Cyrinx 2.0: Measured 65.9 kb/s Schedule-Comparable Acoustic Goodput on a MacBook Pro–Pixel 7a Near-Field Link

Pilot-local reliability weighting and payload-independent microphone diversity

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July 17, 2026

Abstract

We report Cyrinx 2.0, a follow-on evaluation of the MacBook Pro-to-Pixel 7a acoustic downlink. In a prospective, order-balanced eight-pair campaign that retained the prior 48 kHz, five-frame schedule with four 250 ms interframe gaps, a CP96, pilot-spacing-16, 64-QAM rate-2/3 profile achieved **65.875 kb/s** mean strict ordered byte-verified scheduled goodput (65.266–66.641 kb/s; 4,215/4,280 blocks). The receiver used two-channel Android `UNPROCESSED` capture, held-out-pilot selection between the bottom microphone and two-microphone maximal-ratio combining (MRC), and frequency-local known-pilot reliability. Its paired CP240, pilot-spacing-8, 16-QAM rate-3/4 control achieved 44.199 kb/s and recovered 2,999/3,000 blocks. All 16 runs completed and the candidate won all eight pairs (exact one-sided sign test, $p = 1/256$).

The result is 49.0% above the prospective paired control and 1.801× the historical 36.571 kb/s website target. The latter retained the same schedule class but used expected-set membership rather than strict ordered slot attribution. The new candidate failed its predeclared baseline-equivalent reliability gate: 98.481% block recovery versus 99.967% for the control. Replaying identical candidate captures through two frozen receivers isolated an aggregate gain from pilot-local reliability: 4,215 versus 3,868 recovered blocks, or +347, with all eight runs improving. The CP, pilot, modulation, coding, level, and diversity changes otherwise remain a bundle rather than causal ablations. A separate zero-gap class reached 69.652 kb/s at 90.666% recovery; it is not schedule-equivalent and also failed the reliability gate. These are host-decoded, near-field results for one device pair, one route and pose, uninstrumented sound pressure and HVAC state, and no application/ARQ layer.

1 Relationship to the Cyrinx 1.0 report

The original 28-page Cyrinx report established a measured 36.571 kb/s Mac-to-Pixel downlink and 27.307 kb/s Pixel-to-Mac uplink, documented the commodity acoustic channel, and cataloged four physical-layer failures that simulation missed. It remains the system and historical methods paper. This document is a separate Pixel-downlink follow-on: it asks how far measured goodput can be raised without silently changing the accepted schedule class, then records where that optimization lost resilience. Readers should use the original report for prior art, the bidirectional result, channel survey, iPhone and Moto supplements, and the early defect narrative.[1]

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[1] The companion source and PDF are published in the Cyrinx repository.

The techniques are conventional: OFDM, cyclic prefixes, comb pilots, QAM, convolutional coding, soft Viterbi decoding, CRCs, and MRC. The contribution is empirical: a content-bound campaign, a receiver contract that excludes payload leakage, an isolated same-capture receiver comparison, and a detailed record of failed throughput branches.

Claim hierarchy.

- **65.875 kb/s** is the publication flagship: strict ordered byte-verified mean goodput in the same five-frame/four-gap schedule class as the 36.571 kb/s target.
- **49.0%** is the prospective paired improvement over the 44.199 kb/s control. **1.801**× is a comparison with the historical website number, not an isolated algorithmic effect.
- **+347 blocks** is the only same-capture receiver ablation: the aggregate pilot-local reliability estimator versus global-only reliability.
- **69.652 kb/s** is a separate zero-gap research class. It is 1.9045×, not "almost triple," the historical target.

Neither headline is a robustness, generality, bidirectional, real-time, or on-device-decoding claim.

2 Measurement contract

For scheduled slot j, let P_j be its transmitted payload, $\hat{P}_j$ the decoded payload, and L_j its payload length in bytes. Scheduled goodput is

$$G_{\text{sched}} = \frac{8 \sum_j L_j \, \mathbf{1}[\text{CRC}(\hat{P}_j) \text{ valid} \wedge \ \hat{P}_j = P_j]}{T_{\text{scheduled}}}. \tag{1}$$

The denominator runs from the first scheduled frame's chirp through the last scheduled data sample. It includes sync, guard, channel-estimation symbols, comb pilots, FEC, CRC, and declared inter-frame gaps. The verifier retains the slot position: a valid block from another slot does not count. Failed and unattempted scheduled slots remain in the denominator. The campaign also computes a gross denominator that includes declared leading/trailing pads; it does not include ADB orchestration, app launch, analysis time, or a sounder transaction.

