Solitons in Discrete Waveguides

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Abstract

We analyse soliton stability in discrete waveguides, revealing the impact of waveguide parameters and nonlinearity. Our analysis reveals the impact of waveguide parameters and nonlinearity on soliton stability, identifying design guidelines for stable propagation.

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Introduction

Solitons are stable, localized waves that resist dispersion. In discrete waveguides, nonlinearity and coupling effects enable soliton formation with distinct characteristics compared to continuous media [1]. Discrete solitons have been observed in various physical systems, including optical waveguide lattices, Bose-Einstein condensates, and DNA molecules [2,3]. This study explores the behaviors of onsite and intersite discrete solitons, relevant for photonics applications.

Theoretical Background

Discrete solitons in waveguide lattices follow the discrete nonlinear Schrödinger equation:

$$i\frac{dA_n}{dz} + \eta A_n + \beta(A_{n+1} + A_{n-1}) + \gamma|A_n|^2 A_n = 0$$

where A_n the wave amplitude at site n, β is the coupling coefficient, and γ denotes nonlinearity. The linear terms $\beta(A_{n+1} + A_{n-1})$ describe tunneling (or diffraction) of the wave between adjacent lattice sites. The nonlinear term $\gamma|A_n|^2 A_n$ accounts for self-phase modulation, which can lead to localized solutions (solitons). This equation captures the interplay between diffraction, coupling, and nonlinearity, leading to solitonic behavior [4,5].

Types of Solitons

1. Onsite Solitons

Onsite solitons are localized at a single lattice site, meaning their energy or amplitude is concentrated at a particular point in the discrete lattice. These solitons typically emerge in discrete nonlinear Schrödinger equations (DNLS) and other nonlinear lattice models.

Key Characteristics of Onsite Solitons

Strong Localization: The wave function is sharply peaked at one site.

High Stability: Due to their strong localization, onsite solitons are often more stable compared to intersite solitons.

Discreteness Effect: Unlike continuous solitons, onsite solitons experience lattice discreteness, which prevents them from dispersing.

2. Intersite Solitons

Intersite solitons are cantered between two adjacent lattice sites, meaning they are not localized at a single site but rather spread across two or more sites.

Key Characteristics of Intersite Solitons

Weaker Localization: The energy is distributed over multiple sites, usually peaking between two adjacent sites.

Lower Stability Compared to Onsite Solitons: Since their energy is less confined, intersite solitons can be more susceptible to perturbations.

Existence in Various Nonlinear Lattices: Found in photonic lattices, Bose-Einstein condensates, and discrete waveguide arrays.

Methodology

Using numerical simulations, we explored soliton behavior by varying β and γ values, initializing with single-site (onsite) and dual-site (intersite) excitations.

Results

Onsite solitons remained confined and stable, with minimal energy leakage [6]. Intersite solitons required higher coupling for stability and showed sensitivity to small perturbations. Figure 1(a) and (b) shows Onsite and Intersite Soliton Profiles illustrates the distinct spatial distributions of both soliton types. Onsite solitons exhibit strong localization, whereas intersite solitons spread across multiple lattice sites due to coupling effects.

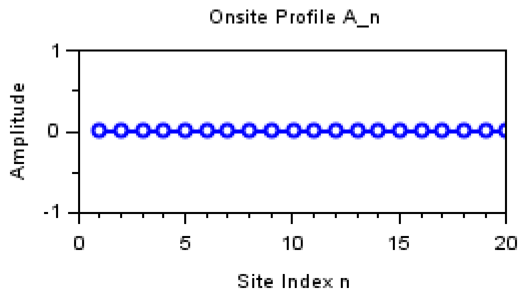

Figure 1(a): Onsite soliton profile.

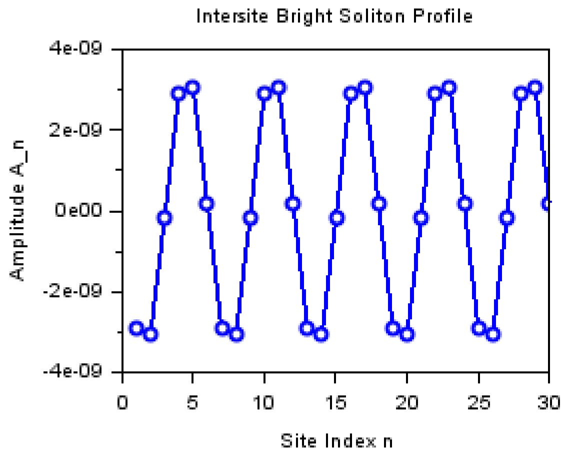

Figure 1(b): Intersite Soliton Profiles

For onsite Profile

Parameters

$$\eta = 1, \beta = 0.5, \gamma = 0.2, n = 20$$

Intersite Bright Soliton Profile

Parameters

$$\eta = -1, \beta = 1, \gamma = 0.5, n = 30$$

Conclusion

Onsite solitons demonstrate greater stability and resilience to parameter variations than intersite solitons. These findings offer insights into discrete solitons potential for robust light localization in photonic applications.

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