Performance Analysis of Multi-pulse PPM for Optical Wireless Hierarchical Transmission System

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* Optical wireless broadcasting
* Hierarchical transmission system
* Proposed hierarchical MPPM system
  • Transmitter and symbol structure
  • PN Codes for MPPM and CNK
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* Evaluation
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* Conclusion
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Optical wireless (OW) broadcasting

• Advantages
  ✓ High information capacity
  ✓ Worldwide available and unlicensed bandwidth
  ✓ Does not interfere with radio bands

Promising supplement to already existing wireless RF technologies.

• OW hierarchical Transmission system for ITS
  [Yamazato, 2007][Oka, 2008]
  - the broadcasted messages can be divided into two or more classes according to its importance.

✓ The important information (Data1) must be recovered by all receivers.
✓ The less important information (Data2) can only be recovered by the “fortunate” receivers.
*Hierarchical transmission system*

Ways to realize the Optical wireless Hierarchical transmission

- **Fusion modulation using Intensity Modulation (IM)**
  - Compatible with on-off signaling
  - Low immunity against ambient noise
  - Photo-Diode (PD)

- **Hierarchical Constellations using subcarrier IM**
  - Robust system for ambient noise
  - Requires higher optical clock rate
  - PD and Image sensor

- **Hierarchical coding using Image enhancement**
  - Robust system for ambient noise
  - Parallel processing
  - Image sensor

We focus on the Fusion modulation (most simple way).

*We propose **new hierarchical MPPM** modulation.*

*Moreover, we evaluate the proposed system taking into account optical wireless noises.*

*MPPM : Multi-pulse Pulse Position Modulation*
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*Transmitter and symbol structure*

- Combine multi-pulse PPM (MPPM) with code number keying (CNK)

**Input bits (Data 1)**
...0110110

**Input bits (Data 2)**
...11101101

**1st modulation**
MPPM

- 00 ➔
- 01 ➔ 0
- 11 ➔ 1
- 10 ➔ n=0 code

**2nd modulation**
CNK

- 0 ➔ n=0 code
- 1 ➔ n=1 code

**MPPM Code:** 1010
**CNK Code:** 0101

Optical signal

Tx1

Step 1) According to data1, *m slots are selected* from *M* slots.

Step 2) According to data2, *n slots are selected from M-m slots* (no overlap).

Step 3) *m MPPM codes are generated in the m slots*, while *n CNK codes are generated in the n slots.*
Conventional MPPM system (M=16, m=8) PN for MPPM (11101000)

Proposed system (M=16, m=8, N=4) PN for MPPM (11101000), PN for CNK (00010111)
*Codes for MPPM and CNK*

- Modified pseudo orthogonal M-sequence sets (kozawa 2007)
  - For example when code length, $L$, is 4,

\[
\begin{align*}
\mathbf{PN} &= \begin{bmatrix} PN_1 \\ PN_2 \\ PN_3 \end{bmatrix} = \begin{bmatrix} 1,0,1,0 \\ 1,1,0,0 \\ 1,0,0,1 \end{bmatrix}, \\
\overline{\mathbf{PN}} &= \begin{bmatrix} PN_1 \\ PN_2 \\ PN_3 \end{bmatrix} = \begin{bmatrix} 0,1,0,1 \\ 0,0,1,1 \\ 0,1,1,0 \end{bmatrix}, \\
\mathbf{RC} &= \mathbf{PN} - \overline{\mathbf{PN}} = \begin{bmatrix} +1,-1,+1,-1 \\ +1,+1,-1,-1 \\ +1,-1,-1,+1 \end{bmatrix}
\end{align*}
\]

- Code characteristics

\[
\begin{align*}
\mathbf{PN} \mathbf{RC}^{-1} &= \frac{L}{2} \mathbf{E}, \\
\overline{\mathbf{PN}} \mathbf{RC}^{-1} &= -\frac{L}{2} \mathbf{E}
\end{align*}
\]

$L : \text{code length} \\
\mathbf{E} : \text{unit matrix}$

- Code for MPPM and CNK ;
  - $\mathbf{PN}$ is used for MPPM
  - $\overline{\mathbf{PN}}$ is used for CNK
  - $\mathbf{RC}$ is used for the reference code at the receiver
**Receiver and symbol detection**

- Demodulate MPPM data and CNK data individually

**Step 1)** Received signal is correlated by the reference code in each slot.

**Step 2)** MPPM symbol is declared by selecting *m* correlation values, which are larger than the other *M-m* correlation values.

