Mission Critical Voice QoE Measurement Methods

National Institute of Standards and Technology
U.S. Department of Commerce

Communications Technology Laboratory

Mission Critical Voice QoE Measurement Methods

- First Mission Critical Voice (MCV) Quality of Experience (QoE) Measurement Method Project
  - Mouth-to-Ear (M2E) Latency
- Most Recent MCV QoE Measurement Method Project
  - End-to-End Access Time
  - Speech Intelligibility
- Future Work/Direction
  - Audio Quality/Intelligibility
  - Access/Retention Probability

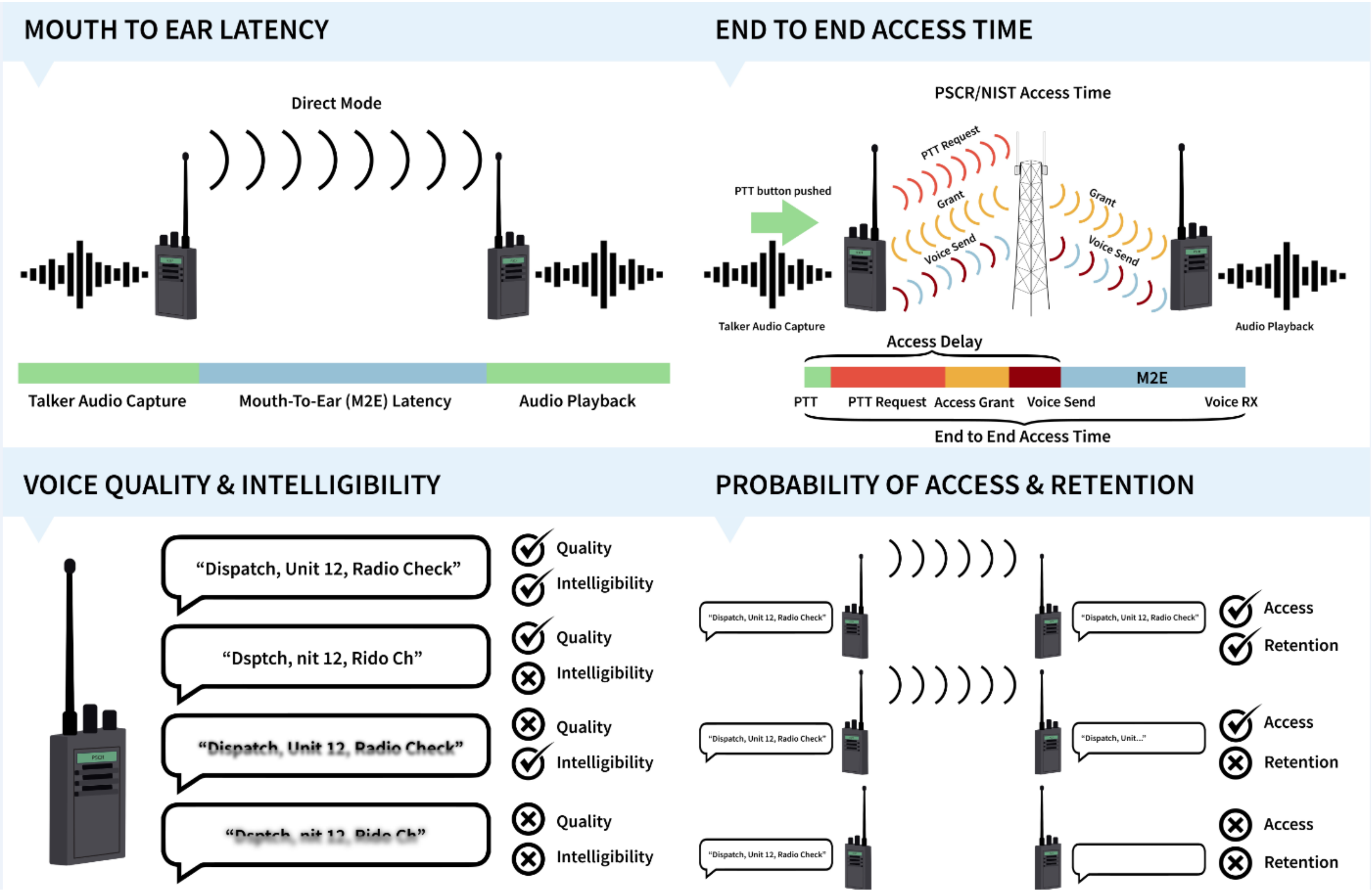
Existing LMR/LTE Key Performance Indicators (KPI)

- Quality of Service (QoS) and Compliance Based
- Technology Specific
- Depend on Complicated/Proprietary/Internal Measurements
- Example: Push To Talk (PTT) Access Time - Standards
  - TIA Definition: Time Between Button Press and Traffic Channel Transmit
  - 3GPP Definition: Time Between Button Press and Acknowledgement from System (KPI 1)
- QoE Definition
  - Time Between Button Press and Receiving User Hearing Intelligible Transmitting User (End-to-End Access Time)

