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THE DIGITAL EXPERIENCE

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Introducing a Start of Word Correction for Access Delay Measurements

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Acronym Index

- Mission Critical Voice (MCV)
- System Under Test (SUT)
- Word Under Test (WUT)
- Push To Talk (PTT)
- Key Performance Indicator (KPI)
- Quality of Experience (QoE)
- Modified Rhyme Test (MRT)
- Articulation Band Correlated Modified Rhyme Test (ABC-MRT)

Overview

- Quality of Experience Based Measurements
- Access Time Measurement System
- Intelligibility
- Access Delay Model
- Start of Word Correction
- Interpretation
- Effect

Quality of Experience Based Measurements

- QoE KPIs for Mission Critical Voice (MCV)
  - Mouth-to-Ear Latency
  - Access Time
  - Voice Quality/Intelligibility
  - Probability of Successful Delivery

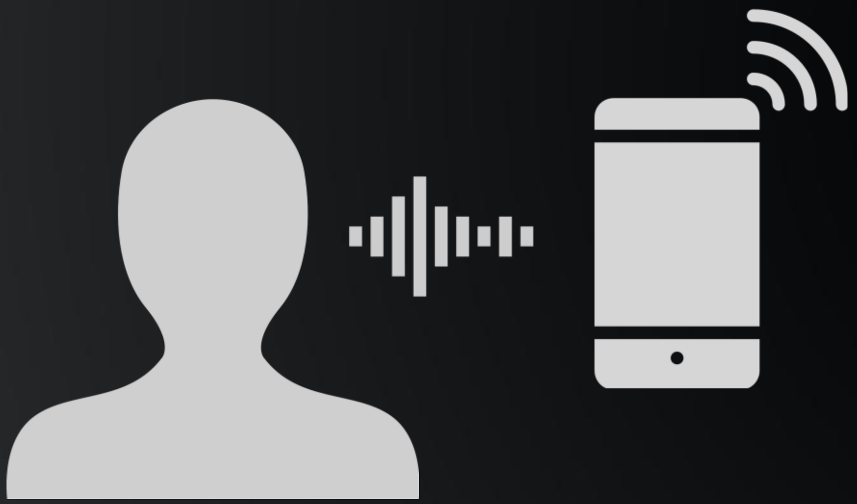
The User Experience: PTT Communications

- Press PTT and speak into a device
- Listening to speech output from a device
- It is all about <u>speech</u>

- Goal - Create measurement systems that are:
  - Based upon the user experience -- speech
  - Comparable and fair across technologies
- This is not:
  - Analyzing internal system design/construction

Technology Agnostic Measurements

Communications System



KPIs:

- Mouth-to-ear Latency
- Access Time
- Intelligibility
- Probability of Successful Delivery

User Driven Access Definition

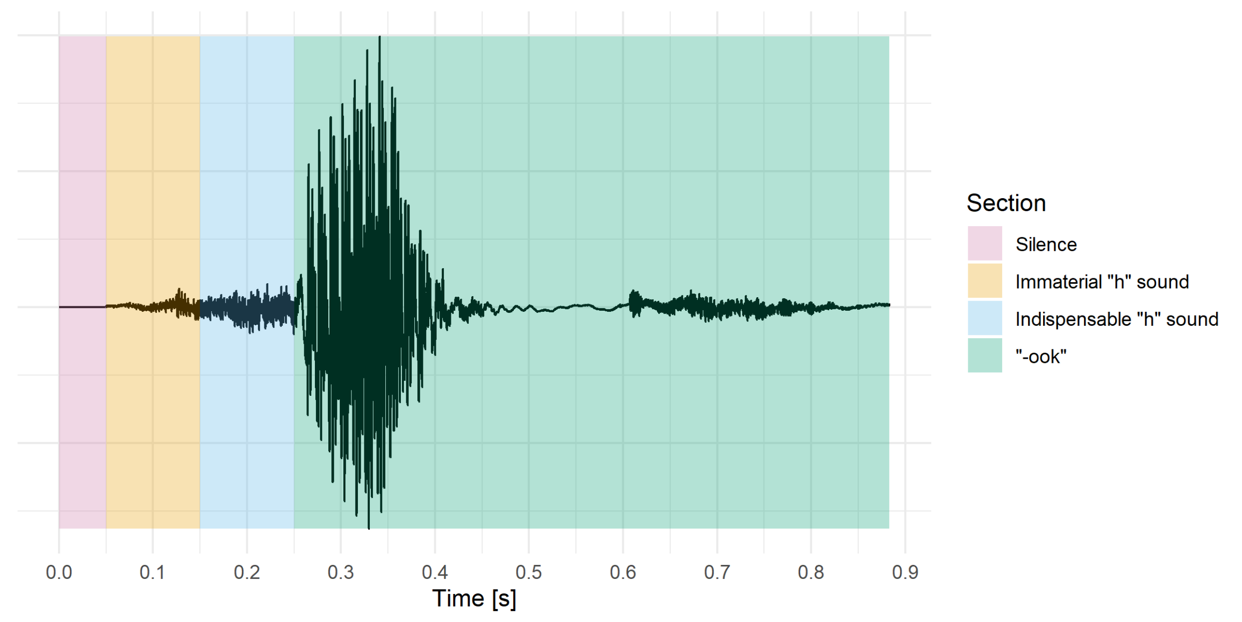
- End-to-end Access Time
  - *The total amount of time from when a transmitting user first presses PTT until a receiving user hears intelligible audio*
- Two components:
  - Mouth-to-Ear Latency
    - *The time between speech being input into one device and its output through another*
  - Access Delay
    - *The minimum length of time a user must wait between pressing a PTT button and starting to speak to ensure that the start of the message is not lost*

