EDCA–Quantum Entanglement Analogs: (1) Single-Spot Nonlocal Collapse and (2) Correlated Spot-Pair Emission with a CHSH-Style Protocol

Raul Sanchez Perez

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Abstract

Energy-Driven Cellular Automata (EDCA) separate logical readiness from physical transition: a lattice site may satisfy a local transition rule yet remains unchanged unless an energy quantum (a *spot*) arrives. Spots propagate as wavefront shells and collapse when intersecting ready sites; collapse occurs at exactly one site selected from a candidate set distributed across the shell. This structure yields an EDCA-native nonlocal state update: when collapse occurs at one location, all other candidates on the same wavefront instantly lose eligibility for that spot event. This paper proposes two EDCA analogs of quantum entanglement. Approach A models *single-spot nonlocal collapse* effects: a delocalized wavefront intersects two distant ready clusters, and collapse in one cluster instantaneously conditions the global state of the other. Approach B introduces *correlated spot-pair emission*, producing Bell/CHSH-style correlations between outcomes at two distant stations whose measurement "settings" are implemented by local readiness/density masks. We present both models, clarify their relationship to collapse and no-signaling, and provide a CHSH-style protocol for simulation-based tests as a function of EDCA parameters such as shell sharpness λ, spin bias, polarity dynamics, and allocation density ρ.

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1 Introduction

EDCA extends classical cellular automata by introducing an explicit energy layer: matter (living cells) evolves according to local readiness conditions, but transitions (birth/death) require the arrival of energy. Energy is carried by mobile entities called *spots*. A spot expands as a wavefront shell and may collapse at any tick when it intersects a transition-ready site. When multiple sites are ready simultaneously on a shell, a selection rule resolves collapse at a single site. This selection may depend on wavefront geometry (privileged distance), a spot-attached spin vector, polarity, and dynamic allocation density $\rho(x, t)$.

This paper studies the question: *Can EDCA support an analog of quantum entanglement?* We propose two complementary models:

1. **Approach A (single spot, two clusters):** a single spot wavefront intersects distant ready clusters; collapse in one cluster excludes collapse in the other for that event. This yields EDCA-native nonlocal state reduction and "shared single-quantum" behavior.

2. **Approach B (correlated spot pairs):** a local event emits two correlated spots whose internal states are linked (e.g., $s_B = -s_A$). Two stations choose settings via readiness/density masks; each outputs ± 1 and correlations can be tested with a CHSH protocol.

Approach A is the minimal EDCA mechanism for nonlocal update. Approach B is the Bell/CHSH entanglement analog (two outcomes per trial with independently chosen settings).

2 Minimal EDCA Constructs Used Here

We assume foundational EDCA definitions of matter, readiness, spots, polarity flip, and dynamic allocation density ρ, but require only the following minimal constructs for entanglement modeling.

2.1 Wavefront shells and shell sharpness

A spot emitted at source x_s and time t_s defines a wavefront radius $r(t)$ and a shell band

$$W_t = \{x : \|x - x_s\| \in [r(t) - \delta_r, r(t) + \delta_r]\}.$$

Shell thickness δ_r is governed by a sharpness parameter λ:

- large $\lambda \Rightarrow$ thinner shell band (more sharply defined distance),
- small $\lambda \Rightarrow$ thicker band (more radial ambiguity).

2.2 Candidate set and exclusive collapse

Let $\mathrm{ready}(x,t)$ be the readiness predicate for a transition at site x at tick t. The collapse candidate set is

$$C_t = W_t \cap \{x : \mathrm{ready}(x,t)\}.$$

When $C_t \neq \emptyset$, collapse occurs at exactly one site $X \in C_t$.

Exclusivity (intrinsic). For each spot event, collapse occurs at exactly one site. Therefore if X collapses, every other $Y \in C_t \setminus \{X\}$ does not collapse for that event.

This exclusivity is the primary source of EDCA nonlocal state reduction in Approach A.

2.3 Spin, polarity, and density bias

Each spot carries:

- a fixed spin vector s that biases selection among competing candidates,
- a polarity $p \in \{+, -\}$ that determines whether alignment is favored $(+)$ or disfavored $(-)$,
- a polarity flip rule upon interaction $(+ \leftrightarrow -)$.

Dynamic space allocation density $\rho(x,t)$ may also bias collapse selection by modifying effective weights of candidates.

3 Geometric Intuition: Candidate Sets and Station Readout

Before presenting entanglement models, we illustrate the key geometric idea: a spot wavefront defines a *distributed candidate set* on a shell. Distant candidate regions can coexist simultaneously, and multi-candidate detector geometries can map collapse location to discrete outcomes.

