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Realizing Waveguide-Grating Network Codecs to Recursively Suppress Optical Interference Noises

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Abstract **-** In this paper, we propose a recursive interference cancellation (RIC) scheme over optical coding access network coder/decoders (codecs). The novel-designed interference noises canceller is structured over arrayed-waveguide gratings (AWGs). By recursively following the recoding, subtraction, and decoding processes, the reconfigured AWG codecs will largely suppress optical interference noises to successfully recover target user data bits. Numerical evaluations are taken to illustrate the RIC processes to compare different recursive rounds and code weights distribution to the SNR performance of target data bit decoding.

Keywords**:** Recursive Interference Cancellation (RIC), Lumped Gaussian-distributed Interference Noises, Arrayed-Waveguide Gratings (AWGs), Optical Coding Access Network.

1. Introduction

In multi-carriers optical network, the problem of multiuser detection (MUD) [1], [2] has been discussed for a long time. For MUD, the receiver needs to extract the desired user signal from the received summed-signal+noises. But the signature codes of network node users are overlapped and cannot be separated completely in the receiver decoder. This multiple-access interference (MAI) [3], [4] incurs deep influence on the error performance of optical access network. When we want to decode the desired user data from the received summed-signal+noises, other non-desired interference signals and noises will affect the results of data decoding.

Several methods have been proposed to deal with interference noises cancellations problem, such as successive interference cancellation (SIC) [5], [6] and parallel interference cancellation (PIC) [7], [8]. Both of them were originally devised to RF receivers to eliminate unmatched signals and spurious interference noises within the received signal+noises. Three processes were involved on data signal decoding: recoding the previous stage of user signals, subtracting the regenerated signals, and decoding the current stage of user signals. These processes were successively implemented until the desired data signal at the final receiver stage completed and full cycle of correlation decoding accomplished.

In this paper, a recursive interference cancelation (RIC) scheme is devised to optical coding access network. The RIC adopts cyclic maximal-length sequence (M-sequence) codes to align with reconfigurable arrayed-waveguide grating (AWG) signature codecs to suppress interference noises in each correlation round and to finally decode the intended target data bits. With such recursive subtraction/decoding scheme realized over single-stage AWG codecs, we integrate the tasks of correlation decoding and interference cancellation in the optical coding access network.

The proposed RIC is basically multi-rounds correlation decoding structure. In this RIC scheme we estimate non-desired users data bits and regenerate the corresponding code signals to be cancelled from the remained signal at the earlier correlation rounds and decode the target user at the final correlation round. By the multi-rounds process we can suppress the interference noises to promote data reliability of the desired target user. We emulate a recursive-operated arrayed-waveguide gratings (AWGs) codecs to accomplish the multi-rounds correlation decoding process. A special clocking switch is designed to control the operation mode of AWG codecs to accomplish the recursive operations.

2. Novel-Designed AWG Codecs to Recursively Suppress Interference Noises

In optical coding access network, orthogonal superposition on nodes signature codes is to achieve data multiplexing transmission. All of the spectral coded signals are combined to generate superposed coded data in the star coupler and broadcast to the remote receiver. In the received summed signals, some interference noises are generated during coding and transmission. To simplify the complexity of simulation, we suppose that all interference noises lump into Gaussian-distributed profile over the coding bandwidth.

In the multi-rounds RIC scheme, during each round of the recursive noises-cancellation of AWG codecs, two coding phases are implemented to suppress the interference noises: the “data recoding” phase over the previous user signature and the “data decoding” phase over the current user signature. In-between is the task of signals subtraction to subtract off the recoded (the previous) user signal from the current remaining summed signals.

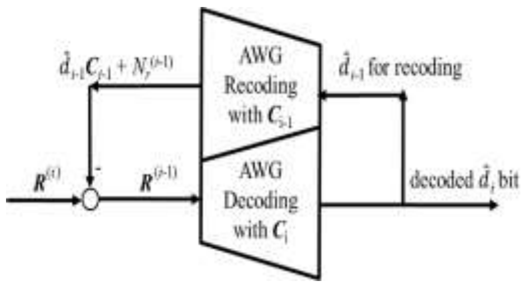


Fig. 1: Conceptual operation round of AWG codecs recoding/decoding.