Formalizing Access Delay

- Access Delay
  - All about if a message is lost or not
  - Intelligibility is the key to the measurement
- Formal definition
  - *The minimum length of time a user must wait between pressing a PTT button and starting to speak to ensure that the first word of the message has an average intelligibility that is no lower than* $\alpha \cdot I_0$
  - $0 < \alpha < 1$, defines acceptable intelligibility level
  - I_0 is the baseline intelligibility of that word through the communications system
    - No system is perfectly intelligible
    - Some level of degradation almost always present

Start of Word Correction - Intuition

- Think about the word “hook”
  - Hear and choose from list of
    - took, cook, look, hook, shook, book
  - Long “h” sound, takes up 200 ms
  - Need 100 ms to understand “hook” from “took”, “look”, etc…
  - Audio clip: 50 ms of silence at beginning
- Problem
  - Currently this extra 150 ms gets misrepresented in access delay measurements



Intelligibility

- Modified Rhyme Test (MRT)
  - Batches of six words
    - *went, sent, bent, dent, tent, rent*
    - Words: consonant-vowel-consonant
    - Each batch: Either leading or trailing consonant varies
  - MRT Trial
    - Carrier phrase + word
    - e.g. “Please select the word *went*”
    - Success (identified) or Failure (mis-identified)
- ABC-MRT16
  - Objective algorithm to estimate MRT scores
  - Get results “on demand”
- For more information see:
  - Designing Remote Listening Experiments for the Partially Muted Word Impairment

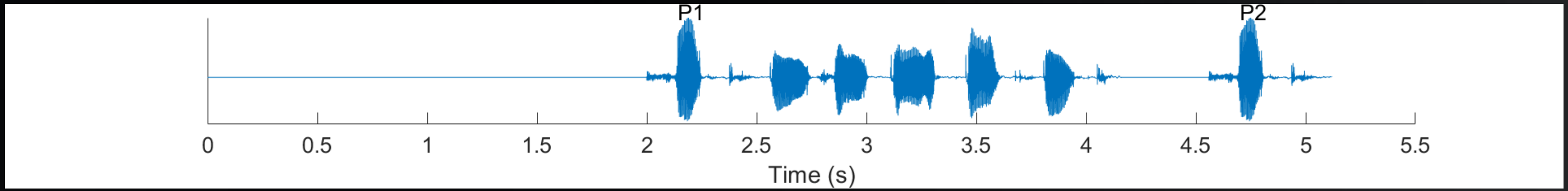
Measurement Concept

- Access Delay definition
  - *The minimum length of time a user must wait between pressing a PTT button and starting to speak to ensure that the first word of the message has an average intelligibility that is no lower than* $\alpha \cdot I_0$
- Repeatedly send pre-defined audio clips through communications system
- Vary where in the clip PTT is triggered
- Measure relationship between PTT time and intelligibility of the first word in the clip
  - No more carrier phrase
  - “Please select the word west” → “west”
- Time between PTT and start of audio clip
  - Not necessarily the same as start of keyword
  - Need to account for this

Measurement Concept

Audio Clips

- Select single word from ABC-MRT16 database[1]
  - Use only words from batches where leading consonant varies
    - E.g. *went, sent, bent, dent, tent, rent*
    - Places majority of intelligibility emphasis on beginning of word
  - Remove carrier phrase
    - Cut out keyword conservatively
    - Extra audio at beginning of clip
- Structure:
  - T seconds of silence
  - Play word, P_1
  - T seconds of speech
  - Play word again, P_2

