavelength. The resulting frequencies are depicted in Figure 3 a) in the upper part. Any back reflections from the downstream wavelengths fall therefore in frequency bands which are disjunctive from the upstream light. Figure 3 b) shows the resulting spectrum at the OLT where the same laser generating the downstream wavelengths is used as a local oscillator for upstream reception as well. In the electrical domain, negative relative optical frequencies are mirrored into the positive frequency domain, so that the resulting electrical spectrum appears as shown. Any back reflections appear in bands which are not evaluated by the digital multichannel receiver.

A laboratory system demonstrating the operating principle is currently under construction at NSN. The system comprises a fully integrated tunable ONU module, an OLT providing 4 independent channels generated from a single laser by means of single sideband modulation, analog amplification and filtering, and real time data processing. The necessary algorithms for wavelength scanning, channel acquisition, frequency lock and clock and data recovery are implemented on-board and real time using 24-lane parallel processing in an FPGA. Standard 1000 Base-T connections are used to interface to test equipment and broadband applications such as video servers.

Figure 4 a) shows an initial measurement of the sensitivity of the system. These data have been taken using DBPSK at 311 Mb/s. Although the lower symbol rate increases the requirements on the laser linewidth and stability, it eases the challenge to the analog RF amplifiers, which in the current implementation limit the bandwidth of the demonstrator. Work on transmission with 1.244 Gbit/s and DQPSK modulation is in progress and results will be presented. For 311 Mbit/s, the sensitivity is -53 dBm for the FEC limit of BER=10^{-3}. For 1.244 Gbit/s, although a lower receiver sensitivity is expected, an improved integrated PIC with a higher LO power is planned to be used to compensate for the higher data rate, resulting a comparable sensitivity as in the case of 311 Mbit/s.. Two different RF amplifiers have been evaluated in this test, resulting in slightly different performance and showing the influence of the signal processing chain after the coherent receiver.

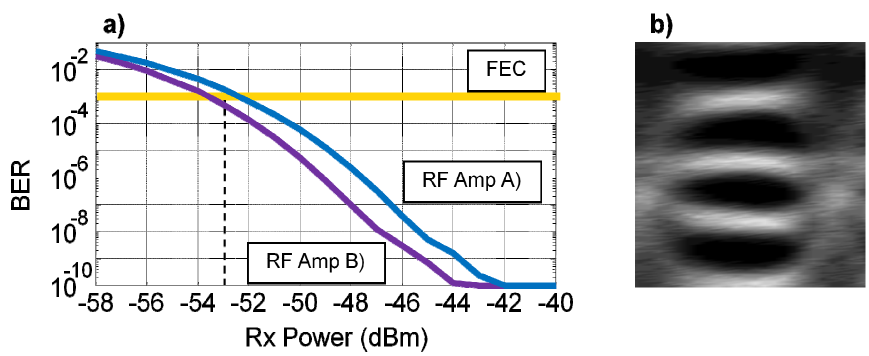

Figure 4: a) BER curve, b) (Pseudo) Eye diagram

Figure 4 b) shows a pseudo-eye diagram for the 1.244 Gbit/s downstream transmissions, generated from the electrical IF signal after the photodiode of the coherent receiver. It can be seen that the bins for the four difference angles of the DQPSK modulation scheme are well separated.

4. Conclusions

The technical feasibility of a coherent optical access system has been demonstrated, using digital signal processing and photonic integrated circuits. Such systems are the only ones which fulfill the requirements of the network operators regarding reach, split and data rate as well as regarding the Metro and Access consolidation. The slightly more expensive optics is therefore more than compensated by the savings in the rest of the system, thus delivering an economic solution for the optical access market in the near future.

5. References

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