

WOOF IS A METAPING

A Quantum Bioacoustic Network Protocol Framework for Scale-Invariant Computational Ethology

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ABSTRACT

Traditional ethological paradigms classify domestic canine vocalizations (specifically barks) as analog, stochastic emotional outbursts lacking structured informational encapsulation. This paper introduces a rigorous counter-framework: the canine bark as a discrete, time-bounded, high-density telemetry packet—termed a **Metaping**. By decomposing the acoustic wave structure via a non-linear source-filter model, we demonstrate that a single vocal event mathematically embeds multi-layered metadata headers, including allometric scaling parameters (immutable physical mass signatures) and dynamic arousal vectors. Furthermore, we model the temporal distribution of successive packets as an adaptive polling cycle designed for environmental echoic mapping and peer-node network state manipulation. This framework shifts the study of computational bioacoustics from behavioral descriptions to formal information-theoretic protocol decoding.

1. Introduction & Theoretical Paradigm Shift

For decades, mammalian bioacoustics has struggled with the challenge of cross-species semantic mapping. In the study of the domestic canine (*Canis lupus familiaris*), vocalizations have historically been processed through continuous, classical emotional state models. These models look at acoustic parameters like duration, peak frequency, and average harshness to interpret internal affective states such as "fear," "aggression," or "playfulness." While useful at a high level, these frameworks fail to explain how animals decode structural traits—like body size and exact location—instantly across diverse physical environments.

This paper proposes a paradigm shift by treating canine communication through the lens of modern network communications and information theory. We model the individual vocalization event (the "Woof") not as an unguided analog stream, but as a quantized, packetized transmission. This **Metaping** operates similarly to an Internet Control Message Protocol (ICMP) ping but with a key difference: rather than verifying simple network presence, the acoustic packet broadcasts a dense, unforgeable metadata header that establishes the sender's biometric profile and updates local network nodes in real time.

2. The Quantum Wave Packet (Time-Domain Analysis)

A bark is characterized by a rapid acoustic onset, high peak amplitude, and sudden decay, distinguishing it from continuous vocalizations like growls or whines. Because of these distinct time boundaries, the event cannot be

analyzed as a continuous wave. Instead, we model the total acoustic pressure wave $W(t)$ as a discrete, time-frequency localized energy quantum:

$$W(t) = \Pi(t) \cdot [S(t)]$$

Where $\Pi(t)$ is a smooth, asymmetric temporal gating window that enforces the physical boundaries of the packet from its initiation (t_{start}) to its resolution (t_{end}). This windowing function is mathematically defined by a dynamic Gaussian envelope with a rapid attack phase and exponential decay:

$$\Pi(t) = \exp(- (t - t_0)^2 / (2\sigma^2(t))) \cdot H(t - t_{start})$$

In this equation, t_0 represents the exact temporal point of maximum amplitude velocity, and $\sigma(t)$ is a time-varying scaling factor that remains small during the initiation envelope (producing a sharp onset) and widens during the decay envelope. The causal activation of the packet is strictly enforced by the Heaviside step function, $H(t)$.

3. The Metadata Manifest: Source-Filter Deconstruction

The internal core signal $S(t)$ contained within the temporal gating window is governed by a non-linear source-filter mechanism. This mechanism separates the raw physiological generation engine from the resonant chambers of the upper vocal tract:

$$S(t) = [E(t) * V(t)] + N(t)$$

Where $*$ denotes mathematical convolution, separating the glottal energy source, the vocal tract filter envelope, and ambient turbulent noise.

3.1. The Glottal Source Engine [Arousal Modulation]

The vocal cord vibration generates a quasi-periodic sequence of asymmetric acoustic pulses that dictate the fundamental frequency (f_0) of the transmission. This carrier wave is defined as:

$$E(t) = \sum_{k=1}^K A_k(t) \cos(2\pi k \int_0^t f_0(\tau) d\tau + \phi_k)$$

The instantaneous trajectory of $f_0(t)$ maps directly to structural motivational states. High-velocity upward shifts in the fundamental frequency signal escalating alert levels and immediate network engagement requirements, while stabilized, low-frequency base frequencies project spatial dominance.