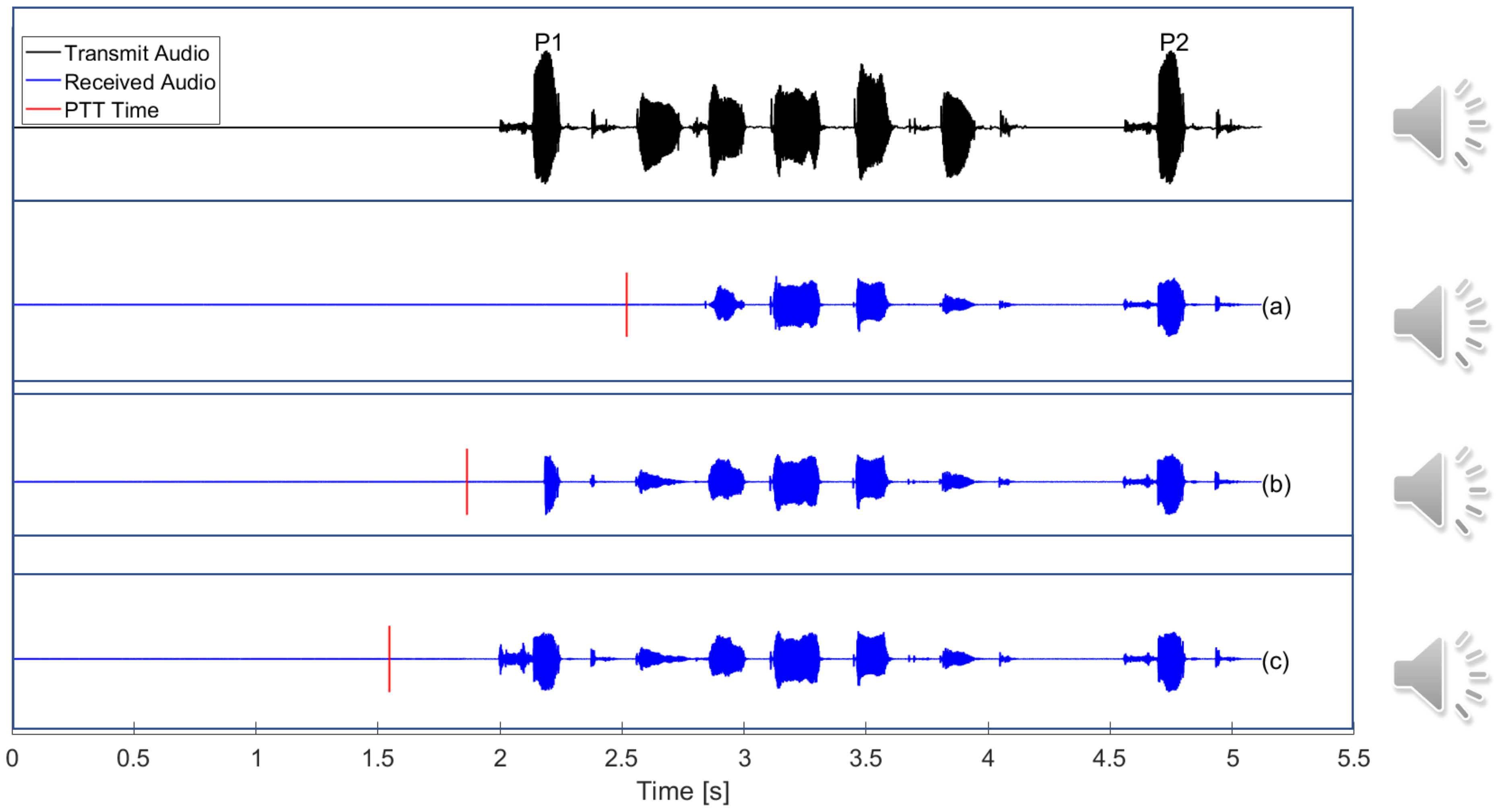


- T chosen so that system access time is less than T seconds
- Intelligibility of P_2 describes the asymptotic intelligibility, I_0
- Intelligibility of P_1 relates PTT time with intelligibility

1: Voran SD (2017) A multiple bandwidth objective speech intelligibility estimator based on articulation index band correlations and attention. 2017 IEEE International Conference on Acoustics, Speech and Signal Processing (ICASSP), pp 5100–5104.doi: 10.1109/ICASSP.2017.7953128

