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CONTROL AND COMMUNICATION DESIGNING USING AGE-CAPPED EVENT TRIGGERING UNDER PACKET LOSS

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Why communication freshness matters

- Periodic updates are predictable but consume bandwidth at every sample.
- A static event trigger can save packets yet assume lost updates were received.
- Bursty loss and delay leave a controller acting on stale state.
- Design objective: save communication without compromising adverse-case control.

Research question and contribution

Core question

How should a simple event-triggered controller react when the network becomes temporarily unreliable?

Proposed policy

Weighted state mismatch + acknowledgement-aware reference + hard information-age cap.

This is an evaluated engineering policy—not a general stability theorem.

Networked feedback model

$$\dot{x}(t) = A\,x(t) + B\,u(t)$$

$$u(k) = -K\,\hat{x}(k)$$

- Sensor samples the full cart-pole state every 10 ms.
- Controller acts on the latest non-stale received state.
- Packet delays and losses create a gap between x and $\hat{x}$.

Proposed age-capped event policy

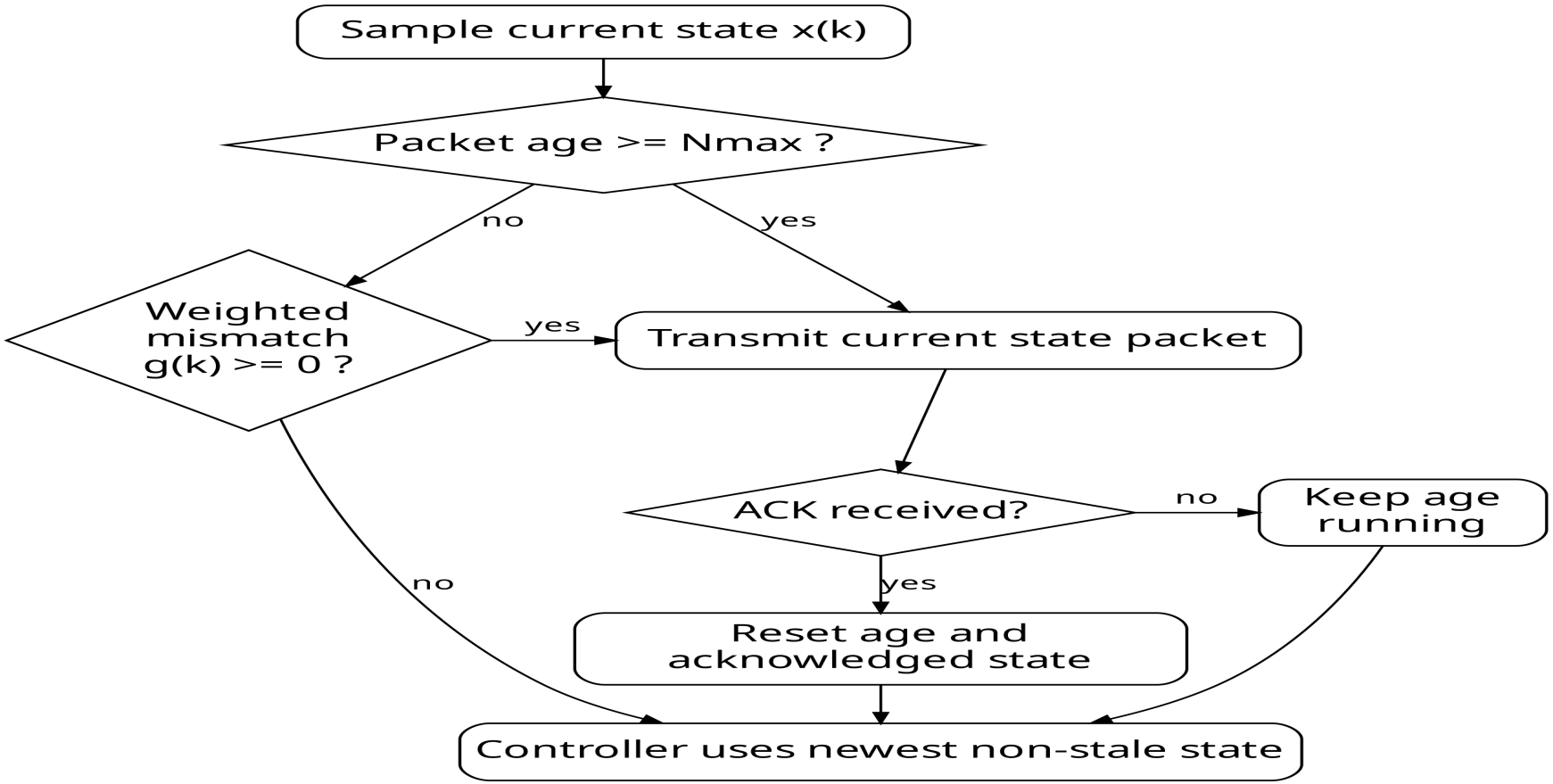
$$e(k) = x(k) - x_a(k)$$

$$g(k) = \sqrt{(e^T W e)} - \varepsilon - \sigma\sqrt{(x^T W x)}$$

$$\text{send}(k) = 1 \quad \text{if} \quad g(k) \geq 0 \quad \text{or} \quad a(k) \geq N_{\max}$$

