

LIST OF FIGURES

- Figure 1.1 Architectural model of wireless CDMA network.
- Figure 1.2 The multiple-access techniques and design issues in an optical network.
- Figure 1.3 The classifications of wavelength division multiplexing techniques.
- Figure 1.4 Implementation of multiple wavelengths in a WDM system.
- Figure 1.5 Optical labels used in a MPLS enabled OCDMA system.
- Figure 1.6 The key components used in an OCDMA system.
- Figure 1.7 The encoder (transmitter), decoder (receiver) and the correlation process (code-matching) in an OCDMA system.
- Figure 1.8 The conventional solutions, design issues and system limitations in OCDMA.
- Figure 1.9 The motivations, objectives and scope of work for MAN optimization.
- Figure 2.1 Connections in an OCDMA system by using star topology.
- Figure 2.2 Encoder (transmitter) and decoder (receiver) models in an OCDMA system.
- Figure 2.3 Different code sets transmit at multiple wavelengths.
- Figure 2.4 Mapping of the source and destination nodes by different codes.
- Figure 2.5 Key functional blocks in an optical packet switched network.
- Figure 2.6 The key elements in an optical switch and label processing.
- Figure 2.7 The encoded signals in a direct-sequence OCDMA by using FDLs.
- Figure 2.8 FDL-based coherent, direct-sequence OCDMA system.
- Figure 2.9 Optical correlations for matched and unmatched codes at the receiver.
- Figure 2.10 The connections of terminal equipment in a local area network.
- Figure 2.11 Architectural model of a metropolitan area network.
- Figure 2.12 Modes of traffic and arrival rates in a packet-switched network.

| | |
|-------------|---|
| Figure 2.13 | Traffic patterns in an optical packet-switched network. |
| Figure 3.1 | The key design considerations in a real optical network. |
| Figure 3.2 | The key design parameters and performance parameters using various OC models in different systems for MAN optimization. |
| Figure 3.3 | Integrated formulation (four key aspects) to be applied in a standard OCDMA system for optimization. |
| Figure 3.4 | Simplified equivalent system model 1 (transmitter). |
| Figure 3.5 | Simplified equivalent system model 1 (receiver). |
| Figure 3.6 | Simplified equivalent system model 2 (transmitter). |
| Figure 3.7 | Simplified equivalent system model 2 (receiver). |
| Figure 3.8 | Simplified equivalent system model 3 (transmitter). |
| Figure 3.9 | Simplified equivalent system model 3 (receiver). |
| Figure 3.10 | Simplified equivalent system model 4 (transmitter). |
| Figure 3.11 | Simplified equivalent system model 4 (receiver). |
| Figure 3.12 | Standard optical encoder/decoder in an OCDMA system. |
| Figure 3.13 | A standard OCDMA system in star configuration. |
| Figure 3.14 | The simplified equivalent MZM structure. |
| Figure 3.15 | A standard multiple-access network without MUI reduction. |
| Figure 3.16 | The working principles of a FBG. |
| Figure 3.17 | Simplified equivalent structure of FBG and the signal propagations. |
| Figure 3.18 | Development of OC models and generation of unique sequences based on the design parameters and grating configurations. |
| Figure 3.19 | Correlation process at the decoder and the recovered signal. |
| Figure 3.20 | Summary of simulation parameters. |
| Figure 3.21 | The code weights in an optical code sequences. |
| Figure 3.22 | Code patterns for $OC_{(1,4,10,25)}$. |
| Figure 3.23 | Code sequences with 7 chips, variable weight. |