Measurement Concept

Intelligibility Examples: *hook*

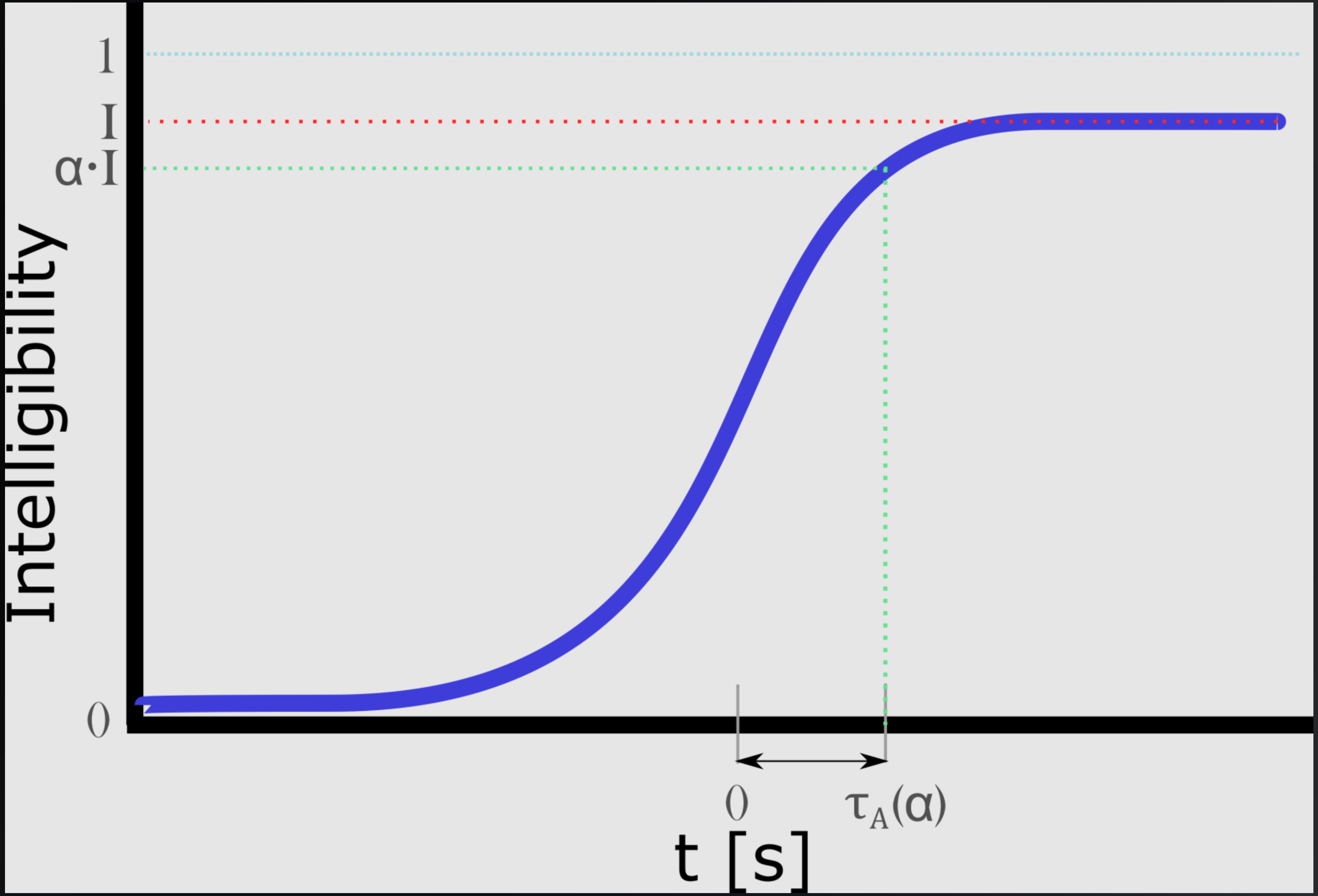


Measurement Concept

- Fit a curve to data
- Logistic curve has properties we want

$$I(t) = \frac{I_0}{1 + e^{(t-t_0)/\lambda}}$$

- $\lambda < 0$, steepness of intelligibility transition
- $t_0 \in \mathbb{R}$, 50% intelligibility point