This is stronger than the historical 36.571 kb/s verifier. That run checked that each CRC-valid decoded block belonged to the deterministic expected set, but did not retain uniqueness, stream order, or scheduled-slot attribution. The old number is therefore an accepted schedule target, not a byte-for-byte equivalent verifier contract. The paired 44.199 kb/s control is the stronger prospective comparator for inference.

Each primary campaign comprised eight candidate/control pairs with balanced within-pair order and independent deterministic payload seeds. All planned runs, including failures, were retained. The pair is the inferential unit: eight candidate wins have the exact one-sided sign-test probability $2^{-8} = 1/256$ under equal win probability. Block fractions are descriptive, not independent-trial confidence intervals, because blocks cluster within frames and runs.

3 Physical cell and route qualification

Table 1 records the exact cell. The Pixel was face-up on approximately 0.5-inch soft cloth above the MacBook's left function-key area, with the bottom microphone close to the left built-in speaker. The

Table 1: Physical route and campaign contract. Endpoint percentages and waveform peaks are not SPL or acoustic-exposure measurements.

Item	Retained value
Transmitter	M4 MacBook Pro built-in left speaker only; 48 kHz; system volume 50%; floating-point waveform peak 0.18
Receiver	Pixel 7a; Android 17 build fingerprint and HIL APK hash retained; 48 kHz PCM16 stereo `UNPROCESSED`, actual source ID 9
Input mapping	Channel 0: bottom microphone, direct. Channel 1: back microphone, direct. Route reports separate device IDs 23 and 24.
Geometry	Pixel face-up on 0.5-inch cloth above the left function-key area; bottom microphone near the left speaker
Environment	A/C enabled but cycling; room tone and SPL uninstrumented
Schedule	Five frames; flagship has four 12,000-sample (250 ms) gaps; zero-gap class has none
Decode	Captured stereo PCM decoded in batch on the host by a frozen canonical-C/KISS receiver; strict ordered verifier

air conditioner was enabled but thermostat-cycling. Neither room noise nor sound pressure level (SPL) was instrumented.

The level was qualified rather than assumed. At volume 50, an initial 16-QAM control/candidate smoke test recovered 75/75 blocks on both profiles; a reverse-order confirmation recovered 75/75 and 74/75. Volume 70 delivered a larger capture peak (about 0.032 versus 0.015) without clipping, but only 24/75 and 57/75 blocks. More amplitude was therefore not treated as more usable SNR. The qualification is specific to this target, APK, route, pose, speaker channel, sample rate, and geometry.

4 What changed in Cyrinx 2.0

The original profile used a 2048-sample FFT, CP768, pilots every eighth used bin, uniform 16-QAM, rate-3/4 punctured convolutional coding, and 64 data symbols. A conservative CP240 version became the paired control for this campaign. The flagship retained the FFT, band, frame count, data-symbol count, and gaps while changing CP, pilot tax, modulation/coding, receiver reliability, and input diversity. Table 2 makes the bundle explicit.

The CP96/p16/64-QAM-r2/3 geometry has a 3.076 s frame rather than 4.000 s, and 27,392 rather than 19,200 payload bytes per error-free frame. The 66.891 kb/s ceiling is above the measured 65.875 kb/s because 65 of 4,280 scheduled blocks failed strict verification. These calculations explain where headroom came from; they do not attribute the measured gain independently, because changing one item changes the operating point seen by the others.

5 Receiver changes

5.1 Frequency-local known-pilot reliability

The 1.x receiver estimated one pilot-residual EVM^2 value per OFDM symbol and used it for every data bin. This correctly demoted whole corrupted symbols but could not express frequency-selective corruption. The 2.0 receiver first removes the affine pilot phase model, computes known-pilot residual powers, endpoint-replicates an 11-pilot boxcar, and linearly interpolates it onto data bins. For bin k and symbol t, the reliability variance is conceptually

$$\sigma^2_{k,t} = \sigma^2_{\mathrm{sync},k} + 0.25E^2_{\mathrm{global},t} + 0.75E^2_{\mathrm{local},k,t}. \tag{2}$$

Table 2: Profile changes and their engineering rationale. Error-free ceilings are geometry calculations in this listed order, not measured causal effects.