3.1 Figure 1: Candidate-set geometry

3.2 Figure 2: Deterministic station (single ready site)

3.3 Figure 3: Multi-candidate station (spin-sensitive geometry)

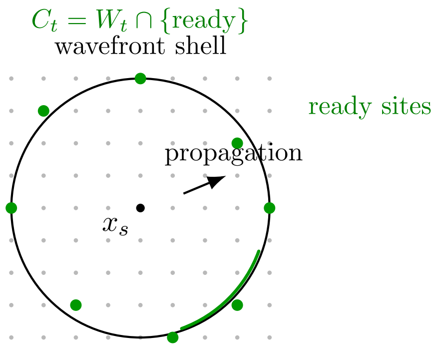


Figure 1: **Candidate-set geometry.** A spot emitted at x_s expands as a wavefront shell. Sites that are both on the shell and transition-ready form the candidate set C_t. Collapse selects one candidate, and exclusivity updates the global spot state.

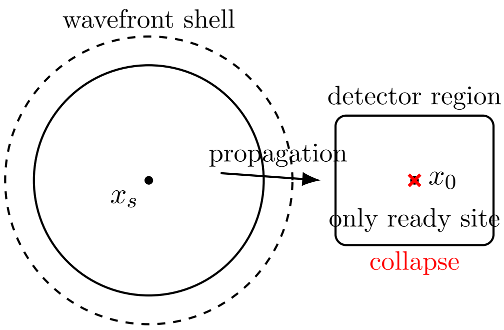


Figure 2: **Single-site collapse.** If only one site x_0 is ready on the shell, collapse is forced there. This illustrates collapse triggering and exclusivity without competition among candidates.

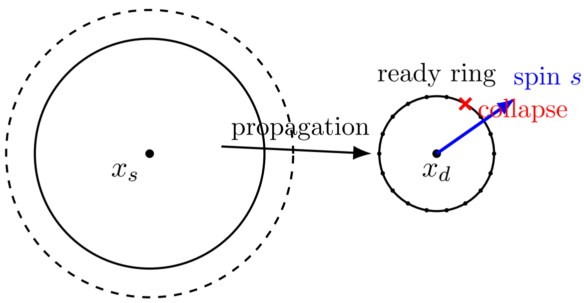


Figure 3: **Multi-candidate station.** A ring detector provides multiple simultaneous candidates. Spin-biased collapse selection produces a measurable outcome distribution, enabling ± 1 station readouts in correlated-pair protocols.

4 Approach A: Single-Spot Nonlocal Collapse (Entanglement Precursor)

4.1 Two distant clusters on one wavefront

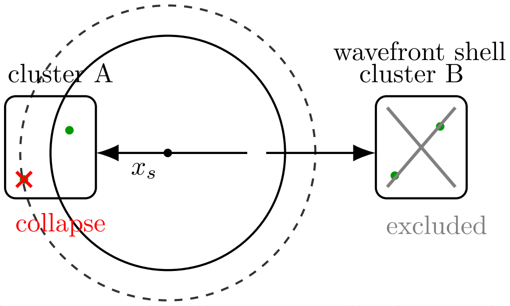
Let A and B be disjoint spatial regions separated by a macroscopic distance. At a given tick t, suppose a single spot's wavefront intersects both regions and both contain ready candidates:

$$C_t = C_t^A \cup C_t^B, \qquad C_t^A = C_t \cap A, \quad C_t^B = C_t \cap B,$$

with $C_t^A \neq \emptyset$ and $C_t^B \neq \emptyset$.

In this configuration, the spot wavefront is globally distributed across the shell, simultaneously "touching" candidates in A and B.

Approach A: One spot, two distant clusters (exclusive collapse)



One collapse event globally removes all other candidates
for that spot event (state reduction).

Figure 4: **Approach A (single-spot nonlocal collapse).** A single spot wavefront intersects two distant ready clusters. Collapse in one region excludes collapse in the other for that spot event (exclusive collapse / state reduction).

4.2 Instantaneous conditioning and global state reduction

Collapse selects one $X \in C_t$. If $X \in C_t^A$, then for the same spot event:

$$\Pr(\text{collapse in } B \mid \text{collapse in } A) = 0.$$

The global candidate state updates instantly: candidates in B become irrelevant because the wavefront no longer exists.

This yields an EDCA analog of state reduction:

- Before collapse: viable outcomes exist in both A and B.
- After observing collapse in A: all B outcomes are excluded for that event.

4.3 Interpretation

Approach A is best understood as an EDCA analog of *single-quantum delocalization*, comparable to "one particle shared between two distant detectors." It reproduces nonlocal exclusivity and global state update, but not a Bell-pair style two-outcome-per-trial experiment.