Measurement Concept

$$I(t) = \frac{I_0}{1 + e^{(t-t_0)/\lambda}}$$

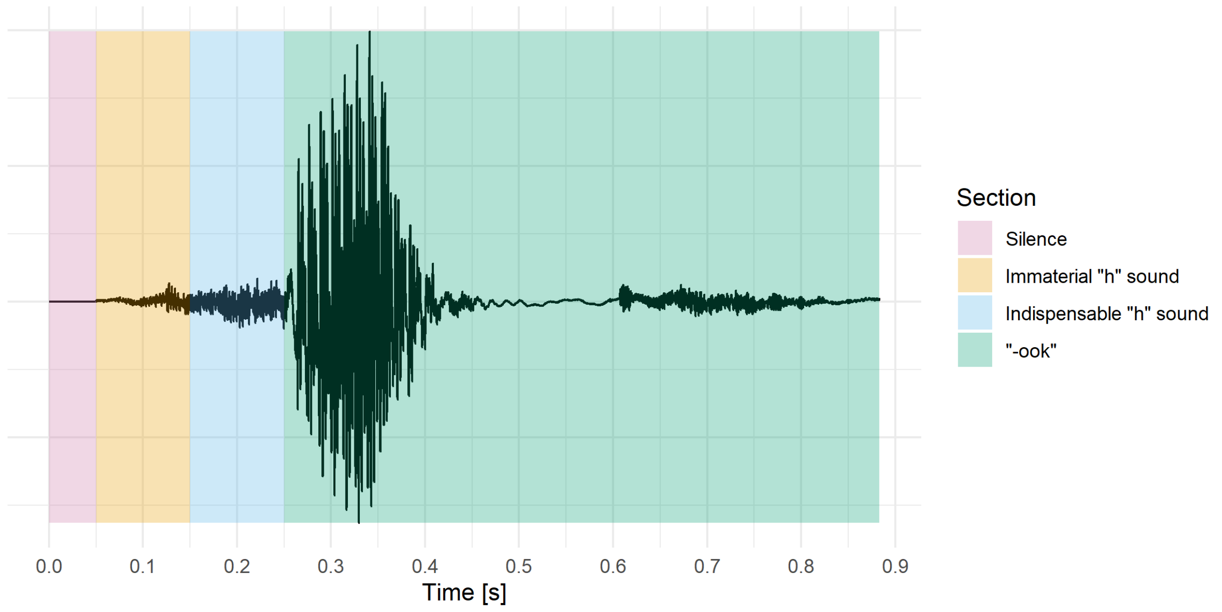
Given $0 < \alpha < 1$, an intelligibility of $\alpha \cdot I_0$ can be achieved with $t = I^{-1}(\alpha \cdot I_0)$

Access Delay defined as:

$$\tau_A(\alpha) = \lambda \cdot \ln\left(\frac{1-\alpha}{\alpha}\right) + t_0$$

Start of Word Correction - Question

- How do we characterize the immaterial from the indispensable?
- Example: “hook”
  - How much leading audio contributes to intelligibility?
  - Cutoff point changes for each word
  - Independent of SUT
  - Approximate an *ideal* SUT: PTT gate only



MRT List: took, cook, look, hook, shook, book

Minimal Access Delay System

- Consider a system, s^*, that minimizes access delay for a given WUT
  - Let S be the set of all SUTs that perform no audio buffering prior to PTT
  - Define $s^* \in S$ such that for any $\alpha \in \left[\frac{1}{2}, 1\right)$, then:
$$\tau_{s^*}(\alpha) \leq \tau_s(\alpha), \forall s \in S,$$
- Theorem: Access delay parameters λ_{s^*}, t_{0,s^*} provide maximum and minimum values, respectively, for the WUT through any SUT, $s \in S$
  - $\lambda_{s^*} \geq \lambda_s$
  - $t_{0,s^*} \leq t_{0,s}$

Minimal Access Delay System

- Minimal Access Delay
  - Minimizes transition time, the magnitude of λ, and offset, t_0
  - Helps discern information about the WUT
  - What is the best practical approximation?

PTT Gate

- What is it?
  - Input → Digital Switch → Output
  - ~ 90µs transition time
- Approximately minimal system
  - PTT gate and nothing else
  - No system effects (squelch, channel access, etc)
  - Access delay always negative
  - Provides baseline access delay per WUT
- Prohibits access delay hiding in system delay
- Correcting data
  - How to use for correcting data?