**Step 3)** CNK symbol is declared by threshold detection with the magnitude of sum of *M* correlation values.

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**Reference code**

RC : +1-1+1-1

**MPPM demodulator**

\[
(q_1, q_2) > (q_3, q_4) \rightarrow 00 \\
(q_1, q_3) > (q_2, q_4) \rightarrow 01 \\
(q_1, q_4) > (q_2, q_3) \rightarrow 11 \\
(q_2, q_3) > (q_1, q_4) \rightarrow 10
\]

**CNK demodulator**

\[
q_1 + q_2 + q_3 + q_4 \geq T_h \rightarrow 0 \\
q_1 + q_2 + q_3 + q_4 < T_h \rightarrow 1
\]

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**Diagram**

- **Rx** (Received optical signal)
- **APD**
- **Correlation value**
- **Data**

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Symbol detection

Proposed system (M=16,m=8,N=4) PN for MPPM (11101000), PN for CNK (00010111)

- CNK data "01" (n=1)
- CNK data "11" (n=2)

4×8-4×1=28
4×8-4×2=24
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**Evaluation : DTR and SER**

- Comparing the proposed system with the conventional MPPM system

**Transmitter**

- Laser wavelength: 830 [nm]
- Optical clock rate: 120 [MHz]
- Code length: \( L = 16 \)
- Modulation extinction ratio: 100
- The num. of MPPM slots: \( M = 16, 32 \)
- The num. of selected slots: \( m, 1, \ldots, M-1 \)
- The maximum num. of selected slots: \( N = M-m+1 \)

**Receiver**

- APD Gain: 100
- Quantum efficiency: 0.6
- Receiver load resistor: 1030 [Ω]
- Receiver noise temperature: 1100 [°K]

**Numerical conditions**

**OW channel**

- Scintillation model
- Log-normal Turbulence
- Scintillation logarithm variance: \( \sigma_s^2 = 0.01 \)
- Background noise: \( P_b = -45 \text{ [dBm]} \)

**Comparing the proposed system with the conventional MPPM system**

- **Proposed system**
  - MPPM
  - CNK
  - MPPM Code
  - CNK Code

- **Conventional MPPM/SS system**
  - MPPM
  - MPPM Code

**Data 1**

- MPPM

**Data 2**

- CNK

**Proposed system**

- MPPM Code

**Conventional MPPM/SS system**

- MPPM Code
Result: DTR

- DTR of the proposed system is better than that of the conventional MPPM system.
- DTR can achieve upper bound when the $m$ is half of $M$.
- DTR of the conventional MPPM system is decreases when $m$ is larger than half of $M$.

Fig. 1, DTR vs. $m$
**Result: SER vs. $P_{\text{bit}}$ (M=16, m=8)**

- **Conventional system (M=4)**

  - Received signal
  - Ref. code
  - Correlation value:
    - $q_1$, $q_2$, $q_3$, $q_4$
  - Difference between $q_2$, $q_3$ and $q_1$, $q_4$ is 2.

- **Proposed system (M=4)**

  - Received signal
  - Ref. code
  - Correlation value:
    - $q_1$, $q_2$, $q_3$, $q_4$
  - Difference between $q_2$, $q_3$ and $q_1$, $q_4$ is 4.

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**Fig. 2, SER vs. $P_{\text{bit}}$**

- Symbol Error Rate
- Averaged received laser power per bit [dBm]

\[
\begin{align*}
\sigma^2 & = 0.01 \\
M & = 16, \ m = 8, \ L = 16 \\
P_b & = -45 \text{ [dBm]}
\end{align*}
\]
Result: SER vs. $P_{\text{bit}}/P_b$ ($M=16$, $m=8$)

Fig. 3, SER vs. $P_{\text{bit}}/P_b$ w/ scintillation

Fig. 4, SER vs. $P_{\text{bit}}/P_b$ w/o scintillation
Conclusion

- We proposed the hierarchical MPPM system using PN codes.
- We analyzed and evaluated the proposed system from theoretical analysis.

- The proposed system can:
  - Improve the data transmission rate compared with the conventional MPPM system.
  - Achieve to SER of conventional MPPM.
  - Transmit MPPM data and CNK data hierarchical because there is the difference between SER of MPPM and SER of CNK.

- Future works:
  - Evaluation of the system in the parallel transmitter case.
  - Comparing with conventional hierarchical systems.
Thank you.