| | |
|-------------|---|
| Figure 3.24 | Chipping pattern of $OC_{(1,10,13,28)}$. |
| Figure 3.25 | Bipolar impulse sequences. |
| Figure 3.26 | Bipolar pulse sequences. |
| Figure 3.27 | BER estimation models. |
| Figure 3.28 | Standard parameters in an eye diagram measurement. |
| Figure 3.29 | Simplified schematic diagram of a photo detector. |
| Figure 3.30 | Unique sequences generated by OC_{25} model. |
| Figure 3.31 | Unique sequences generated by OC_{20} model. |
| Figure 3.32 | Unique sequences generated by OC_{18} model. |
| Figure 3.33 | Unique sequences generated by OC_{15} model. |
| Figure 3.34 | Unique sequences generated by OC_{16} model. |
| Figure 3.35 | Unique sequences generated by OC_{30} model. |
| Figure 3.36 | Grating configurations for OC_{63} model. |
| Figure 3.37 | The decoded signals (unique sequences) by using different OC models before optimization. |
| Figure 3.38 | Development of optimized MAN and key design considerations. |
| Figure 4.1 | Development of an intensity modulation, direct detection system and the design considerations for MAN optimization. |
| Figure 4.2 | Signals observed at different stages using OC_{25} in 10 km transmission before optimization. |
| Figure 4.3 | Signal observation at different stages using OC_{25} in 50 km transmission before optimization. |
| Figure 4.4 | Optical spectrum measured at encoder and decoder using OC_{25} . |
| Figure 4.5 | BER over received power and input power using RZ-OOK- OC_{25} in a four-channel system. |
| Figure 4.6 | Signals observed at different stages using OC_{20} in 40 km transmission before optimization. |
| Figure 4.7 | Optical spectrum measured at encoder and decoder using OC_{20} . |
| Figure 4.8 | BER over received power and input power using RZ-OOK- OC_{20} in a four-channel system. |

- Figure 4.9 Signals observed at different stages using OC₁₈ in 40 km transmission before optimization.
- Figure 4.10 Estimation of optimal sample time, ps in a four-channel system at bit rate of 2.5 Gbps.
- Figure 4.11 BER over received power and input power using RZ-OOK-OC₁₈ in a four-channel system.
- Figure 4.12 Signals observed in 40 km transmission using OC₁₅ before optimization.
- Figure 4.13 Optical spectrum and eye diagram measured at encoder/decoder using OC₁₅.
- Figure 4.14 BER over received power using RZ-OOK-OC₁₅ in a four-channel system.
- Figure 4.15 Signals observed at different stages in 40 km transmission using OC₁₆ before optimization.
- Figure 4.16 Optical spectrum and eye diagram measured at encoder/decoder using OC₁₆.
- Figure 4.17 BER over received power using RZ-OOK-OC₁₆ in a four-channel system.
- Figure 4.18 Signals observed at different stages using OC₃₁ in 10 km transmission before optimization.
- Figure 4.19 Received power over DCF length measured at 50 km and 100 km transmissions at $P_{r(max)}$ and $P_{r(min)}$.
- Figure 4.20 Optimal dispersion compensating fiber lengths in 5 km to 50 km transmissions measured at $P_{r(max)}$ and $P_{r(min)}$ in a two-channel, 16 chips (variable code weights) system.
- Figure 4.21 Optimal dispersion compensating fiber lengths in 60 km to 100 km transmissions measured at $P_{r(max)}$ and $P_{r(min)}$ in a two-channel, 16 chips (variable code weight) system.
- Figure 4.22 Optimal BER (user 1) and tradeoff BER (user 2) measured at $P_{r(max)}$ and $P_{r(min)}$ using 16 chips.
- Figure 4.23 Optimal BER (user 2) and tradeoff BER (user 1) measured at $P_{r(max)}$ and $P_{r(min)}$ using 16 chips.
- Figure 4.24 Encoded/decoded signals, eye diagram, phase shifts and chipping patterns measured in a two-channel, 7 chips system.
- Figure 4.25 Received power over dispersion compensating fiber lengths measured at 50 km and 100 km transmissions.