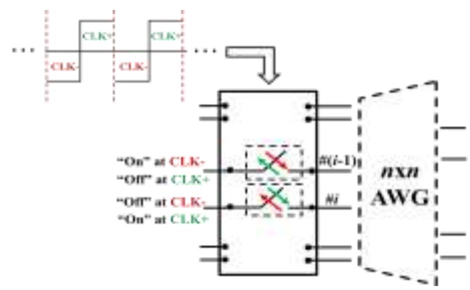
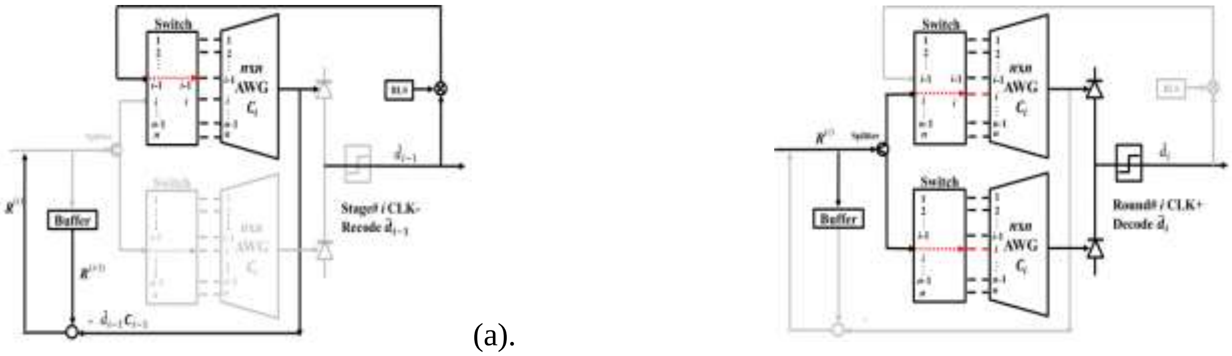


Fig. 2: Switch on/off for recoding/decoding with clock time.

Figure 1 draws the relative phase of data-recoding and data-decoding within each round of correlation operation. The decoded data bit $\hat{d}_{i-1}$ out from the #(i-1)-th round of correlation decoder will recode with signature code $\boldsymbol{C}_{i-1}$ to obtain the recoded signal+noises $\hat{d}_{i-1}\boldsymbol{C}_{i-1}$+ $\boldsymbol{N}_{o}^{(i-1)}$. This recoded signal+noises is subtracted from the previously remained summed-signal+noises $\boldsymbol{R}^{(i)} = \boldsymbol{R}^{(i-1)} - \hat{d}_{i-1}\boldsymbol{C}_{i-1} - \boldsymbol{N}_{o}^{(i-1)}$ originated from the #(i-1)-th round of correlation decoder. Figure 2 depicts, on the adjacent (i-1)-th and i-th switching rounds, i=1, 2, …, n, the clocking switch turns on/off the entering summed signal+noises to the corresponding AWGs input ports. In the CLK- clock interval, the (i-1)-th switch is “on” while the i-th switch is “off” so that AWGs are switched to function as “Data Recoder” with configured signature $\boldsymbol{C}_{i-1}$. In the CLK+ clock interval, the (i-1)-th switch is “off” while the i-th switch is “on” so that AWGs are switched to function as balanced “Data Decoder” with configured signature $\boldsymbol{C}_{i}$.

Figure 3(a) presents an example for totally n network users. Following the #3-round negative clock phase, receiver codecs recodes the decoded data bit $\hat{d}_2$ out from the #2-round. After recoding the data bit $\hat{d}_2$, the connection of input port switches to the input port#3 of codecs for decoding the current data bit $\hat{d}_3$. Figure 3(b) shows the same configuration but works at the positive clock time (CLK+). At this step, clocking switch turn off input port#2 and turn on input port#3 of AWG pair to decode data bits $\hat{d}_3$.



(a). (b).

Fig. 3: (a). AWG recursive configuration on data recoder; (b). Recursive configuration on correlation decoder.

By repeating the above processes (n-1) times, we recursively estimate user data bits, recode them, subtract them, and and decode them for the next estimate. In each correlation round, based on the remaining signal+noises, non-desired user data bits may be decided success or failure. We expect that the data bits estimation in the later correlation rounds will suffer lower and lower interference noises. That is, if we run more decoding rounds, higher probability the final target user data bits can be successfully determined.