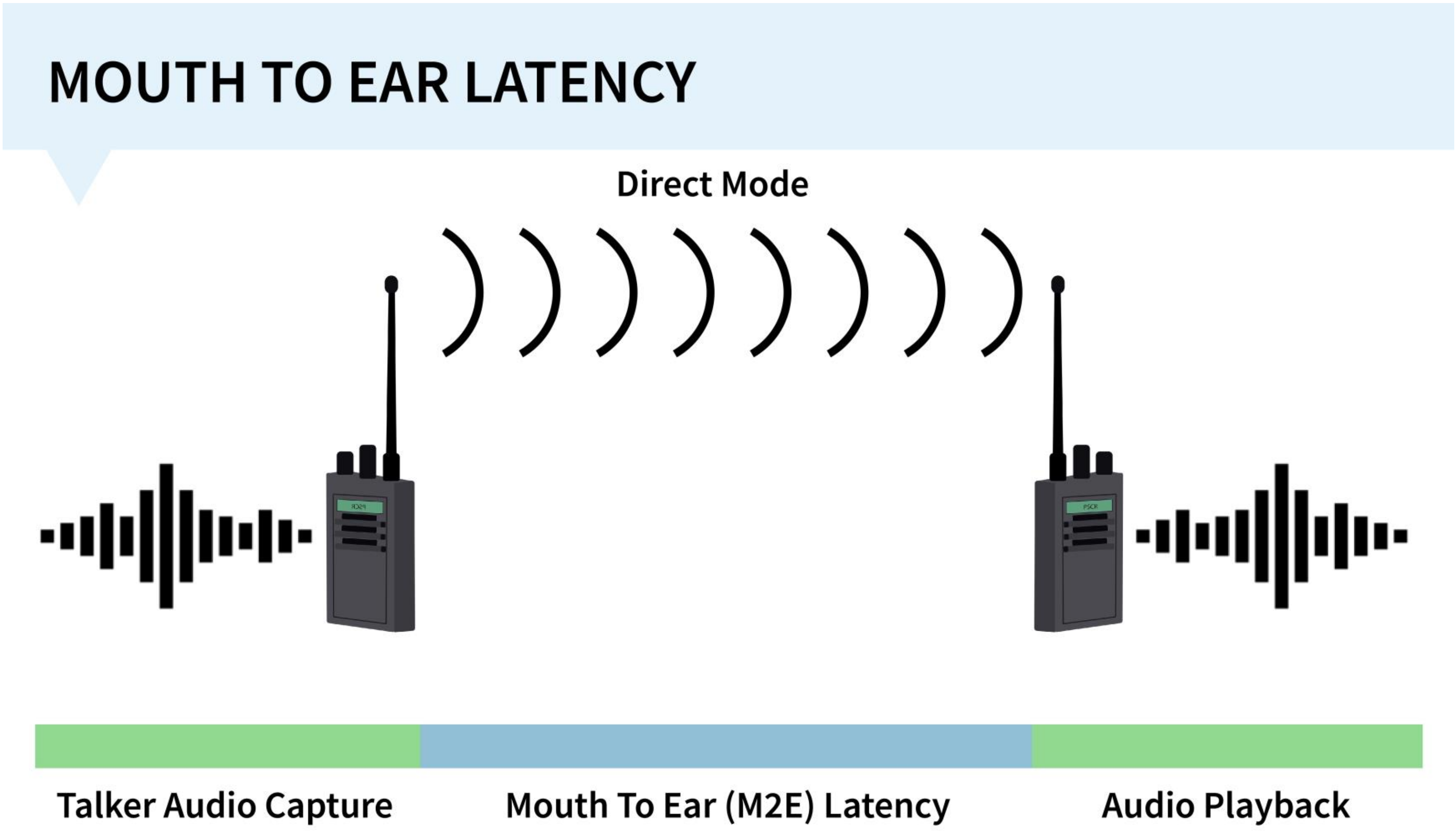
QoE KPIs for MCV - MCV Roundtable 2017

- Mouth-to-Ear (M2E) Latency
  - Time it Takes Audio to Get from Transmitting User to Receiving User
- End-to-End Access Time
  - Time Between Button Press and Receiving User Hearing Voice
  - M2E Latency + Access Delay
- Audio Quality/Intelligibility
  - Public Safety Cares Most About Intelligibility
- Access/Retention Probability
  - Ability to Establish Call
  - Ability to Retain Call