4.4 No-signaling condition

No station can control where collapse occurs. Therefore the instantaneous global update cannot be used for superluminal communication. Nonlocality resides in conditional state descriptions, not in controllable signaling.

5 Approach B: Correlated Spot-Pair Emission (Bell-Like Analog)

Approach B introduces one additional postulate consistent with EDCA energy dynamics: a local event may emit two correlated spots whose internal states are linked.

5.1 Correlated pair emission postulate

A local transition at source x_s emits two spots S_A and S_B propagating toward distant stations A and B. The two spots carry anti-correlated spin vectors:

$$s_B = -s_A,$$

and optionally anti-correlated polarity or internal parameters. This is the EDCA analog of a singlet-like pair: the pair is created with shared internal structure that induces correlations at distant detections.

5.2 Stations and settings as readiness/density masks

Each station can choose a local setting (measurement basis) by shaping:

- which local sites become ready (readiness mask),
- density bias $\rho(x,t)$ across the station region,
- a geometric mapping from collapse location to discrete outcomes ± 1.

We denote settings by a (station A) and b (station B). The setting affects collapse selection locally, but not the other station directly.

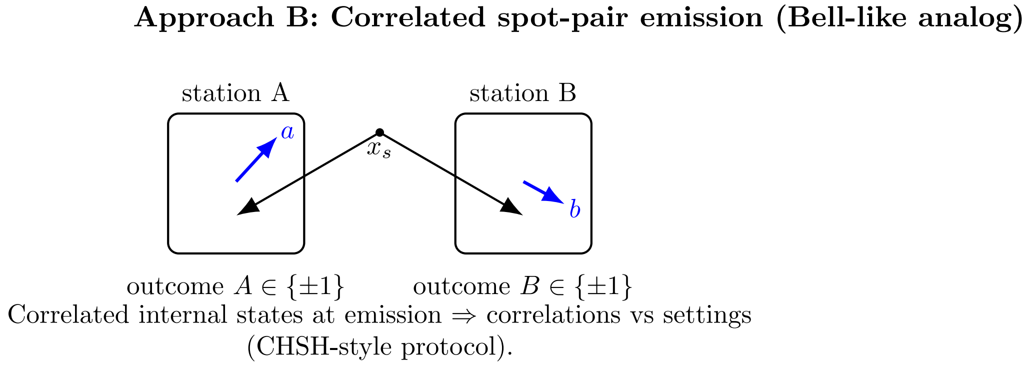


Figure 5: **Approach B (correlated spot-pair emission).** A source emits a correlated spot pair toward two stations with independently chosen settings a, b implemented by readiness/density masks. Each station produces a ± 1 outcome, enabling CHSH-style tests.

5.3 Binary outcome readout

A typical implementation is a ring or shell detector split into two halves relative to the setting direction. The station outputs:

$$A(a) \in \{+1, -1\}, \qquad B(b) \in \{+1, -1\},$$

depending on which half of the station ring/shell contains the collapse.

5.4 Correlation mechanism

Because $s_B = -s_A$ and because collapse selection depends on alignment with the local setting, outcomes become correlated through shared emission conditions. In an idealized smooth-bias regime, the correlation may vary approximately as

$$\mathbb{E}[A \cdot B] \approx -\cos(\theta_{ab}),$$

where θ_{ab} is the relative angle between settings a and b.

5.5 No-signaling in the pair model

Although correlations exist, no station can force an outcome. Each station controls only the setting (readiness mask), not collapse outcome. Thus correlations do not enable faster-than-light signaling.

6 A CHSH-Style Protocol for EDCA (Simulation Procedure)

This section provides an explicit protocol for testing correlation strength in Approach B using an EDCA simulation, analogous to CHSH tests in quantum foundations.

6.1 Protocol overview

We simulate repeated trials in which:

- a source event emits a correlated spot pair (S_A, S_B),
- station A chooses a setting $a \in \{a_0, a_1\}$,
- station B chooses a setting $b \in \{b_0, b_1\}$,
- each spot collapses locally when its wavefront intersects ready sites in its station,
- each station outputs a binary value in $\{+1, -1\}$ determined by collapse location.

We estimate $E(a_i, b_j)$ and compute the CHSH parameter

$$S = E(a_0, b_0) + E(a_0, b_1) + E(a_1, b_0) - E(a_1, b_1).$$

Classical local hidden-variable models satisfy $|S| \le 2$, whereas quantum singlet correlations can reach $2\sqrt{2}$. EDCA may or may not exceed 2 depending on its collapse weighting and correlation postulate; the protocol makes this testable.