3. SNR Performance versus Recursive Rounds

Optical multiple-access networks with different number of active users can be examined on the proposed recursive noises cancellations. We assume that the summed spectral-coded signals are contaminated with Gaussian-distributed interference noise. To access the user data bit, one cycle of n stages of data re-coding, signal subtraction and data decoding will be implemented. The signal+noises remained from the previous round of signal subtractions will successively enter into each input port of AWG codecs to proceed the next round of data decoding and interference noise cancellation. On signals entering into input port#j of AWG, j=1, 2, …, n, the AWG codecs behaves like one with configured signature $\boldsymbol{C}_j=T^j\boldsymbol{C}_1$, a j-chips cyclic shift-right code vector with respect to the reference signature code $\boldsymbol{C}_1$.

Following the recursive rounds of recoding, subtraction, and decoding, we evaluate SNR on each round to observe the suppression of Gaussian-distributed interference noises. Notice that, during the i-th round of noises cancellation, the recoded signal+noises $\widehat{d}_{i-1}\boldsymbol{C}_{i-1}+(\boldsymbol{N}_0/n)\boldsymbol{C}_{i-1}$ is subtracted from the previous (i-1)-th round of remained summed- signal+noises $\boldsymbol{R}^{(i-1)}$ to result in the updated summed-signal+noises $\boldsymbol{R}^{(i)} = \boldsymbol{R}^{(i-1)} - \widehat{d}_{i-1}\boldsymbol{C}_{i-1} - (\boldsymbol{N}_0/n)\boldsymbol{C}_{i-1}$. The i-th remained summed-signal+noises $\boldsymbol{R}^{(i)}$ then correlates with signature $\boldsymbol{C}_i$ to evaluate SNR$_i$ and to make the $\hat{d}_i$ bit estimate accordingly.

For numerical evaluations, Table I depicts a case of three active transceivers with signatures of $\boldsymbol{C}_2$ = (0,1,1, 1,0,0,1), $\boldsymbol{C}_3$ = (1,0,1, 1,1,0,0), and $\boldsymbol{C}_4$ = (0,1,0, 1,1,1,0). The transmitted code signals will result in the summed code vector $\Sigma d_i\boldsymbol{C}_i$ = (1,2,2, 3,2,1,1). After adding lumped Gaussian-distributed interference noises $\boldsymbol{N}_0$ = (0.03, 0.05, 0.08, 0.10, 0.08, 0.05, 0.03), the received summed-signal+noises becomes $\boldsymbol{R}^{(0)} = \Sigma d_i\boldsymbol{C}_i+\boldsymbol{N}_0$ = (1.03, 2.05, 2.08, 3.10, 2.08, 1.05, 1.03). On the RIC processes in the receiver, the received $\boldsymbol{R}^{(0)}$ first subtract the initially null-recoded signal and one part noise to obtain $\boldsymbol{R}^{(1)} = \boldsymbol{R}^{(0)} - (\boldsymbol{0}+\boldsymbol{N}_0/n)$ = (1.03-0.004, 2.05-0.007, 2.08-0.012, 3.10-0.014, 2.08-0.012, 1.05-0.007, 1.03-0.004). The subtracted $\boldsymbol{R}^{(1)}$ then correlates with signature $\boldsymbol{C}_1$ to decode data bit ^d_1. The decoded ^d_1 bit make a feedback to recode with the previous signature $\boldsymbol{C}_0$ and the current round of $\boldsymbol{R}^{(1)}$ replace the previous round of $\boldsymbol{R}^{(0)}$. In the next round of RIC process, the $\boldsymbol{R}^{(1)}$ first subtract the previous recoded-signal and one part of lumped-noise to obtain $\boldsymbol{R}^{(2)} = \boldsymbol{R}^{(1)} - (\hat{}d_1\boldsymbol{C}_0+(\boldsymbol{N}_0/n)\boldsymbol{C}_0)$. The subtracted $\boldsymbol{R}^{(2)}$ then correlates with signature $\boldsymbol{C}_2$ to decode data bit ^d_2. The decoded ^d_2 will feedback to recode with the previous signature $\boldsymbol{C}_1$ and the current round of $\boldsymbol{R}^{(2)}$ replace the previous round of $\boldsymbol{R}^{(1)}$. Following this way, the processes recursively run until the target data bit ^d_7 is decoded.