QoE KPIs for MCV

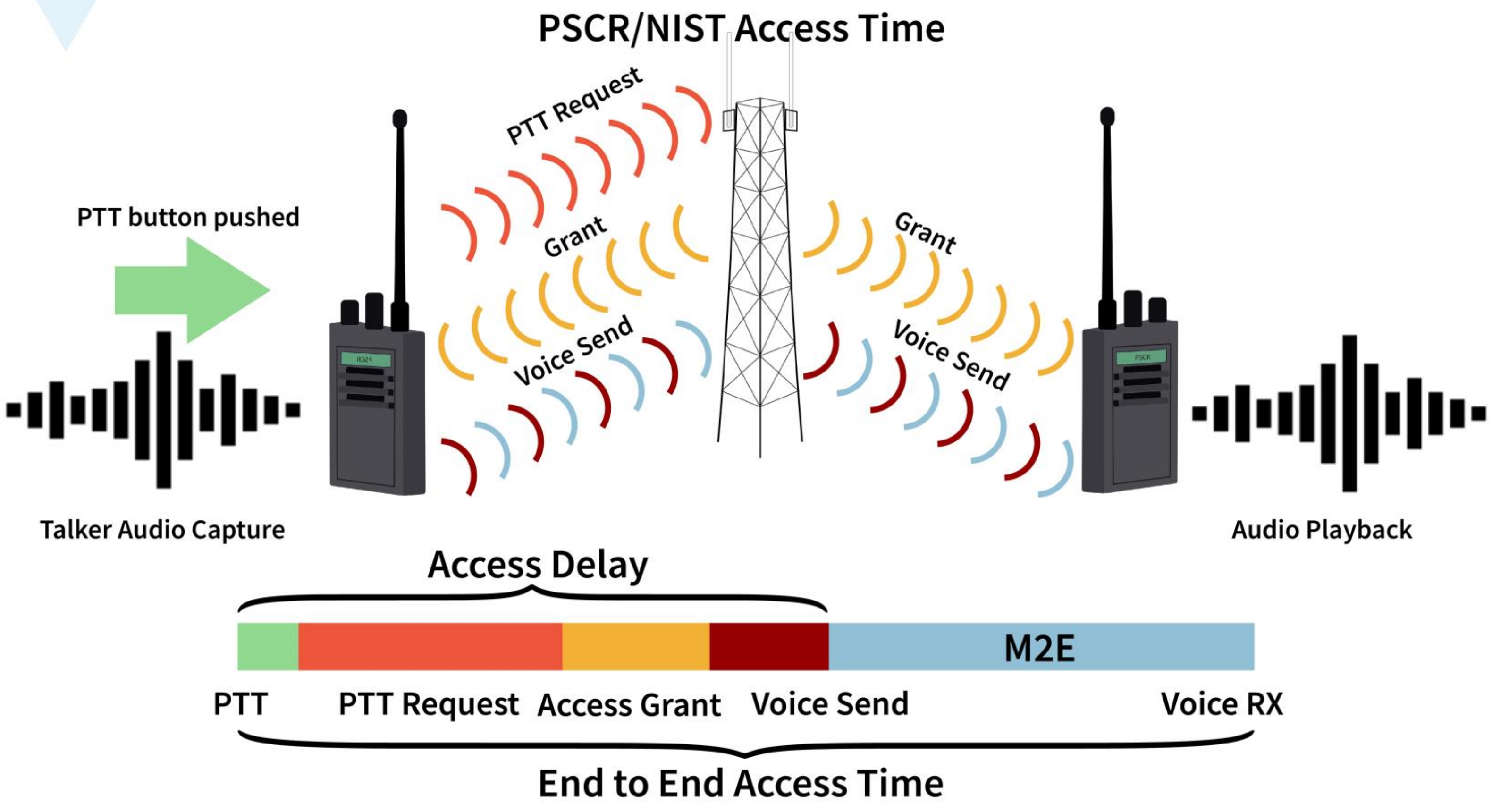


QoE KPIs for MCV

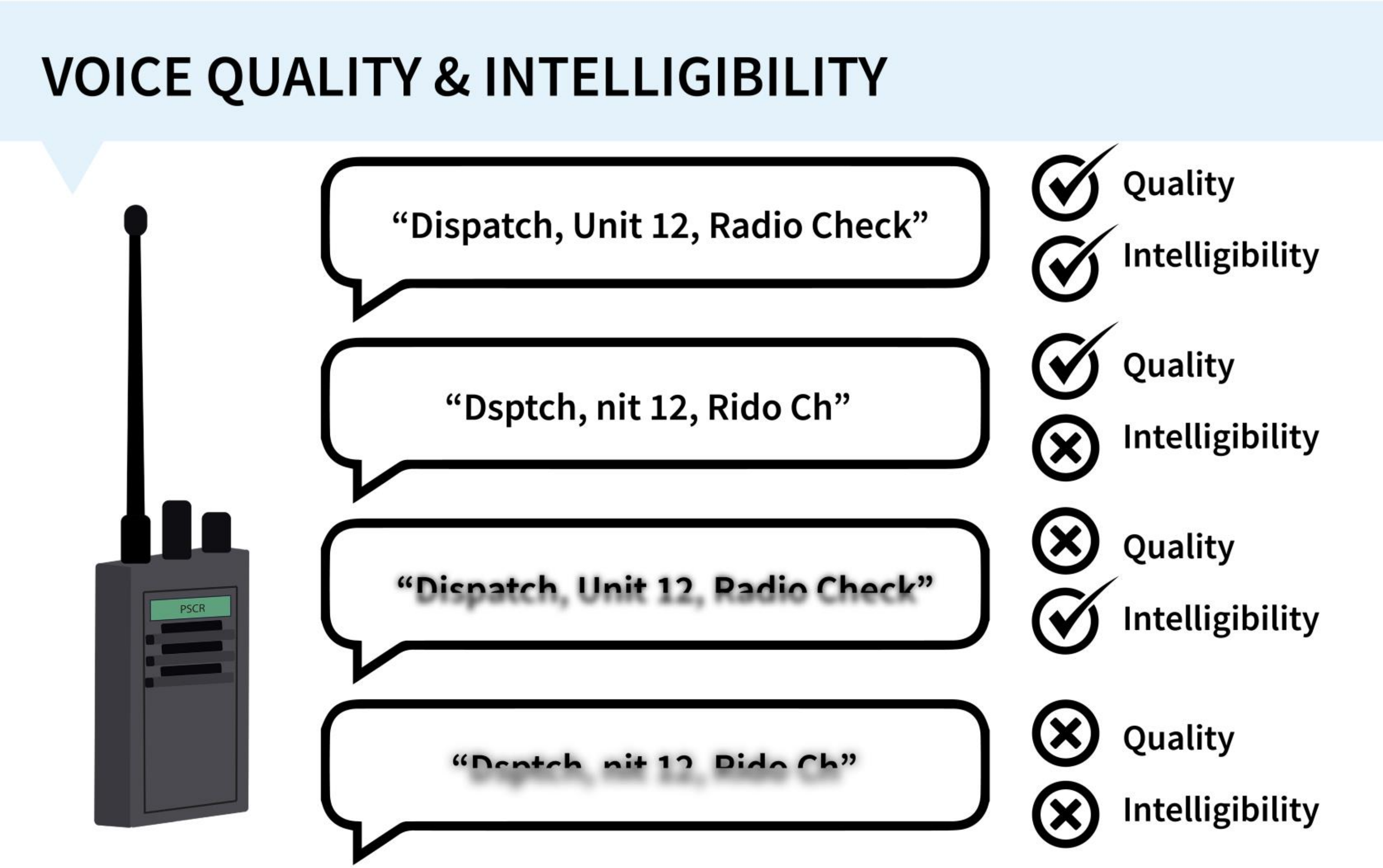


QoE KPIs for MCV

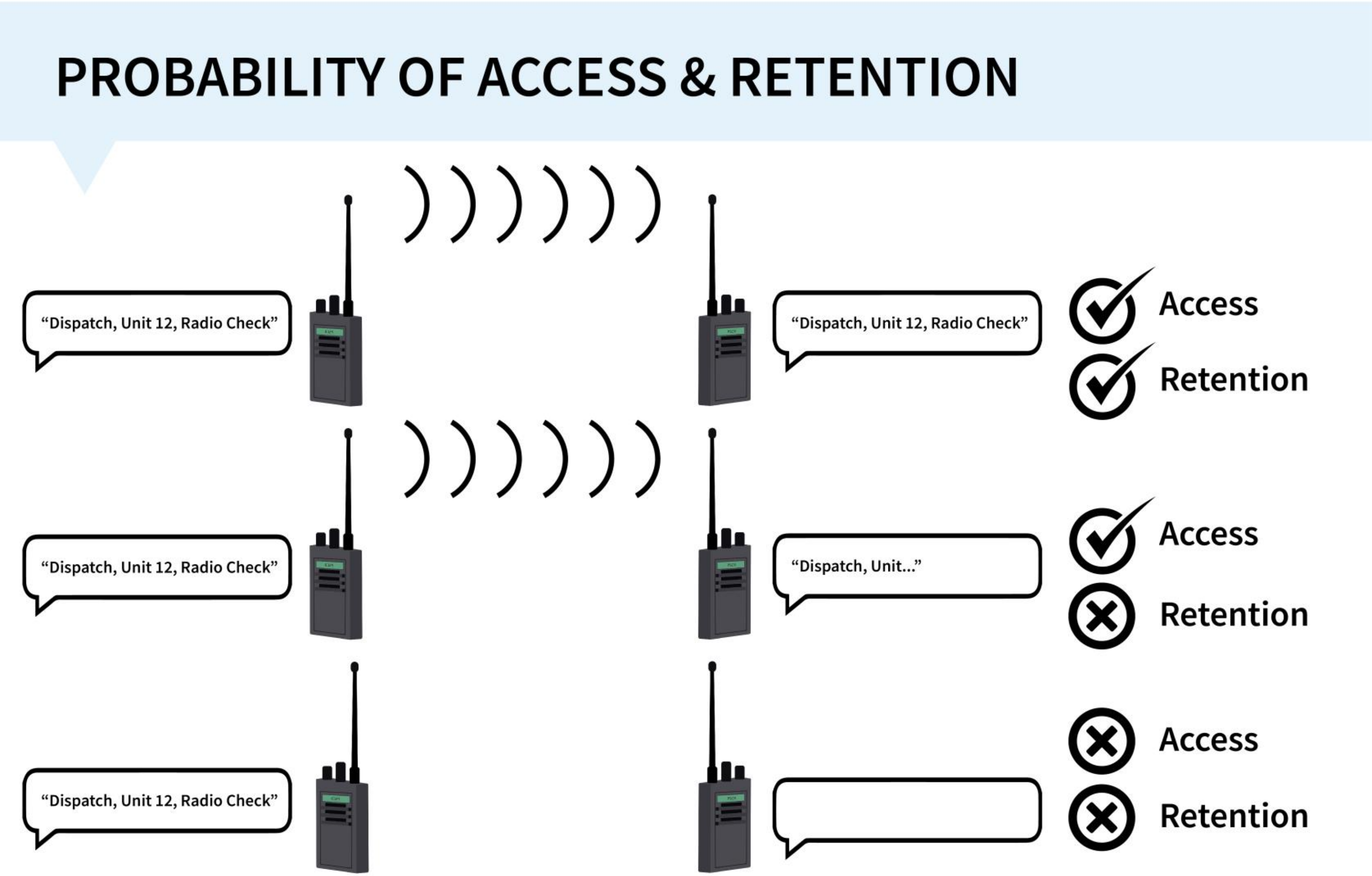
END TO END ACCESS TIME



QoE KPIs for MCV



QoE KPIs for MCV



The User Experience: PTT Communications

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

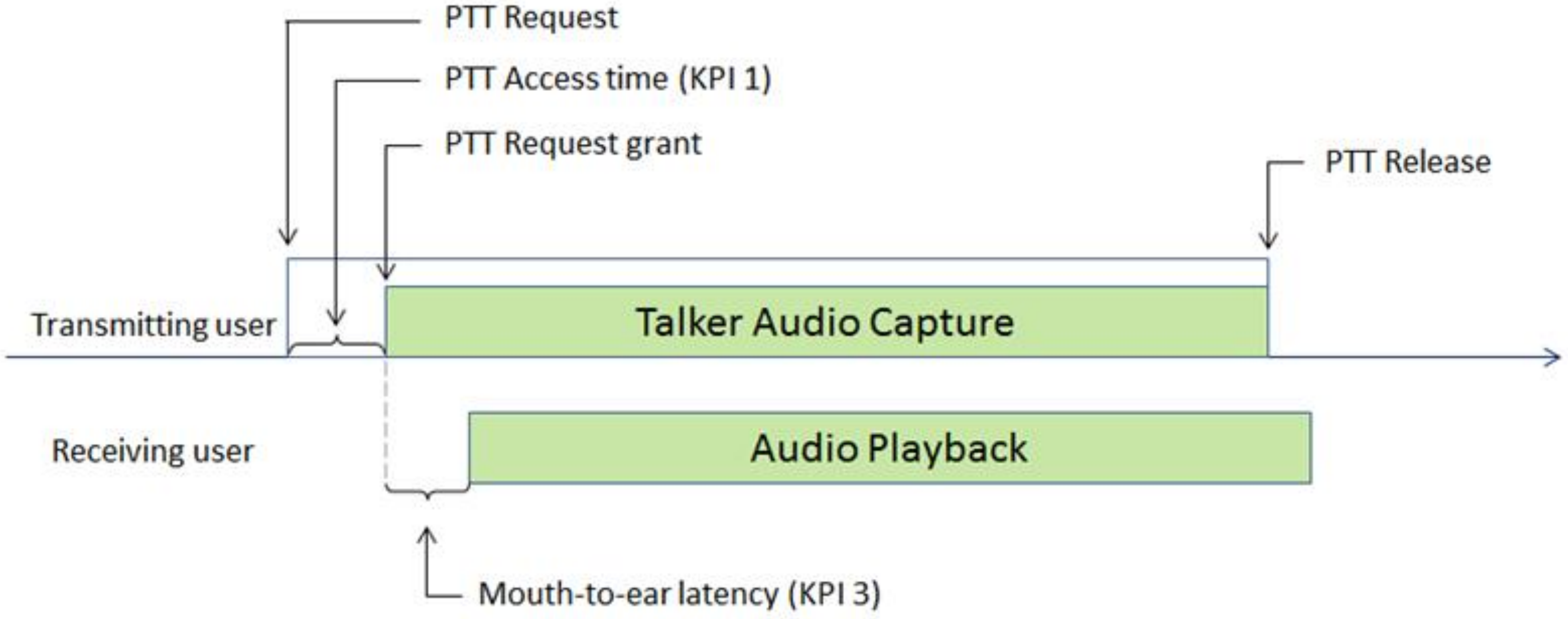
- **Goal - Create measurement systems that are:**
  - Based upon the user experience -- speech
  - Comparable and fair across technologies

QoE KPIs for MCV - M2E Latency

- M2E Latency Measurement Method
  - Develop a method to measure & quantify M2E latency of any voice communications system
  - Method is based on audio in/audio out and is technology agnostic
  - Very challenging to develop this measurement methodology
    - Development of audio based measurements
    - Optimal volume levels
    - Component to system level testing complexities with uncertainties
  - First step in establishing QoE-based KPIs

3GPP Defined KPIs

3GPP M2E Latency and Access Time



3GPP (2017) Mission Critical Push to Talk (MCPTT). 3rd Generation Partnership Project (3GPP), Technical Specification (TS) 22.179. Version 16.0.0 URL: https://portal.3gpp.org/desktopmodules/Specifications/SpecificationDetails.aspx?specificationId=623