3.2. The Vocal Tract Filter [Biometric Metadata Header]

As the glottal pulse train $E(t)$ travels through the pharyngeal and oral cavities, it is shaped by an acoustic filter that produces resonant peaks known as formants. In the discrete Z -domain, this physical filtering process is modeled as an autoregressive Linear Predictive Coding (LPC) all-pole transfer function:

$$V(z) = 1 / [1 - \sum_{i=1}^P a_i z^{-i}]$$

The roots of the denominator polynomial yield complex conjugate pairs that reveal the exact frequencies of the dominant formants ($F_1, F_2, \dots, F_n$). Because these formants are bounded by the physical vocal tract length (L), their dispersion pattern (ΔF) provides an unforgeable physical signature:

$$\Delta F = [1 / (N-1)] \sum_{i=1}^{N-1} (F_{i+1} - F_i) = c / 2L$$

Where c is the speed of sound in warm air (~350 m/s). Because vocal tract length correlates directly with skeletal dimensions across mammalian phenotypes, the system extracts the sender's actual structural mass (M_{kg}) using an allometric power-law transformation:

$$M_{kg} = \alpha (c / 2\Delta F)^\beta$$

Security Properties of the Biometric Header: Because formant dispersion is determined entirely by physical skeletal geometry, a small canine node (e.g., a Chihuahua) cannot spoof its metadata header to mimic the scale profile of a large node (e.g., a Mastiff), ensuring secure identity validation within the acoustic network topology.

3.3. Chaotic Noise Injection [Valence Optimization]

To convey urgent state changes or defensive boundaries, the packet injects a non-linear deterministic noise component, $N(t) = \gamma(t) \cdot \xi(t)$, where $\xi(t)$ represents zero-mean Gaussian white noise and $\gamma(t)$ is a scaling envelope controlled by the Harmonic-to-Noise Ratio (HNR). A high noise ratio (low HNR) strip-mines harmonic structure, signaling localized threat states or aggressive deterrence.

4. The Network Ping Protocol & State Transitions

A single packet compiles these acoustic parameters into an unified Telemetry Packet Matrix (Ψ_w), mapping physical variables directly to intent vectors:

Acoustic Parameter	Encoded Metadata Layer	Network Telemetry Function
Fundamental Freq. (f_0)	Arousal & Urgency Tracking	System priority indicator and internal state-change velocity.
Formant Dispersion (ΔF)	Biometric Scaling Header	Unforgeable verification of sender mass and physical dimensions.
Harmonic-to-Noise (HNR)	Signal Valence Filter	Determines cooperative/play (+) versus defensive/threat (-) state.
Inter-Bark Interval (IBI)	Temporal Network Pacing	Adjusts polling rates based on environmental echo or target distance.

4.1. Environmental Echoic Mapping

When a node broadcasts a packet, it measures environmental parameters by tracking the echoic return latency (τ_e). This calculation defines the distance to local obstacles or physical boundaries:

$$\tau_e = 2 \cdot d_{obstacle} / c$$

By modulating the Inter-Bark Interval (IBI), the node optimizes its transmission loop to prevent echo collisions, behaving like an automated network diagnostic tool mapping local topography.

4.2. Target Node State-Space Transformation

When a receiving node j at distance d_{ij} intercepts the metadata matrix, its internal state vector (X_j) adjusts based on the incoming signal, attenuated by geometric distance:

$$X_j(t + \tau_p) = X_j(t) + \Omega \cdot [\Psi_W \cdot (1 / d_{ij}^2)]$$

Where τ_p is the propagation delay (d_{ij} / c) and Ω represents the receiver's baseline sensitivity matrix. This equation demonstrates how a single packet works as an automated network routing instruction, updating the behavioral states of surrounding nodes.

5. Algorithmic Applications & Zero-Shot Models

Understanding the canine bark as a structured data packet allows us to improve machine learning architectures for cross-species decoding. Current models require vast amounts of labeled data for each specific breed. By introducing an allometric normalization layer based on equation (6), we can remove variations caused by physical body size.

This allows self-supervised audio models like WavLM or HuBERT to perform zero-shot intent decoding. By separating the biological structure from the intentional payload, neural networks can process vocal inputs from any domestic canine through a single, shared semantic model.

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