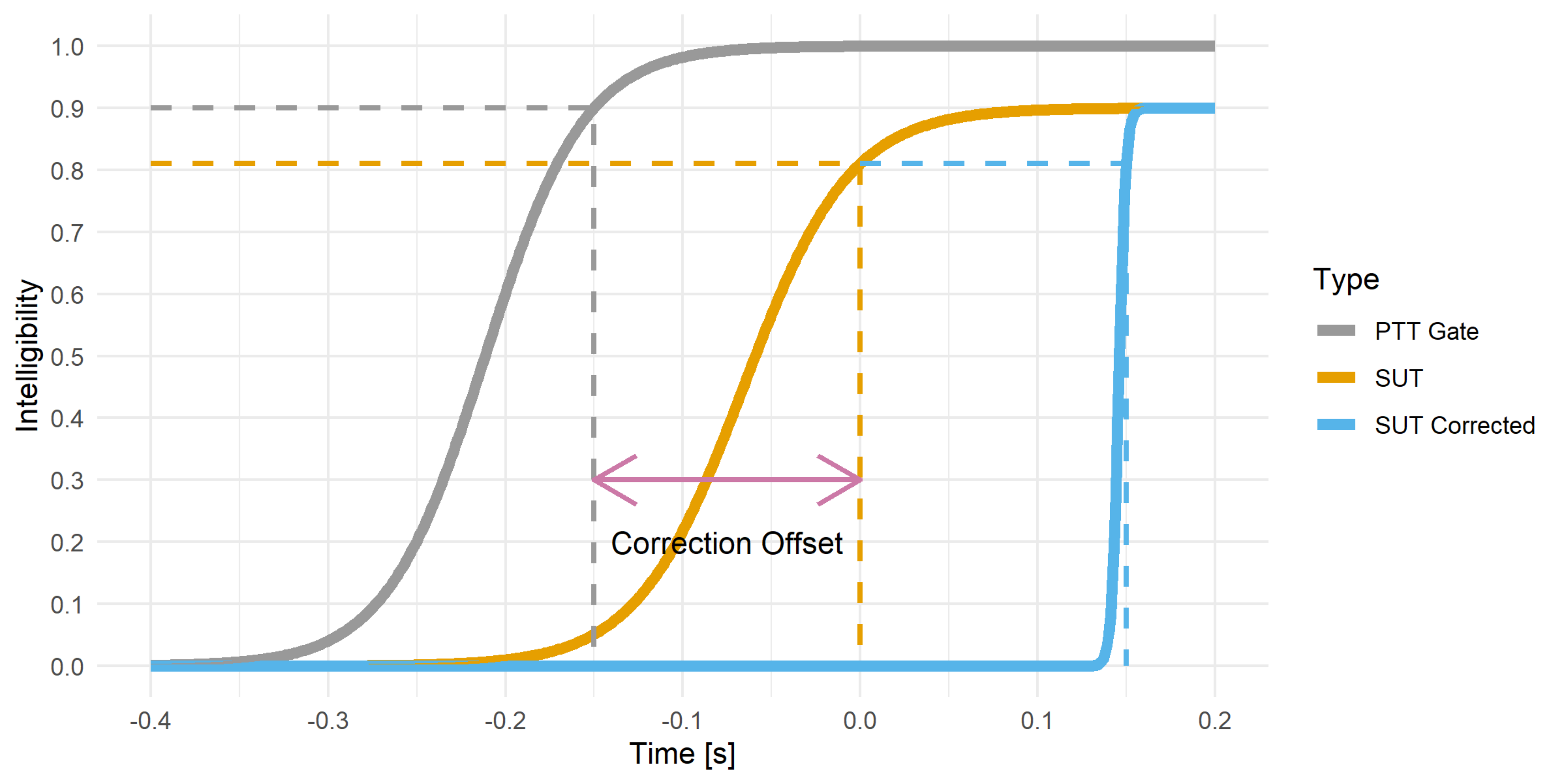
Linear Combinations of Access Delay

- Access delay functions have nice properties
  - Adding Access Delay → Adding Parameters
- Hope you like math
  - Given some fixed α
  - Invert logistic curve for access delay function
  - $\tau = \ln\left(\frac{1-\alpha}{\alpha}\right)\lambda + t_0$ for one word
  - Combine as usual
  - $a\,\tau_1 + b\,\tau_2 = \ln\left(\frac{1-\alpha}{\alpha}\right)(a\lambda_1 + b\lambda_2) + (at_{0,1} + bt_{0,2})$
  - $a\lambda_1 + b\lambda_2 < 0$ to be valid