M2E Latency Measurement Results

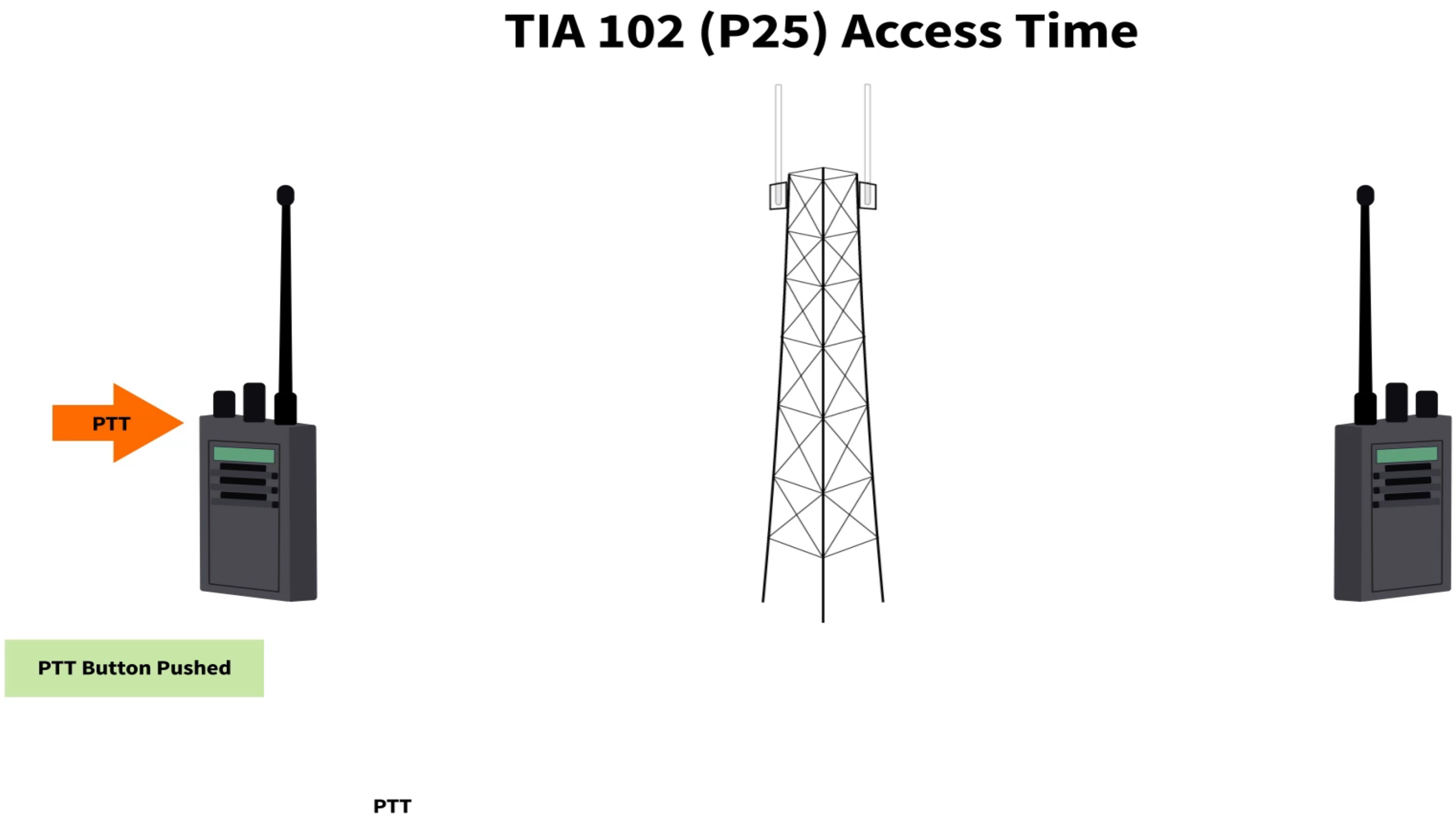
	Single Location Lab (ms)	Two Location Lab (ms)	Two Location Field (ms)
Audio Device Characterization	21.85 ± 0.07	21.85 ± 0.07	21.85 ± 0.07
UHF-P25 Direct	201.4 ± 0.4	201.2 ± 0.3	201.8 ± 0.4
UHF-P25 Trunked	415.8 ± 2.8	413.1 ± 3.3	417.0 ± 2.9
VHF-P25 Direct	201.7 ± 0.5	201.6 ± 0.4	202.4 ± 0.4
VHF-P25 Trunked	403.9 ± 1.8	403.3 ± 2.8	405.3 ± 1.2

- 7 km distance between TX and RX radios for two location field tests
  - 23 µs (microsecond) propagation delay (negligible)
- Untuned prototype Mission Critical PTT system - one location field measurements
  - Not optimized for performance, tested to verify measurement method works on LTE