6.2 Settings implemented by readiness masks

Each station implements its setting by modifying local readiness and/or density bias to define two outcome regions.

Geometric implementation (ring detector). Let each station be a ring of ready candidates at radius R around a detector center x_d. For a chosen setting direction vector a at station A, define:

- the "+1" region = ring sites with $(x - x_d) \cdot a \geq 0$,
- the "−1" region = ring sites with $(x - x_d) \cdot a < 0$.

Similarly for station B with setting b.

6.3 Collapse weighting (EDCA-compatible form)

A generic EDCA-compatible weighting among candidates is:

$$w(x) \propto \exp\Big(\beta\, p\, s \cdot \hat{d}(x)\Big) \cdot \rho(x,t) \cdot g_\lambda(\|x - x_s\|),$$

where:

- $\hat{d}(x)$ is the station-defined direction toward candidate x,
- $\beta \geq 0$ is spin-bias strength,
- $p \in \{+,-\}$ is polarity (+ favors alignment; − reverses),
- $\rho(x,t)$ biases selection via allocation density,
- g_λ encodes shell gating (sharper for larger λ).

6.4 Choice of CHSH settings

A standard CHSH choice uses four settings with relative angles:

$$a_0 = 0^\circ, \quad a_1 = 90^\circ, \quad b_0 = 45^\circ, \quad b_1 = -45^\circ.$$

In EDCA ring geometry these correspond to four different readiness-mask half-plane splits.

6.5 Trial procedure

For N independent trials:

1. Initialize a source transition at x_s that emits a correlated spot pair (S_A, S_B) with $s_B = -s_A$.
2. Randomly choose $a \in \{a_0, a_1\}$ and $b \in \{b_0, b_1\}$ with equal probability.
3. Configure station A readiness/density mask according to setting a.
4. Configure station B readiness/density mask according to setting b.
5. Evolve EDCA ticks until each spot collapses within its station.
6. Record outcomes $A \in \{\pm 1\}$ and $B \in \{\pm 1\}$ from collapse location.

6.6 Estimating correlations

For each setting pair (a_i, b_j), compute:

$$E(a_i, b_j) = \frac{1}{N_{ij}} \sum_{k=1}^{N_{ij}} A_k(a_i)\, B_k(b_j),$$

where the sum runs over the N_{ij} trials using that setting pair. Then compute

$$S = E(a_0, b_0) + E(a_0, b_1) + E(a_1, b_0) - E(a_1, b_1).$$

6.7 Expected EDCA behavior and parameter regimes

Correlation strength depends on:

- **Spin bias β:** stronger bias yields more deterministic alignment readout and typically larger $|E|$.
- **Shell sharpness λ:** very low λ yields thick shells and may reduce clean station readout.
- **Density bias ρ:** uneven allocation density can skew outcomes; it should be controlled or randomized.
- **Polarity dynamics:** polarity flips upon collapse. The protocol should specify whether each trial resets polarity or uses natural evolution.

Interpretation of $|S| > 2$. If EDCA yields $|S| > 2$ under this protocol, then correlated pair emission combined with readiness-masked settings produces Bell-type correlations beyond classical local bounds.

If $|S| \leq 2$. Even if $|S| \leq 2$, EDCA still reproduces Approach A's nonlocal state reduction and may produce strong correlations consistent with local hidden-variable explanations under the selected weighting.

7 Discussion: "Instantaneous Influence" vs No Signaling

The central intuition underlying the present construction can be stated as follows:

> A spot wavefront can collapse at any tick whenever it intersects a ready site, independent of distance from origin. Therefore two distant clusters on the same wavefront may behave "entangled" because collapse at one instantaneously affects the global state of the other.

EDCA supports this interpretation as *exclusive collapse* and *state reduction*. However, it remains consistent with no-signaling because outcomes are not controllable: stations may choose readiness masks (settings) but cannot force a selected collapse outcome.

8 Conclusion

EDCA's wavefront collapse and exclusivity naturally yield nonlocal state update. Approach A captures this as a single-spot entanglement precursor: a distributed wavefront collapses in one of two distant clusters, excluding all other candidates for that event. Approach B extends EDCA with correlated spot-pair emission and local setting-dependent readiness masks, enabling Bell/CHSH-style correlation tests. We provided a practical protocol for measuring CHSH parameter S as a function of EDCA parameters. Together these models form an EDCA-native framework for entanglement analogs and motivate simulation experiments.

Reference

Raul Sanchez Perez, *Energy-Driven Cellular Automata (EDCA): Foundational Definition, Dynamic Space, and Conservative Properties*, EDCAWorld, Jan 2026.
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