- Figure 4.26 Optimal dispersion compensating fiber lengths in 5 km to 50 km transmissions measured at $P_{r(\max)}$ and $P_{r(\min)}$ in a two-channel, 7 chips (variable code weights) system.
- Figure 4.27 Optimal dispersion compensating fiber lengths in 60 km to 100 km transmissions measured at $P_{r(\max)}$ and $P_{r(\min)}$ in a two-channel, 7 chips (variable code weights) system.
- Figure 4.28 Optimal dispersion compensating fiber lengths in 5 km to 40 km transmissions measured at $P_{r(\max)}$ and $P_{r(\min)}$ in a two-channel, 7 chips system with reduction of $P_{in(\text{peak})}$.
- Figure 4.29 Optimal BER (user 1) and tradeoff BER (user 2) measured at $P_{r(\max)}$ and $P_{r(\min)}$ by using 7 chips.
- Figure 4.30 Optimal BER (user 2) and tradeoff BER (user 1) measured at $P_{r(\max)}$ and $P_{r(\min)}$ by using 7 chips.
- Figure 4.31 Back-to-back measurement in a two-channel, 7 chips (variable code weights) system.
- Figure 4.32 Back-to-back measurement in a four-channel, 25 chips (constant code weight) system.
- Figure 4.33 Effect of code weights in a two-channel, variable code weights system.
- Figure 4.34 Effect of chip lengths and code weights in a two-channel system.
- Figure 4.35 Effect of gain controlled amplifier measured before transmission in a two-channel, 7 chips system.
- Figure 4.36 Effect of input power in a four-channel, 25 chips system (left) and two-channel, 7 chips system (right).
- Figure 4.37 Effect of pulse type (Gaussian) in a two-channel, 7 chips system to the encoded/decoded signal, eye diagram and optical spectrum.
- Figure 4.38 Effect of transmission distances in a four-channel system using OC₂₅ with (left) and without (right) MUI reduction.
- Figure 4.39 Effect of transmission distances in a four-channel system using OC₂₀ with MUI reduction.
- Figure 4.40 Effect of transmission distances in a four-channel system using OC₁₈ with MUI reduction.
- Figure 4.41 Effect of transmission distances in a four-channel system using OC₁₅ with MUI reduction.
- Figure 4.42 Effect of transmission distances in a four-channel system using OC₁₆ with MUI reduction.

- Figure 4.43 BER over received power measured at different transmission bit rates in a two-channel system.
- Figure 4.44 Encoded/decoded and recovered signals measured in a two-channel, 7 chips system at 2.5 Gbps.
- Figure 4.45 Effect of transmission bit rates in a four-channel system using OC₂₀ model (left) and OC₂₅ model (right).
- Figure 4.46 System performance enhancement with MUI reduction in a four-channel system using OC₂₅ model measured at $P_{r(max)}$ and $P_{r(min)}$.
- Figure 4.47 Received power over MAN distances with and without MUI reduction measured at $P_{r(max)}$ and $P_{r(min)}$.
- Figure 4.48 System performance enhancement with MUI reduction in a two-channel, 16 chips (variable code weights) system measured at $P_{r(max)}$ and $P_{r(min)}$ based on optimal and tradeoff results for user 1 (left) and user 2(right).
- Figure 4.49 System performance enhancement using 7 chips and 16 chips in a two-channel system (variable code weights) measured at $P_{r(max)}$ and $P_{r(min)}$ based on optimal and tradeoff results for user 1 (left) and user 2 (right).
- Figure 4.50 Comparative analysis on unipolar and bipolar encodings (three different schemes) in a two-channel system using 7 chips.
- Figure 4.51 Comparative analysis of OC₂₀ and OC₂₅ in a four-channel system at 5 Gbps.
- Figure 4.52 Comparative analysis of OC₂₀ and OC₂₅ in a four-channel system at 2.5 Gbps over MAN transmission distances with MUI reduction measured at $P_{r(max)}$ and $P_{r(min)}$.
- Figure 4.53 Comparative analysis of OC₁₈ and OC₂₅ in a four-channel system at 2.5 Gbps over MAN transmission distances with MUI reduction measured at $P_{r(max)}$ and $P_{r(min)}$.
- Figure 4.54 Comparative analysis of OC₁₅ and OC₂₅ in a four-channel system at 2.5 Gbps over MAN transmission distances with MUI reduction measured at $P_{r(max)}$ and $P_{r(min)}$.
- Figure 4.55 Comparative analysis of OC₁₆ and OC₂₅ in a four-channel system at 2.5 Gbps over MAN transmission distances with MUI reduction measured at $P_{r(max)}$ and $P_{r(min)}$.
- Figure 5.1 Application in MAN by using integrated optimization formulation.
- Figure 5.2 BER improvement in a four-user, NRZ-MZM system using different OC models.