QoE KPIs for MCV – Access Time

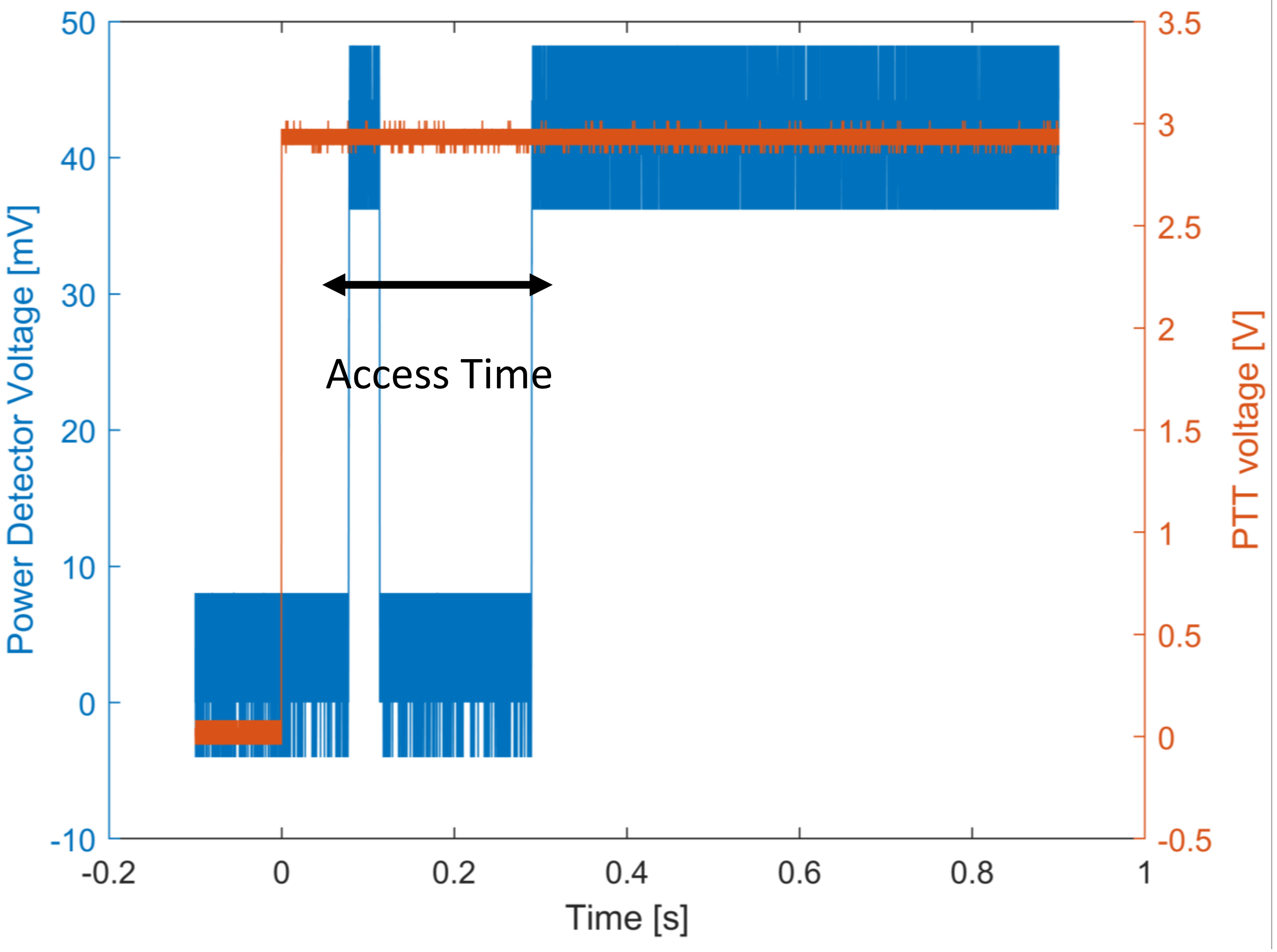
- Access Time
  - Trunked Mode/Mission Critical PTT
  - Direct Mode
  - Measurement Methods/Definitions
    - TIA-102 P25 - Voice Access Time
    - 3GPP Definition - PTT Access Time (KPI 1)
    - NIST/PSCR Definition
      - End-to-End Access Time
  - Very challenging to develop this measurement methodology
    - Tried Several Different Audio Clips
    - Some Words More Challenging than Others to Achieve Intelligibility
  - Critical Next Step in establishing QoE-based KPIs