- x_a is the last acknowledged state—not merely the last attempted packet.
- A lost packet keeps the trigger reference unchanged.
- Sequence numbers reject packets arriving out of order.

Acknowledgement and age-cap decision flow



Benchmark and burst-loss channel

Cart–pole / LQR

Linearized upright cart-pole

$T_s = 0.01$ s; horizon = 10 s

Q = diag(10,1,100,1), R = 0.1

Age cap Nmax = 10 samples

Gilbert–Elliott channel

Two-state, temporally correlated losses

Good-state loss: 0.5%

Bad-state loss: 70%

Successful delay: 1–3 samples

100 matched channel trials

Three policies compared

PERIODIC

Update attempt every sample

1,000 attempts per 10-second trial

STATIC EVENT

Mismatch threshold

Reference updates after attempted send

No age cap

AGE-CAPPED

Mismatch threshold + cap

Acknowledged reference

Repeat after loss

All three policies use the same channel realization at each fixed seed.

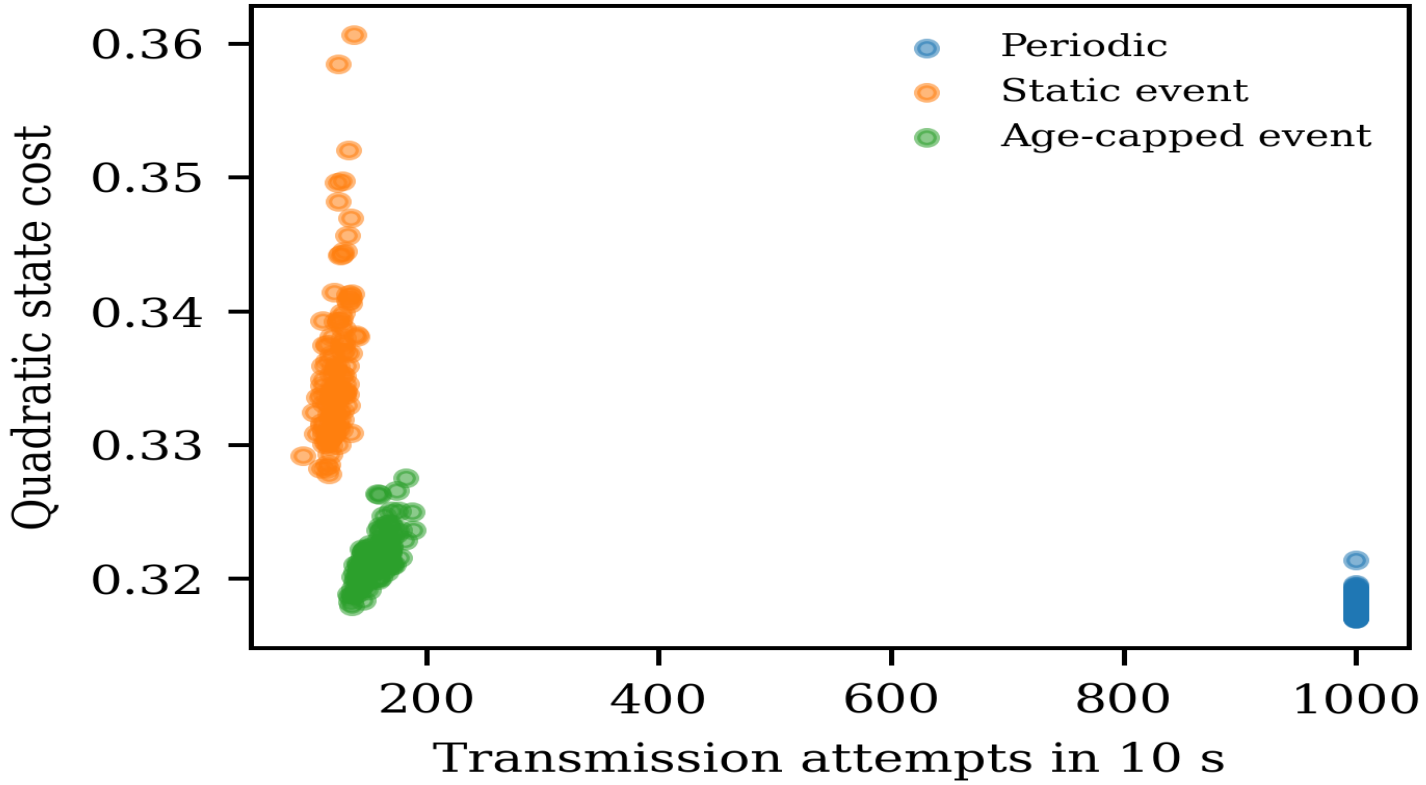
Average control–communication trade-off

Policy	Attempts	Pole IAE	State cost Jx	Mean settle
Periodic	1000.00	0.02889	0.3183	1.342 s
Static event	122.15	0.03908	0.3358	2.101 s
Age-capped	**155.39**	**0.03110**	**0.3215**	**1.372 s**

Main result

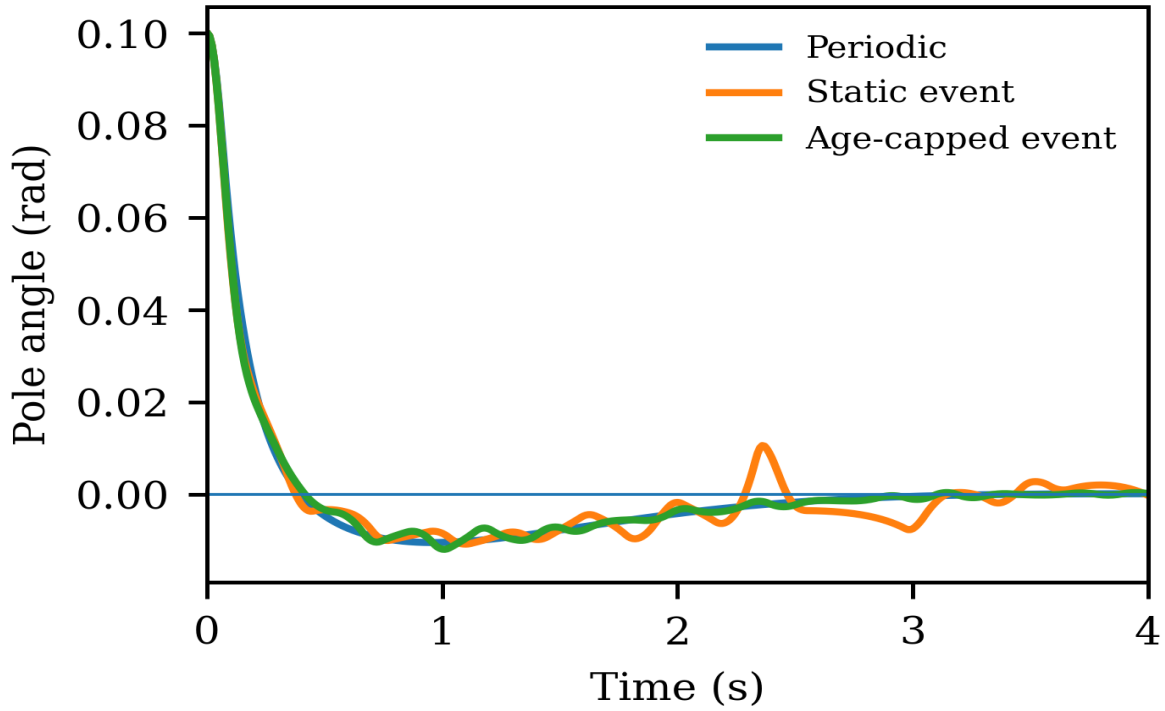
84.46% fewer attempts than periodic, with only 1.02% higher quadratic state cost.

All 100 trials: packets versus state cost



The static trigger uses fewer packets but has worse and more variable control cost.