Change	Error-free scheduled ceiling	Rationale and evidence boundary
1.x: CP768, p8, 16-QAM r3/4	36.571 kb/s	Accepted geometry and website target; historical expected-set verifier
CP96 only	46.886 kb/s	Reduces cyclic-prefix overhead. CP48 was unstable under opposite profile orders; CP96 is route-specific, not a universal delay spread prescription.
Pilot spacing 16	50.012 kb/s	Reduces known-pilot tax from 117 to 59 pilot bins and increases data bins from 818 to 876. Sparser pilots reduce observation density.
64-QAM, rate 2/3	66.891 kb/s	Raises coded bits per symbol from 3,272 to 5,256 while strengthening FEC relative to r3/4. Pixel r3/4 and r5/6 screens failed.
Pilot-local LLR reliability	—	Uses the frequency structure of known-pilot residuals; this is the only component with a same-capture comparison.
Held-out-pilot mic0/MRC selection	—	Can exploit both Pixel microphones without consulting payload bins, decoded bits, Viterbi metrics, or CRC. No separate causal increment was measured.
Qualified volume/route	—	Establishes an enabling signal condition; it is not an algorithmic contribution or transferable safety setting.

Only sync and known pilots enter this estimate. Non-finite observations are mapped to low-confidence erasures instead of strong LLRs. A fixed 72-byte receiver-contract structure, deterministic edge/interpolation fixtures, and KISS/vDSP byte-exact decode tests pin these semantics.

5.2 Payload-independent microphone diversity

The C API can demodulate mic0 alone or combine two microphones per subcarrier. In the familiar MRC form, each branch is phase-corrected by its channel estimate and weighted by branch reliability before summation. Blindly choosing whichever full decode passes CRC would leak the outcome into receiver selection and inflate a benchmark. Cyrinx instead partitions known pilots: even pilot ordinals train the phase model, while held-out odd ordinals score mic0 and MRC. The selection is fixed before payload demapping. Payload bytes, ordinary data-bin EVM, decoded bits, Viterbi metrics, and CRC results are forbidden inputs.

In the zero-gap confirmatory campaign, this rule selected MRC for 26 of 40 candidate frames and mic0 for 14. The counts demonstrate that both paths were actually exercised; they do not establish an oracle comparison or isolate a diversity gain. The route exposed bottom and back microphones directly, but the close bottom microphone remained best often enough that unconditional MRC was not assumed.

6 Prospective campaign construction

The campaign was designed dry before playback. An execution plan bound the Pixel serial/model/build, installed APK hash, route signature, calibration qualification, profile parameters, sample-integral schedule, balanced order, payload seeds, Python referee modules, canonical C sources, KISS inputs, and runtime receiver contract. The decoder was built from retained source snapshots, made read-only, hashed before playback, and rehashed afterward. Every scheduled run produced a manifest entry even on failure.

This process addressed three recurring benchmark hazards: silently changing an Android audio source, optimizing against the same payload used for scoring, and rebuilding a decoder after seeing captures. It does not make the current public repository a complete reproduction package. The raw PCM, frozen binaries, full manifests, and replay reports remain in ignored local `artifacts/`; tracked ledgers retain exact aggregates and content hashes. The hashes can authenticate a future archive, but do not reconstruct the missing bytes.

7 Flagship result

Table 3 reports both throughput and resilience. The candidate won all eight pairs, completed all runs, and exceeded the prospective control by 49.0% in mean scheduled goodput. It nevertheless recovered 1.486 percentage points fewer blocks than the control. The campaign's baseline-equivalent reliability gate therefore failed.

Table 3: Primary results. "Gross" includes declared stream pads. The control gross mean is not retained in the compact public ledger.