Corrected Access Delay

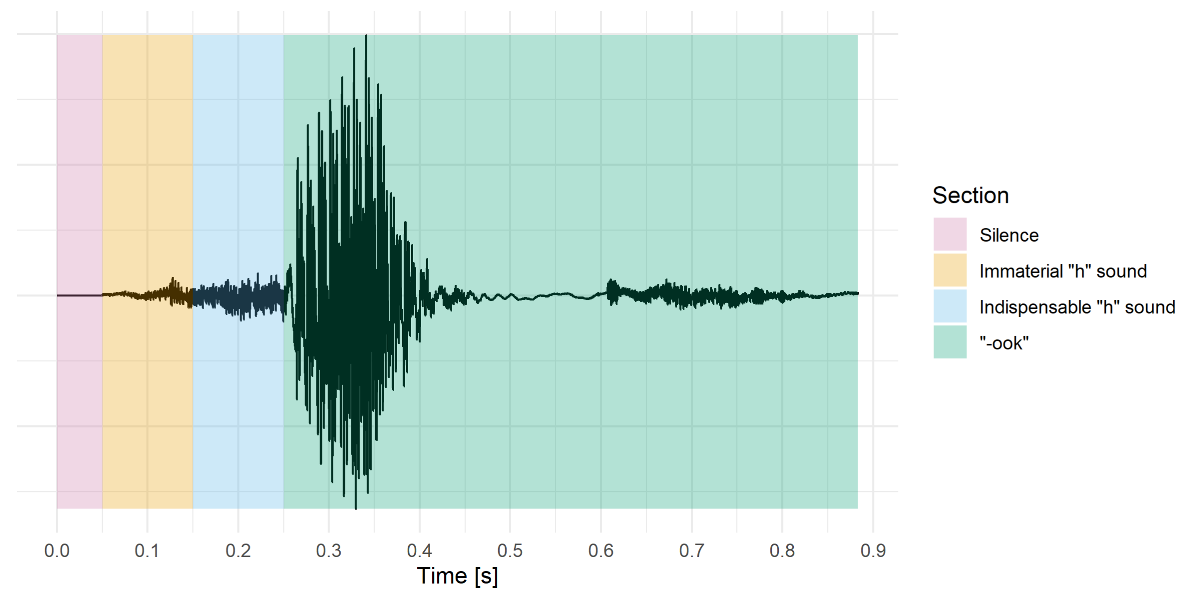
- Remove effects of immaterial audio
  - PTT gate tests characterize WUT related effects
  - Subtract off access delay from PTT gate for given WUT
    - $\tau_{SUT} - \tau_{PTT} = \ln\left(\frac{1-\alpha}{\alpha}\right)(\lambda_{SUT} - \lambda_{PTT}) + \left(t_{0,SUT} - t_{0PTT}\right)$
  - Corrected access delay characterizes SUT only effects
- Average over different WUTs
  - $\tau_c = \frac{1}{N}\sum(\tau_{SUT} - \tau_{PTT}) = \ln\left(\frac{1-\alpha}{\alpha}\right)\frac{1}{N}\sum(\lambda_{SUT} - \lambda_{PTT}) + \frac{1}{N}\sum\left(t_{0,SUT} - t_{0,PTT}\right)$
  - $\lambda_{PTT} > \lambda_{SUT}$ implies valid parameters
  - Multiple WUT used to sample how SUT responds to different words/talkers
- Corrected access delay times also follow logistic curve

Corrected Access Delay - Example



Start of Word Correction - Example

- Fix $\alpha = 0.9$
- Think about the word "hook"
- $\tau_{PTT}(\alpha) = -150$ ms
- $\tau_{SUT}(\alpha) = 0$ ms
  - Before correction: no access delay
  - Know that the first 150 ms of the audio clip "worthless"
- $\tau(\alpha) = \tau_{SUT}(\alpha) - \tau_{PTT}(\alpha) = 0 - -150 = 150$ ms
  - Captures the "truth" better
  - System needs 150 ms of setup time to send "hook" through intelligibly



Interpretation

- For single word
  - t_0 will shift intelligibility midpoint and become larger
  - λ will remain negative and become smaller in size (less negative)
    - This is true because the PTT gate approximates minimal access delay
    - Removes word features from intelligibility transition
    - Focuses on SUT effects only
    - Smaller intelligibility transition region
- For aggregated words
  - t_0 average time to reach 50% intelligibility point
  - λ describes average intelligibility transition time
    - No word effects included
    - SUT dealing with different stimuli

Uncertainty

- Let $C = \ln\left(\frac{1-\alpha}{\alpha}\right)$
- Uncertainty for single, uncorrected access delay estimate

$$\mathrm{Var}(\tau(\alpha)) = C^2\mathrm{Var}(\lambda) + \mathrm{Var}(t_0) + 2C \cdot \mathrm{Cov}(\lambda, t_0)$$

- Propagation of uncertainty from linear combinations
  - Note that parameters for PTT and SUT curves are independent