- Figure 5.3 Required SNR for a specific BER in a four-user, NRZ-MZM system.
- Figure 5.4 BER improvement in a four-user, NRZ-MZM system with and without MUI reduction using different OC models.
- Figure 5.5 BER improvement using NRZ-MZM-OC₂₅ model and the measured threshold values.
- Figure 5.6 BER improvement in a four-user, NRZ-DPSK system using OC₂₅ and OC₂₀ models.
- Figure 5.7 The required SNR for a specific BER in a four- user, NRZ-DPSK system (with precoding) and RZ-OOK system (without precoding).
- Figure 5.8 BER improvement by comparing NRZ-DPSK (with precoding) and RZ-OOK (without precoding) using OC₂₅ and O₂₀ models.
- Figure 5.9 Optimization in a four-user, DPSK system for 5 km to 100 km transmissions.
- Figure 5.10 BER improvement using different encoding schemes in a four-user, DPSK system and the PDF of symbol error rate (SER) estimation.
- Figure 5.11 Effect of optimization in a four-user system measured in 5 km and 100 km transmissions at 10 Gbps using Sechant source (transmitter).
- Figure 5.12 Effect of transmission distances and filtering in a RZ-OOK system.
- Figure 5.13 BER improvement using OC₂₅ in a four-user, DQPSK system.
- Figure 5.14 The required SNR for a specific BER in a four-user, NRZ-DQPSK-OC₂₅ system.
- Figure 5.15 BER improvement in a four-user, RZ-OOK-OC₂₅ system (without precoding).
- Figure 5.16 SNR required for a specific BER in a four-user, NRZ-DQPSK with MUI reduction.
- Figure 5.17 Multilevel phase shifts in a four-user, NRZ-DQPSK system using OC₂₅ and OC₂₀ models with MUI reduction
- Figure 5.18 SNR and BER measured in an eight-user system using different encoding schemes.
- Figure 5.19 BER improvement using OC₂₅ in different modulation systems measured before transmission without MUI reduction.

- Figure 5.20 BER improvement using NRZ-MZM-OC₂₅ in comparison with multi-wavelength system with MUI reduction.
- Figure 5.21 Effect of noise power density on BER in a four-user, NRZ-DPSK system measured in 5 km and 100 km transmission.
- Figure 5.22 BER and SNR measured in a four-user, NRZ-DQPSK system at different noise power densities.
- Figure 5.23 Effect of noise power density in 5 km and 100 km transmissions using NRZ-DQPSK-OC model.
- Figure 5.24 Effect of dispersion levels in 10 km and 20 km transmissions at 40 Gbps without MUI reduction using different modulation techniques and OC models.
- Figure 5.25 Effect of modulation techniques and transmission distances at 10 Gbps using multilevel phase shift in 10 km and 50 km transmissions.
- Figure 5.26 Effect of modulation techniques and transmission distances at 10 Gbps using multilevel phase shift in 100 km transmission.
- Figure 5.27 Effect of modulation techniques and transmission bit rates using multilevel phase shift at 40 Gbps.
- Figure 5.28 Effect of modulation techniques and transmission bit rates with MUI reduction at 10 Gbps (without optimization in encoding scheme).
- Figure 5.29 Effect of modulation techniques and transmission bit rates with MUI reduction at 40 Gbps (without optimization in encoding scheme).
- Figure 5.30 Inconsistency of user performances in NRZ-DQPSK-OC₃₁ (left) and NRZ-DQPSK-OC₁₅ (right) system.
- Figure 5.31 BER measured at user 4 using OC₃₁ model and user 1 using OC₁₅ model in NRZ-DQPSK system.
- Figure 5.32 Inconsistency of user performances where user 1 achieves satisfactory performance whereas other users encounter similar deterioration patterns.
- Figure 5.33 Eye diagrams measured in a four-user, DQPSK system in 5 km and 100 km transmissions using OC₁₅ model.
- Figure 6.1 Investigation on the feasibility of integrated formulation in MAN optimization under higher aggregated traffic and user numbers.
- Figure 6.2 BER improvement in 4-user, NRZ-MZM-OC system at 20 Gbps and 40 Gbps.