Metric	Flagship candidate	Paired control
Configuration	CP96/p16/64-QAM r2/3	CP240/p8/16-QAM r3/4
Mean scheduled goodput	**65.875 kb/s**	44.199 kb/s
Observed run range	65.266–66.641 kb/s	not retained in compact ledger
Mean gross goodput	64.562 kb/s	not retained in compact ledger
Strict verified blocks	4,215/4,280	2,999/3,000
Block recovery	98.481%	**99.967%**
Pair wins	8/8	0/8
One-sided sign test	$p = 1/256$	—
Reliability gate	**failed**	reference

Figure 1 places this point beside the complete zero-gap campaigns. Vertical whiskers are observed run minima and maxima, not confidence intervals. Every candidate in the figure won 8/8 pairs and every candidate failed its baseline-equivalent reliability gate.

8 Same-capture receiver comparison

The fresh flagship captures were replayed through two frozen decoders with identical capture identity, timing, decode margins, payloads, and automatic diversity policy. The only receiver-family difference was global-only versus pilot-local reliability. The legacy receiver recovered 3,868/4,280 blocks (90.374%); the current receiver recovered 4,215/4,280 (98.481%). The +347 blocks are an 8.108-percentage-point gain, and reduce failed blocks from 412 to 65. All eight runs improved and none regressed.

Because all other profile changes are held fixed in this replay, it is the strongest causal evidence in the 2.0 campaign. It does not isolate microphone selection, which is the same on both sides, and it does not show that the specific smoothing width or blend is optimal.

9 Separate zero-gap frontier

Removing the four 250 ms gaps changes the schedule and denominator class. It is useful for studying continuous streaming but cannot replace the schedule-comparable flagship. The highest eight-pair

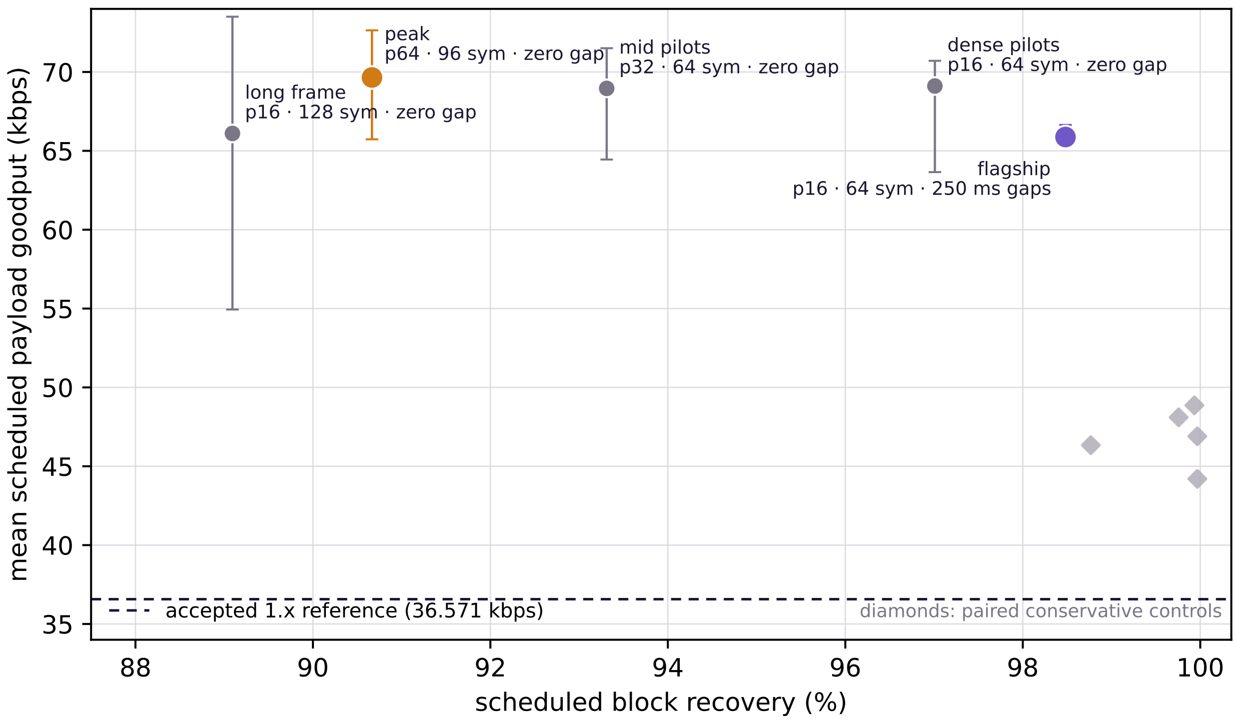

Figure 1: Observed goodput–recovery trade space from five separate complete campaigns. Circles are candidates, diamonds their paired controls, and vertical whiskers are observed per-run ranges. The sessions were not a randomized pilot/frame-length factorial; no causal trend line is implied.