Table 1: Numerical evaluations on multi-rounds correlation decoding.

Initial conditions: $\boldsymbol{N}_0$ = (0.03, 0.05, 0.08, 0.10, 0.08, 0.05, 0.03), $\boldsymbol{R}^{(0)}$ = (1.03, 2.05, 2.08, 3.10, 2.08, 1.05, 1.03).					
round $\#i$	$\boldsymbol{C}_{i\text{-}1}$	$\hat{d}_{i-1}\boldsymbol{C}_{i\text{-}1}+(\boldsymbol{N}_0/n)\boldsymbol{C}_{i\text{-}1}$	$\boldsymbol{R}^{(i)} = \boldsymbol{R}^{(i\text{-}1)} - (\hat{d}_{i-1}\boldsymbol{C}_{i\text{-}1} + (\boldsymbol{N}_0/n)\boldsymbol{C}_{i\text{-}1})$	Z_i => $\hat{}d_i$	SNR_i
1	(1,1,1,0,0,1,0)	(0.004, 0.007, 0.012, 0, 0, 0.007, 0)	(1.026, 2.043, 2.069, 3.100, 2.080, 1.043, 1.030)	0.44=>0	5.72
2	(0,1,1,1,0,0,1)	(0, 0.007, 0.012, 0.014, 0, 0, 0.004)	(1.026, 1.036, 1.057, 2.086, 2.080, 1.043, 1.026)	5.12=>1	3.26
3	(1,0,1,1,1,0,0)	(1.004, 0, 1.012, 1.014, 1.012, 0, 0)	(0.022, 1.036, 0.045, 1.072, 1.068, 1.043, 1.026)	4.14=>1	5.67
4	(0,1,0,1,1,1,0)	(0, 1.007, 0, 1.014, 1.012, 1.007, 0)	(0.022, 0.029, 0.045, 0.058, 0.056, 0.036, 1.026)	4.15=>1	9.03
5	(0,0,1,0,1,1,1)	(0, 0, 1.012, 0, 1.012, 1.007, 1.004)	(0.022, 0.029, 0, 0.058, 0, 0, 0.022)	0.08=>0	37.27
6	(1,0,0,1,0,1,1)	(0.004, 0, 0, 0.014, 0, 0.007, 0.004)	(0.018, 0.029, 0, 0.044, 0, 0, 0.018)	0.02=>0	39.4
7	(1,1,0,0,1,0,1)	(0.004, 0.007, 0, 0, 0.012, 0, 0.004)	(0.014, 0.022, 0, 0.044, 0, 0, 0.014)	0.01=>0	40.87

The term $Z_i = |\boldsymbol{R}^{(i)}\boldsymbol{C}_i$ - $\boldsymbol{R}^{(i)}\underline{\boldsymbol{C}}_i|$ in Table I denotes balanced correlation subtraction on the *i*-th round. Half code weight of $w/2$ is set as decision threshold. If $Z_i > w/2$, the data bit is decided to "$\hat{d}_i$=1", and if $Z_i \leq w/2$, the data bit is decided to "$\hat{d}_i$=0". In accomplishing correlation decoding round, we also evaluate the corresponding SNR_i to see how correct target data bit decoding can be enhanced with recursive rounds of interference noises suppression.

Note that wrong decisions may occur at the earlier recursive rounds. But after several rounds of recursive interference cancellation, the interference noises would be suppressed and the target user data bit will be correctly decoded. We find that code weight distribution is an influential factor of network performance. Because we consider lumped Gaussian noises in the system, the distribution of code weight would affect the decoding result of the target data bit.

4. Conclusions

We have designed a novel receiver which consists of interference cancellation scheme and AWG router. We illustrate two different cases and the proposed system actually mitigate the influence of noise in these cases. We compare the performance between light traffic and high traffic. The proposed system achieves the expected purpose of noise suppression and promote the performance of SNR. In the other word the proposed system mitigates the interference during transmission and promotes the reliability of optical coding network. The achievement of the paper can make the coding access techniques more feasible in optical communication. In the future work we will consider different type of noise and code sequence and compare the difference between them.

We find that code weight distribution is an influential factor of network performance. Because we consider lumped Gaussian noises in the system, the distribution of code weight would affect the correlations subtraction result of interference noises. Also, different target user will affect the residual noise distribution in the final correlation decoding round.

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