- Figure 6.3 BER over transmission distances in a four- user system using NRZ-DPSK-OC measured at 10 Gbps, 20 Gbps and 40 Gbps without MUI reduction.
- Figure 6.4 SNR required for a specific BER in a four-user system measured at 20 Gbps ad 40 Gbps without MUI reduction using NRZ-DQPSK-OC.
- Figure 6.5 BER over transmission distances and the required SNR in a four-user system using NRZ-DQPSK-OC at 10 Gbps, 20 Gbps and 40 Gbps without MUI reduction.
- Figure 6.6 Eye diagrams measured in a four-user, NRZ-DQPSK system at 10 Gbps and 20 Gbps without MUI reduction and optimization.
- Figure 6.7 Eye diagrams measured in a four-user, NRZ-DQPSK system at 40 Gbps without MUI reduction and optimization.
- Figure 6.8 NRZ-DQPSK-OC in a four-user system at 40 Gbps without MUI reduction.
- Figure 6.9 8-user, NRZ-MZM-OC system at 10 Gbps with and without MUI reduction.
- Figure 6.10 Eye openings and Q-value over sample time in eight-user, NRZ-MZM system.
- Figure 6.11 Sample time and PDF used for BER estimation in 8-user, NRZ-MZM system.
- Figure 6.12 SNR required for a specific BER in an eight-user system using NRZ-DPSK measured at 10 Gbps.
- Figure 6.13 BER improvement in an eight-user, NRZ-DPSK system measured at 10 Gbps, 20 Gbps and 40 Gbps with and without MUI reduction.
- Figure 6.14 BER improvement using MUI reduction in an eight-user, DPSK system measured at 10 Gbps.
- Figure 6.15 BER improvement using integrated formulation in an eight-user, DPSK system measured at 10 Gbps.
- Figure 6.16 Effect of user numbers to BER in an eight-user, DPSK system for 5 km to 100 km transmissions.
- Figure 6.17 Eye diagram measurements on the effect of transmission rates without MUI reduction in an eight-user, DPSK system.
- Figure 6.18 SNR required for a specific BER in an eight-user, DQPSK-OC system without MUI reduction.

- Figure 6.19 BER over transmission distances and SNR required at 20 Gbps and 40 Gbps without MUI reduction in an eight-user DQPSK system.
- Figure 6.20 SNR required for a specific BER in an eight-user, NRZ-DQPSK-OC with MUI reduction.
- Figure 6.21 Eye diagram measurements in an eight-user, NRZ-DQPSK system at 10 Gbps without optimization.
- Figure 6.22 Eye diagram measurements in an eight-user, NRZ-DQPSK system at 40 Gbps without MUI reduction and optimization.
- Figure 6.23 Eye diagram measurements in an eight-user, NRZ-DQPSK system at 10 Gbps and 20 Gbps without MUI reduction and optimization.
- Figure 6.24 Eight-user, NRZ-DQPSK system at 40 Gbps without MUI reduction.
- Figure 6.25 Eight-user, NRZ-DQPSK system measured at 40 Gbps without MUI reduction in 100 km transmission.
- Figure 6.26 BER over transmission distances and the required SNR for a specific BER in a twelve-user, NRZ-DPSK-OC system measured at 10 Gbps.
- Figure 6.27 Effect of user numbers in NRZ-DPSK-OC system measured at 10 Gbps.
- Figure 6.28 Eye diagram measurements in a twelve-user, NRZ-DPSK system at 10 Gbps.
- Figure 6.29 Eye diagram measurements in a twelve-user, NRZ-DPSK system at 10 Gbps without MUI reduction and optimization.
- Figure 6.30 BER over transmission distances and SNR required for a specific BER in a twelve-user, DQPSK system measured at 10 Gbps with MUI reduction.
- Figure 6.31 The eye diagrams observed in a twelve-user, DQPSK system at bit rate of 10 Gbps without optimization.
- Figure 6.32 Eye diagram measurements on the effect of different OC models without MUI reduction (before transmission) in a DQPSK system.
- Figure 7.1 Optimization formulation to be integrated in the all optical label swapping (AOLS) enabled router.
- Figure 7.2 OCDMA based label processing in the AOLS enabled router.
- Figure 7.3 The optimized formulation to be integrated into an optical label enabling switching system.

- Figure 7.4 The optimized formulation to be integrated into the hybrid
OCDMA switching architecture.
- Figure 7.5 Multiple-access via OCDMA technique in an optical label
processing network.
- Figure 7.6 The architectural model of a label edge router.