mean used CP96, pilot spacing 64, 64-QAM rate 2/3, and 96 data symbols: 69.652 kb/s scheduled (65.731–72.641), 68.636 kb/s gross, and 6,129/6,760 recovered blocks (90.666%). Its control achieved 48.103 kb/s and 4,509/4,520 blocks (99.757%). It won 8/8 pairs and failed the reliability gate.

Table 4: Cross-session observed frontier. All candidates used CP96 and 64-QAM rate 2/3. Values are descriptive rather than a randomized factorial.

Pilots / symbols / gap	Mean kb/s	Range kb/s	Blocks	Recovery
16 / 64 / 250 ms	65.875	65.266–66.641	4,215/4,280	98.481%
16 / 64 / zero	69.110	63.650–70.708	4,152/4,280	97.009%
32 / 64 / zero	68.960	64.449–71.507	4,143/4,440	93.311%
64 / 96 / zero	**69.652**	65.731–72.641	6,129/6,760	90.666%
16 / 128 / zero	66.102	54.938–73.504	7,662/8,600	89.093%

The observations do not show a monotonic amortization win. The denser p16 64-symbol zero-gap profile gave nearly the peak mean with materially higher recovery. The 128-symbol run was slower and less reliable than the shorter zero-gap alternatives. Since configurations were run in separate sessions, these differences may mix pilot density, frame length, channel drift, HVAC, and other temporal variation.

10 Setbacks and rejected branches

Optimization was dominated by branches that appeared plausible in rate arithmetic and failed over the air. Table 5 retains the failures so that the 65.875 kb/s result is not mistaken for a monotonic sweep to

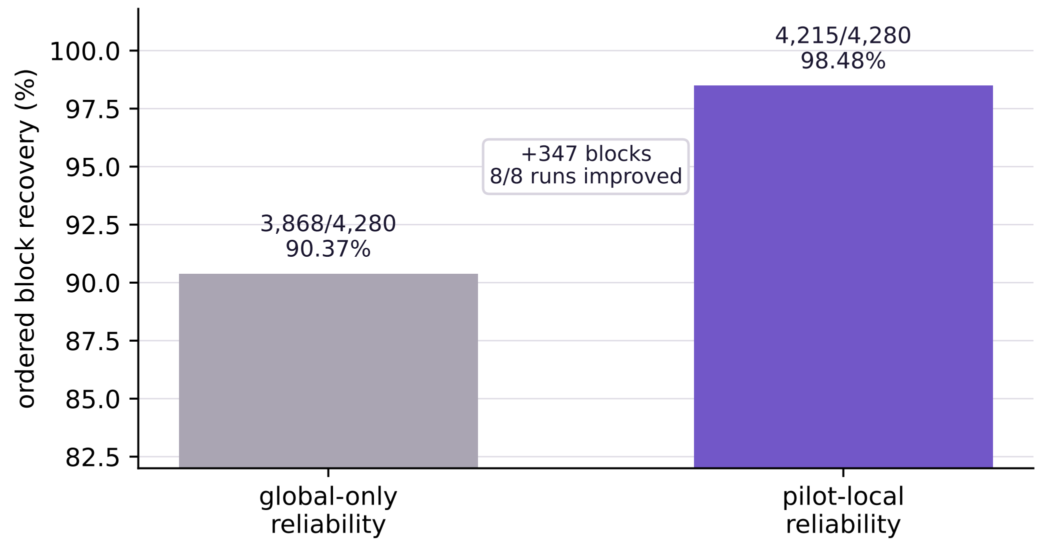

Figure 2: Aggregate same-capture receiver replay. The retained PCM and slot timing are identical; only global-only versus pilot-local reliability changes. This isolates the estimator as a bundle, not its boxcar, interpolation, edge, or 25/75-blend subcomponents.

a predetermined answer.