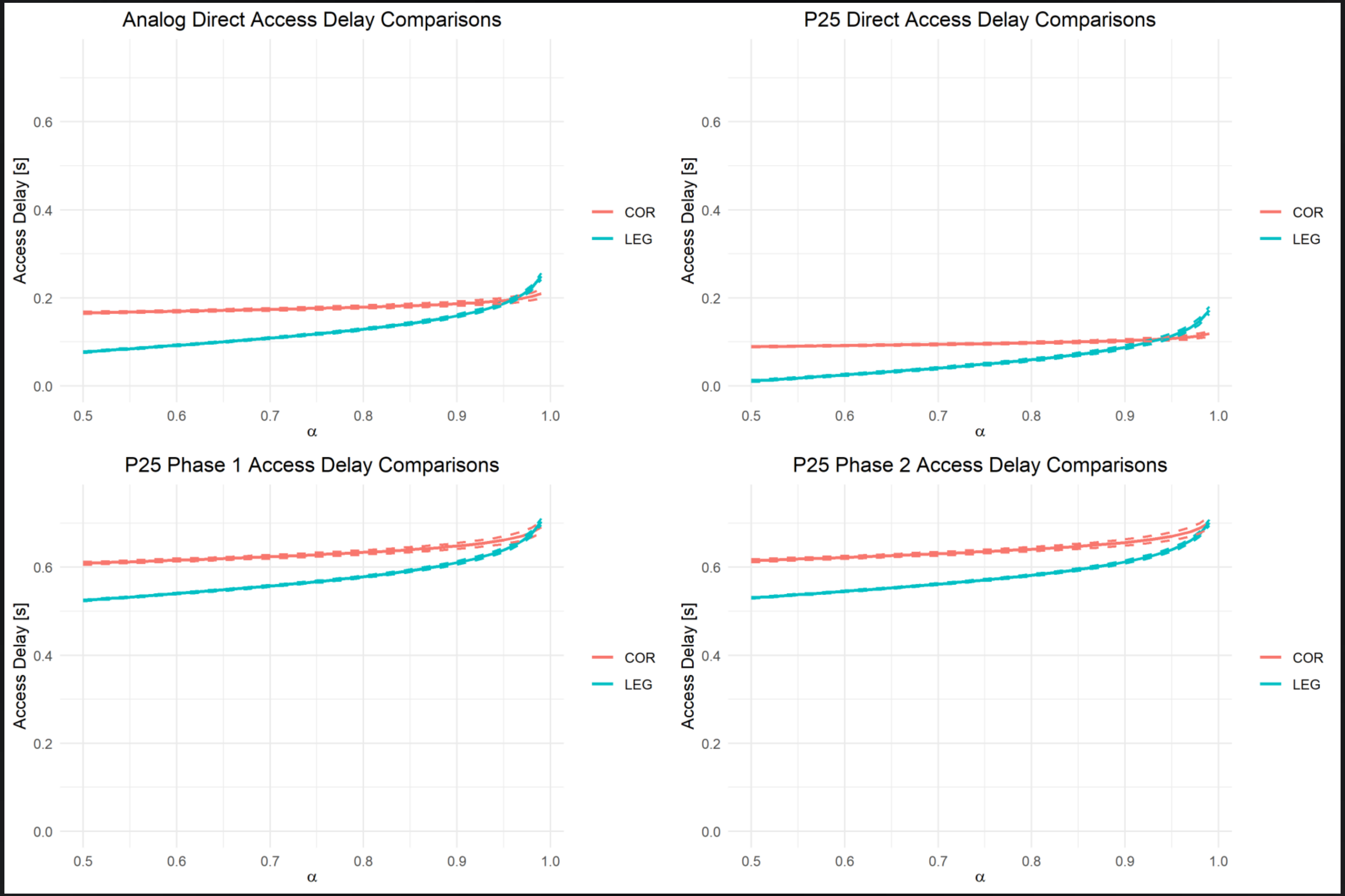
$$\mathrm{Var}(\tau_{\mathrm{sys}}(\alpha)) = \frac{1}{N^2}\left(C^2\sum_{j=1}^{N}\mathrm{Var}(\lambda_{j,\mathrm{C}}) + \sum_{j=1}^{N}\mathrm{Var}(t_{0,j,\mathrm{C}}) + 2C\sum_{j=1}^{N}\mathrm{Cov}(\lambda_{j,\mathrm{C}}, t_{0,j,\mathrm{C}})\right)$$

Impact on Measurement Results

- Access Delay increases across technologies
  - Difference between ~15ms to ~45ms
  - WUT are ‘hang’, ‘law’, ‘bed’, ‘not’
  - α fixed to 90%
  - 95% confidence interval included

Technology	New Access Delay $[ms]$	Old Access Delay $[ms]$	Difference $[ms]$
P25 Direct	103.0(99.6, 106.4)	87.9(83.4, 92.4)	15.14(9.49, 20.79)
P25 Phase 1	648.2(641.4, 655.1)	610.2(606.4, 614.0)	38.0(30.2, 45.8)
P25 Phase 2	656.4(649.4, 663.3)	612.2(608.7, 615.7)	44.1(36.3, 51.9)
Analog Direct	186.8(181.7, 191.9)	159.3(155.7, 162.8)	27.5(21.2, 33.7)

Impact on Measurement Results



Publications

- Mission Critical Voice Start of Word Correction for Access Delay Measurement System (2021)
  - Please see the link on the conference website
- Mission Critical Voice Quality of Experience Access Time Measurement Method Addendum (2020)
- Mission Critical Voice Quality of Experience Access Time Measurement Methods (2019)

Related PSCR 2021 Sessions

- Mission Critical Voice Quality of Experience Measurement Methods Overview
- Measuring the Probability of Successful Delivery: a QoE Based Approach
- Designing Remote Listening Experiments for the Partially Muted Word Impairment
- Optimal Transmit Volume Conditions for MCV QoE Measurement Systems
- QoE Software and Hardware Packaging
- QUARC: Quality Under Adjustable Realistic Conditions for Communication Systems
- Lab from Home: Distributed QoE Testing for Mission Critical Voice

Thank You

- Questions? Come to our Q&A!

THANK YOU

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