Stress trial: prolonged bad-channel run



Seed 119

30 consecutive samples in the bad channel

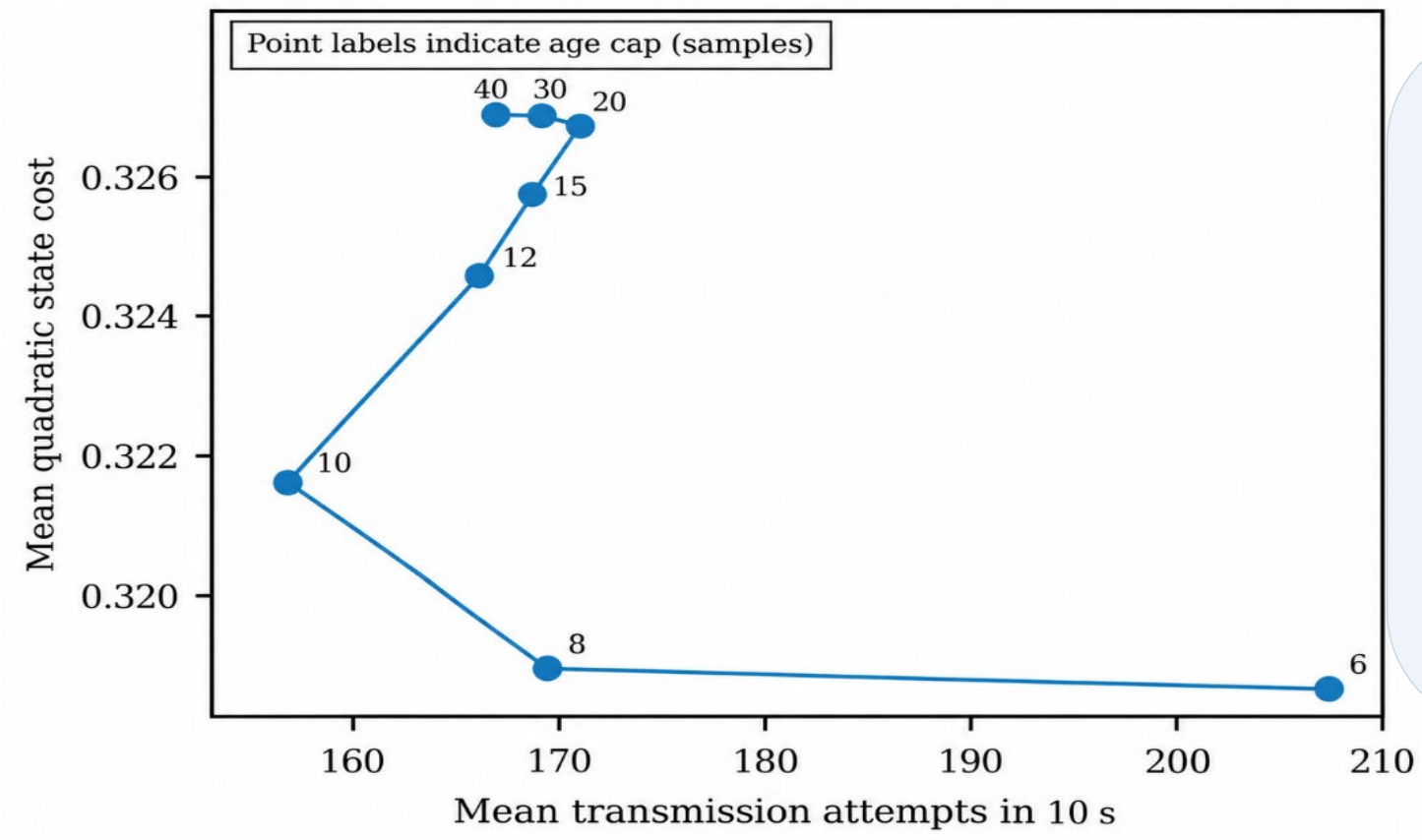
Settling:

Periodic 1.35 s

Static event 6.53 s

Age-capped 1.38 s

Tighter age caps do not always mean more traffic



Closed-loop feedback effect

Refreshing state earlier can prevent larger later deviations and repeated corrective transmission attempts.

The attempts–age-cap relation is non-monotonic.

Information age: engineering interpretation

$$a_{\max} \leq N_{\max} + L + d_{\max}$$

- Applicable if consecutive losses L and delay dmax have deterministic bounds.
- The stochastic burst-loss benchmark has no guaranteed finite worst-case burst.
- Evaluate freshness tails and adverse-case settling, not packet averages alone.

Limitations and extensions

- Linearized cart-pole and full-state sensing; results are simulation-only.
- Acknowledgements are assumed reliable after acceptance.
- The Gilbert–Elliott model does not cover all wireless-channel phenomena.
- Future: observer-based triggers, state-dependent caps and shared networks.
- Validate with measured wireless traces and sensor-side energy metrics.

Conclusions

- An age-capped acknowledged trigger balances traffic and feedback quality.
- 84.46% reduction in transmission attempts; 1.02% higher state cost.
- 95th-percentile settling: 1.41 s age-capped vs. 6.53 s static event.
- Information freshness and acknowledgement state matter more than packet count alone.