Table 5: Negative and inconclusive Cyrinx 2.0 experiments.

Branch	Measurement	Interpretation
CP48	Candidate-first screen: 93/107, 63.277 kb/s. Opposite order: 64/107, 43.546 kb/s. Both CP240 controls: 75/75.	The apparently fast first screen was order-sensitive; CP48 was not promoted.
64-QAM rate 3/4	87/121 blocks, 57.925 kb/s, versus 75/75 control.	More code rate did not produce usable net goodput at this constellation density.
64-QAM rate 5/6	24/134 at volume 50 (15.979 kb/s); 21/134 at volume 60 (13.982 kb/s).	Weaker FEC failed, and more level did not rescue it.
Lower edge 600 Hz	60/110, 39.948 kb/s, versus 77/77 control.	Stopped at the predeclared gate. With no reverse order or same-MCS 1.1 kHz control, this rejects promotion but does not isolate the lower edge causally.
Volume 70	Higher capture peak without clipping; only 24/75 and 57/75 versus near-error-free volume-50 qualification.	Endpoint level is not a monotonic proxy for post-DSP demodulation quality.
128 symbols	66.102 kb/s and 7,662/8,600 (89.093%).	Longer frames did not amortize their way to a better result in this session.

Branch	Measurement	Interpretation
Fixed-comb channel tracking	Frequency-local changes remain interpolated between repeatedly observed pilot bins.	A decision-directed update at $\alpha = 0.05$ may propagate wrong 64-QAM decisions; it remains unvalidated and unshipped.
Both speakers, same waveform	Historical left+right playback in this geometry raised EVM from about 0.06 (left only) to about 0.5.	Blind summation is not MIMO. The second speaker needs orthogonal sounding and precoding/spatial multiplexing, not duplication.

The results also corrected an earlier over-broad statement that uniform 64-QAM "does not close." High-rate 64-QAM r3/4 failed in the earlier cell; 64-QAM r2/3 closes with the current CP, pilot lattice, local reliability, and qualified route. A modulation name without code rate, CP, pilots, receiver, and cell is not a portable claim.

11 Calibration and device policy lessons

The research harness now constructs a deterministic tone matrix: the Mac left speaker is exercised while both Android input channels are retained, a safety gate is evaluated, and then the right speaker is exercised. Ramped single tones from 997 Hz through 21.001 kHz and two intermodulation pairs measure the end-to-end speaker–room–microphone–OS path. Sync markers estimate clock and alignment; the plan binds the target, route, calibration artifact, and exact waveform hashes. This is relative channel characterization, not an SPL meter, and two logical channels alone do not prove independent capsules.

The current physical runner measures the two Mac outputs against the two Android inputs. A complete product calibration should generalize this to every available transmitter/receiver pair, including each device's own speaker-to- microphone paths where simultaneous platform routing permits it. That same-device matrix is a design requirement, not a completed 2.0 feature.

Orientation is useful context but not a sufficient Android source policy. A face-down accelerometer state suggests that a rear-facing capsule may be exposed, but OEM routing can map `CAMCORDER`, `UNPROCESSED`, `MIC`, stereo masks, and sample rates differently. Cyrinx therefore binds an observed route signature and tone response. On this face-up Pixel, 48 kHz stereo `UNPROCESSED` exposed direct bottom and back channels; selecting `CAMCORDER` merely from pose would have discarded measured evidence. A future policy can use accelerometer pose as a prior, then confirm the actual route with a short tone check.

12 Ultrasonic and pleasant-audible modes

The companion research record demonstrates a one-way ultrasonic profile, not an integrated 2.0 mode. At 96 kHz, the Mac-to-Pixel route carried about 9 kb/s in 18.5–23.9 kHz using 16-QAM rate 3/4 with 39/39 blocks recovered. The reverse coherent route did not close: Pixel and iPhone micro-speakers radiated high-frequency power but exhibited large phase jitter above about 18 kHz. Figure 3 shows the retained iPhone repetitions.

An integrated ultrasonic mode therefore needs a C profile, 96 kHz route and capability negotiation, device-specific characterization, and a non-coherent phone-uplink fallback such as energy-detected MFSK or OOK. The likely symmetric rate is much lower than the audible downlink because the mobile transmit transducer, not the nominal bandwidth, is limiting.

