OCDMA with advanced modulation formats

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Outline

- Background
- DPSK/DQPSK-OCDMA
- CSK-OCDMA
- Summary
The last mile problem

Bandwidth requirement for next-generation services (ethernet, video, voice and etc.)

Optical access

Promising for future last mile networks.

**TDMA**  
Time-Division-Multiple-Access

**SCMA**  
Sub-Carrier-Multiple-Access

**WDMA**  
Wavelength-Division-Multiple-Access

**OCDMA**  
Code-Division-Multiple-Access

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Features and advantages of OCDMA

- All optical processing
- Fully asynchronous transmission
- Low-latency access
- Dynamic allocation of bandwidth
- Protocol transparency
- Decentralized architecture
- Soft capacity on demand
- Physical layer QoS Control
- Potential confidentiality
Classification of OC processing techniques

By coding dimension

1-dimensional
Time-spreading (TS)

2-dimensional

By operating principle

Incoherent

Coherent

Channel 1
Channel 2
Channel N

Incoherent: FDL, PLC, SSFBG, AWG

Coherent: SLM, FBG, AWG, MRR

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OOK-OCDMA: Coherent coding, OOK data format

\[ Z = T_c \Re P_d + T_c \Re \sum_{i=1}^{m} P_i + 2\Re \sum_{i=1}^{m} \sqrt{P_d P_i} \int_{0}^{T_c} \cos(\omega_{i,d}(t, \tau_i) + \phi_{i,d}(t, \tau_i)) dt + 2\Re \sum_{j=i+1}^{m} \sum_{i=1}^{m-1} \sqrt{P_d P_j} \int_{0}^{T_c} \cos(\omega_{i,j} t + (\omega \tau)_{i,j} + \phi_{i,j}(t, \tau_{i,j})) dt + \int_{0}^{T_c} n_0(t) dt \]

Signal  MAI  Signal-interference beat noise  Interference-interference beat Noise  Receiver noises


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Issues with OOK-OCDMA

a. MAI and beat noise

Data-rate detection in presence of MAI and beat noises
Noise tolerance enhancement

b. Vulnerable confidentiality

Eavesdropper
Data-rate power detection
Break without code information

C. K estimation and dynamic Th setting Requirement

Complexity and cost

Advanced modulation formats (DPSK, DQPSK, CSK, M-ary CSK)
DPSK/DQPSK-OCDMA

DPSK-OCDMA: Coherent coding, Differential-phase-shift-keying data format

[Diagram of DPSK-OCDMA system with components labeled: Data, Optical PG, DPSK encoder, PM, Star Coupler, OCDMA Encoder, OCDMA Decoder, Interferometer, PD, 1-bit delay, MAI, Beat, Signal, Thermal, Shot, Noises, Integrals, and other related components.]
Performance improvement of DPSK-OCDMA

Theory

Number of active users

OOK, opt Th

511 chip

OOK, fix Th

DPSK

BER=6e-5

~4 dB improvement

-36
-32
-28
-24
-20

10
15
20
25
30
35

66
99
1717

Experiment

Maximum interference number (\(K\)) for BER=6\times10^{-5}

Single interference level \(\xi_1\), dB

3~4 dB improvement

Experimental set up of WDM/DPSK-OCDMA

- MLLD 1550.2 nm
- MLLD 1553.4 nm
- MLLD 1556.6 nm
- Tunable optical delay line
- Phase modulator
- LN-PM
- Bandpass filter
- PC
- WDM
- Spectrum
- 3.2 nm (400 GHz)
- 1nm/div
- Delay: 0, 10, ..., 160 m
- Port 1
- Port 16
- VOA
- Multi-ports OCDMA Encoder
- Pattern Generator/ BER
- Pattern Generator/ BI
- Pattern Generator/ BER test
- Pattern Generator/ Pattern Generator/ BER
- Interferometer (10.71 GHz)
- 20 ps/div
- Bandpass filter
- PC
- DPSK Encoder
- RF Amp.
- LN-PM
- Koganei
- Tokyo
- Koganei
- Yokohama
- Chiba
- Metro area
- 100 km installed fiber
- Tokyo
- Koganei
- 50 km
- 10.71 GHz
- Clock
- 20 ps/div
- 1 nm/div
- 400 GHz
- DPSK detection
- (30 GHz, 10.71 GHz)
- Bandpass filter
- Interferometer
- (−93 ps)
- 5 nm
- 20 ps/div
- Optical switch
- Waveform
- 3 WDM, 12 OCDMA, 10.71 Gbps/user
- Data Clock
- 20 ps/div
- 10 km
- SMF
- 20 nm
- 400 GHz
- Programmable OCDMA Decoder
- Code 4, 8, 12, 16
- Field area
- Metro area
- 100 km installed fiber
- Tokyo
- Koganei
- 50 km
- 100 km installed fiber
- Tokyo
- Koganei
- 50 km
- 100 km installed fiber

* X. Wang, et al, OFC’06 postdeadline, PDP44, 2006

**Koganei**

**Tokyo, Japan**
Back-to-back BER performance

Spectral efficiency ($\eta$) ≈ 0.32 bit/s/Hz
Field transmission BER performance

Asynchronous environment
- Balanced power
- Random delay
- Random bit phase
- Random polarization state

Worst-case scenario
\[ \eta \approx 0.27 \text{ bit/s/Hz} \]
Tera-bit WDM/OCDMA field trial

* X. Wang, et al, OFC’07 postdeadline, PDP14, 2007
Field transmission BER performance

OCDMA #: 25
Total capacity: 1.24 Tbps
\[ \eta \approx 0.41 \text{ bit/s/Hz} \]
DQPSK-OCDMA experiment

- Sync. DQPSK-OCDMA
- 4OCDMA*2PolM
- FEC
- $\eta \approx 0.87 \text{ bit/s/Hz}$

*J. Jackel et al, OFC’07 postdeadline, PDP7, 2007
CSK-OCDMA

CSK-OCDMA: Coherent coding, Code-shift-keying data format

Proposed scheme

Two-dimensional operation

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Experimental setup


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Enhanced confidentiality

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CSK-BD

Eye opening

Eye closure

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Enhanced multi-user capability

Decoder port 1 (Mark 0)  Decoder port 8 (Mark 1)  Balanced detection

K=1

K=8
BER performance

(a) LOG(BER) vs. Received Power, dBm

(b) PP, dB vs. Number of active users, K

Decoder #6

FEC OFF

FEC ON

K=1 K=4 K=8 K=12

K=14

Received power, dBm

* X. Wang, et al, ECOC’05 postdeadline, Th 4.5.3, 2005

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M-ary CSK-OCDMA

Summary

- Novel OCDMA schemes with DPSK, DQPSK, CSK and M-ary CSK data formats have been proposed and experimentally demonstrated.

- Performance improvement over OOK-OCDMA:
  1. Improved receiver sensitivity;
  2. Better tolerance to beat noise and MAI noise;
  3. No need for optical thresholding;
  4. No need for dynamic threshold level setting;
  5. Enhanced confidentiality.

- High capacity asynchronous OCDMA experiments with DPSK and CSK data format.

- Further Enhancement: multi-level modulations (DQPSK, M-ary CSK, etc).
Thank you!

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