A "pleasant audible" mode has not been implemented or listening-tested. The credible research direction is perceptual spectral shaping rather than a claim that ordinary OFDM static can simply

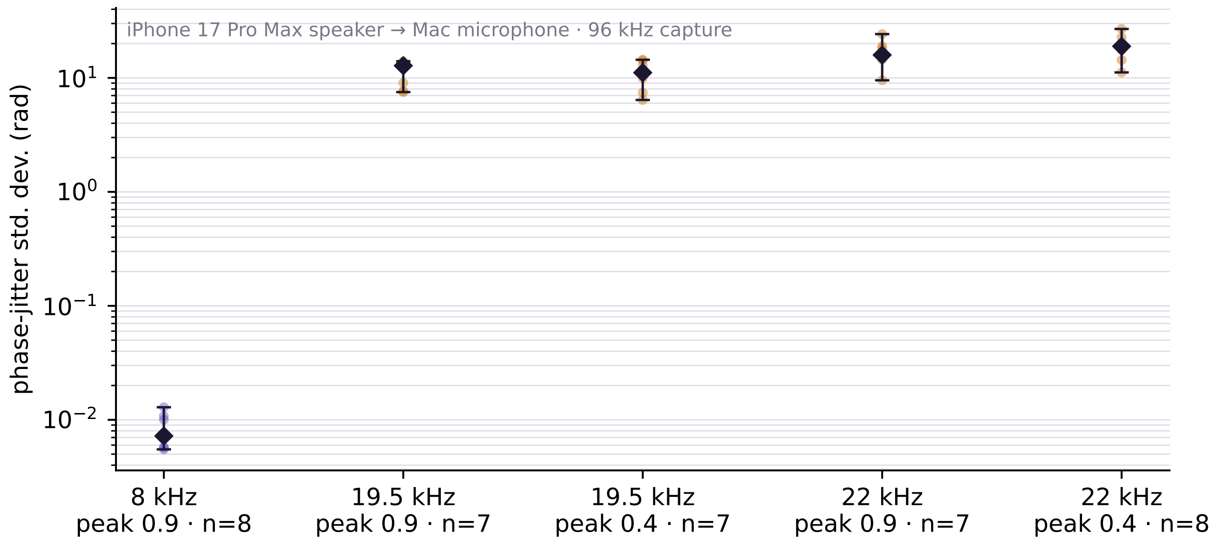

Figure 3: Detrended phase jitter for the iPhone 17 Pro Max speaker measured by the Mac microphone at 96 kHz. Points are 7–8 retained valid repetitions per condition; diamonds and whiskers show median and observed range. High-frequency power is present, but the phase coherence needed by QAM is not.

be made quiet: measure room tone, reserve frequencies near masking energy, window transitions, avoid chirp-like onsets, constrain crest factor, and optimize a lower-rate waveform under a declared listening protocol. Candidate approaches include sparse/staggered tones, shaped spread spectrum, or perceptually weighted OFDM. The objective must include listener ratings and acoustic level, not goodput alone.

13 Implementation convergence

The portable C codec is the canonical PHY implementation. It owns modulation, FEC, demodulation, MRC, automatic receiver selection, and pilot-local reliability. Swift is a thin binding and retains deterministic contract tests. Python remains valuable as an independently implemented research oracle and campaign referee. The Android Kotlin demodulator is still a legacy fork; the Pixel 2.0 campaign captured PCM on Android and decoded it with frozen C on the host rather than through an Android JNI binding.

This four-language state is a real drift risk. The convergence plan is not to rewrite the same DSP four times: bind Android to the C core through JNI, keep Swift thin, retain Python only where independence improves verification, and run every binding against the same receiver-contract and captured-waveform fixtures before retiring Kotlin DSP. Until then, Cyrinx 2.0 is not a real-time mobile transport mode.

14 Threats to validity and next experiments

The strongest claim is narrow by design. It covers one Mac, one Pixel, one near-field pose, one Android route, one speaker channel, and a short campaign on one day. HVAC cycled, room tone and SPL were uninstrumented, and the phone was unusually close to the laptop speaker. The result is downlink-only. It does not include app/ADB setup, a preceding sounder, ARQ, retransmission latency, or application framing. Host-side batch decoding does not establish real-time CPU, buffering, or on-device behavior. Eight pairs support the exact within-session sign test but not broad device or room generalization.

Multiple development screens preceded the fresh confirmatory campaign. The prospective pair design protects the final comparison, but the selected profile is still the product of exploratory work in this cell. The raw evidence is locally retained but not yet in a public archival bundle. Finally, the automatic selector's 26/14 decisions prove payload-independent operation, not that the selector is optimal.

The next research sequence is:

1. qualify reliability first: replicate across days, HVAC states, levels, small offsets, and held-out devices; optimize an explicit goodput–loss objective rather than the mean alone;
2. run a randomized pilot-spacing/frame-length factorial, including staggered known pilots and a code rate near 0.70;
3. integrate the C receiver on Android, measure real-time end-to-end transport with block ARQ, and include sounding/cold-start overhead;
4. execute the separately labeled fixed 3-foot campaign, remeasuring route, room tone, level, and delay spread rather than inheriting the near-field profile;
5. test orthogonal two-speaker sounding and a true 2×2 channel matrix before attempting precoding or spatial multiplexing; and
6. evaluate ultrasonic and pleasant-audible modes under per-device calibration and, for pleasant audio, a preregistered listening metric.

15 Conclusion

Cyrinx 2.0 raises the measured Mac-to-Pixel mean from the accepted 36.571 kb/s schedule target to 65.875 kb/s, and from its prospective paired control's 44.199 kb/s by 49.0%. The gain comes from shorter guards, lower pilot overhead, 64-QAM with stronger rate-2/3 coding, a qualified route, frequency-local known-pilot reliability, and payload-independent use of two microphones. Same-capture replay attributes +347 recovered blocks to the local reliability receiver as a bundle. The candidate's 98.481% recovery remains below the control's 99.967%, and the faster 69.652 kb/s zero-gap class falls to 90.666%. The engineering conclusion is therefore not that near-field acoustic goodput has been maximized; it is that materially higher measured goodput is available, while reliability-qualified generalization is now the limiting problem.

A Evidence bindings and availability

The tracked aggregate source is the repository's Pixel results ledger. The tracked route-qualification bundle retains target, route, and level provenance. The manuscript figures are generated by `gen-cyrinx2-paper-figures.py` from that ledger and the tracked iPhone phase-coherence JSON.

Table 6: Content bindings for the two primary campaigns.

Artifact	SHA-256
Flagship plan	`fe295a7835061ccb55f9ffe277c455c` `97b3487decb6e9da38b01af61c32e05ef`
Flagship completed manifest	`3d46bf7eccf669a6d29ca6593662c6c4` `23710c24062aebe6c9ec16ddf7646ec6`

Artifact	SHA-256
Flagship frozen decoder	`bd7e52acaf1d9c7a1994d5a350af8ba f2ea2fef03f47ed3a0f59fd8513c0327c`
Same-capture replay file	`57522f6b3cafb5e925a2bfbb1ea70e54 48999a17052aa3201a6f4f91367009bc`
Same-capture canonical content	`e25d099550d4e72b9686a6bf5a3c54e c6b7b75b5eb52aa761bca42994e12a50b`
Zero-gap plan	`8e5f1062dcccc42bbfac866a8659bf8d 1884dd54bb054a9f42d944a1919e966b`
Zero-gap completed manifest	`9846a33717c18e457169578217dbbdabe 740eaa26c09965cb24ce128c9d1e462`
Zero-gap frozen decoder	`c6e4e5adc0865a379dc036c549cef4cd 91528152ffffa66ee2fdf9be47580956`
Route signature, canonical JSON	`8da17a36acdd7a79d0f70f9fc085b99 a8faf508f862387edec3b093180a827d0`
Calibration qualification	`ec28faa1b67bfcea8a615ee4b6dd6d85 f3427d79fae075e30b5b6ffd84ff165d`
Target provenance	`5f87abe17227315ae77ea3632bdd21cbf e3364ae5875b1f7d35ca2a04a0c8251`

The ledgers and qualification records are public in the source tree. Full manifests, raw captures, frozen binaries, and detailed replay reports are currently ignored local artifacts. A stable supplemental archive is required before describing the experiment as publicly reproducible from raw PCM.