TIA-102 P25 Access Time – Trunked Mode

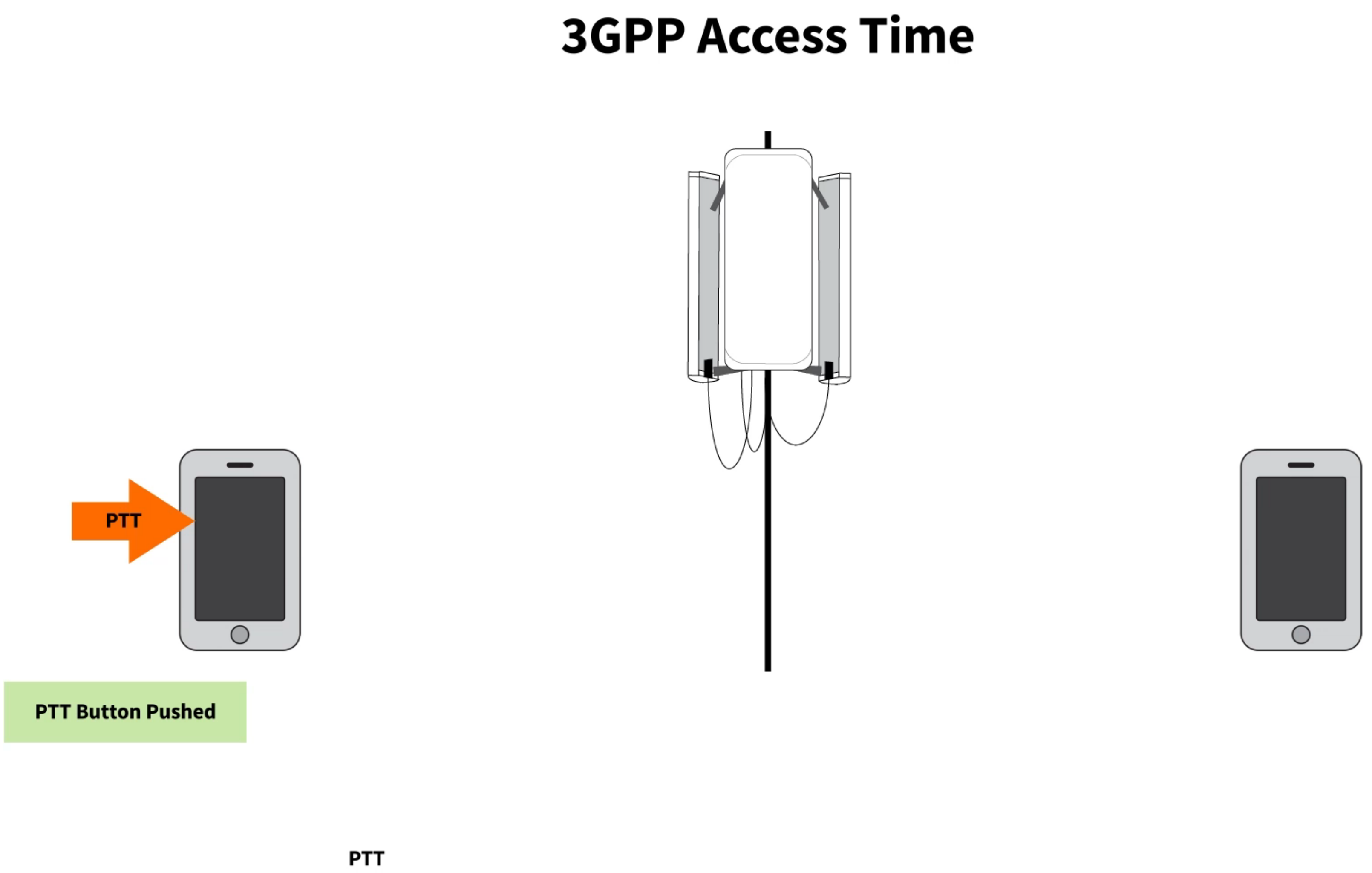


TIA-102 P25 Access Time

- Measure the power coming from the TX radio
- TIA-102 defines access time as the time between the PTT signal and the last rising edge of the power detector
- The TX radio will transmit a request signal
- Once access is granted, the TX radio transmits the encoded audio
- Does not consider the end user
    - No reference to receiving user or speech



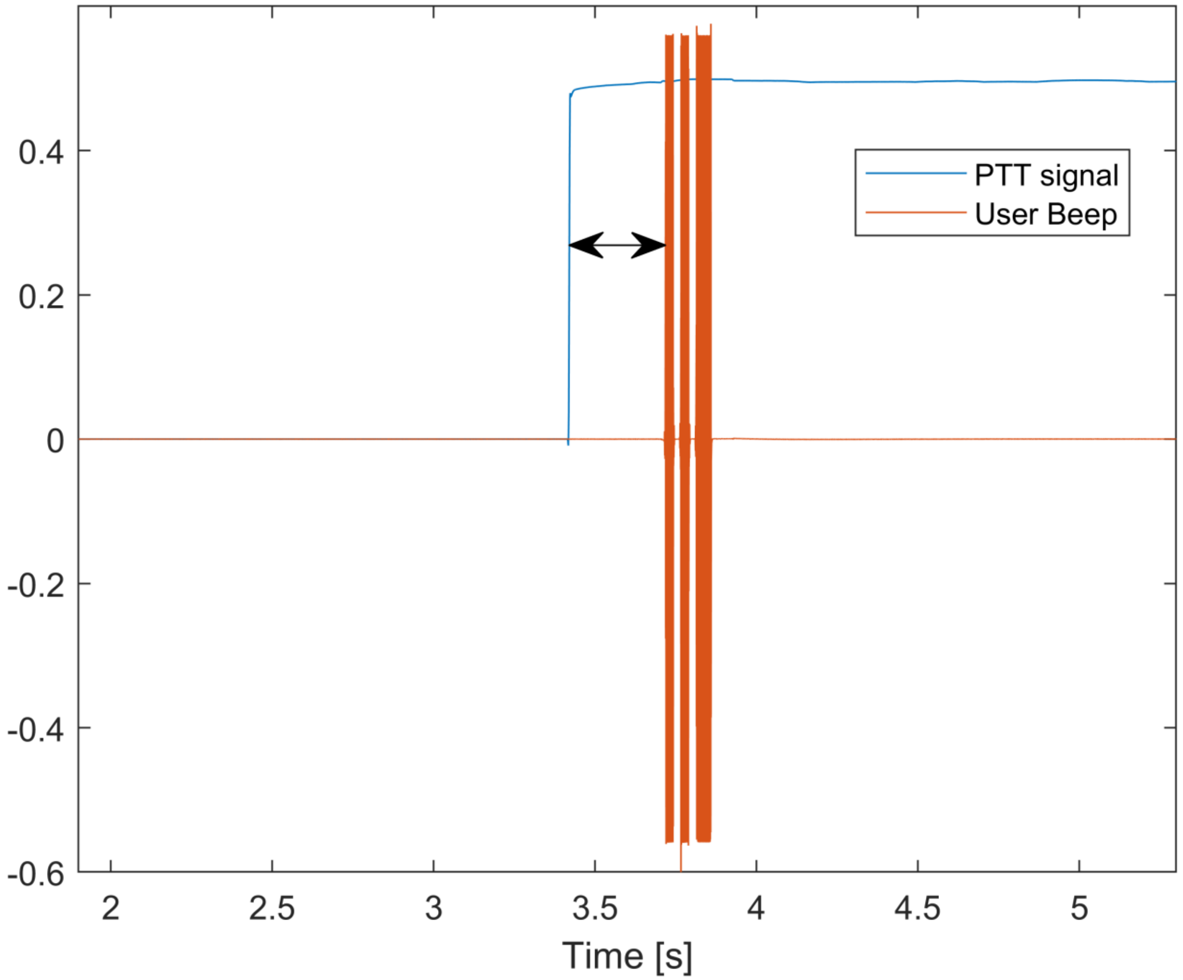
3GPP Access Time



3GPP Access Time

3GPP Defined PTT User Access Time (KPI 1)

- Measures the time between the PTT signal and the signal (or beep) from the TX radio
- Does not consider the end user



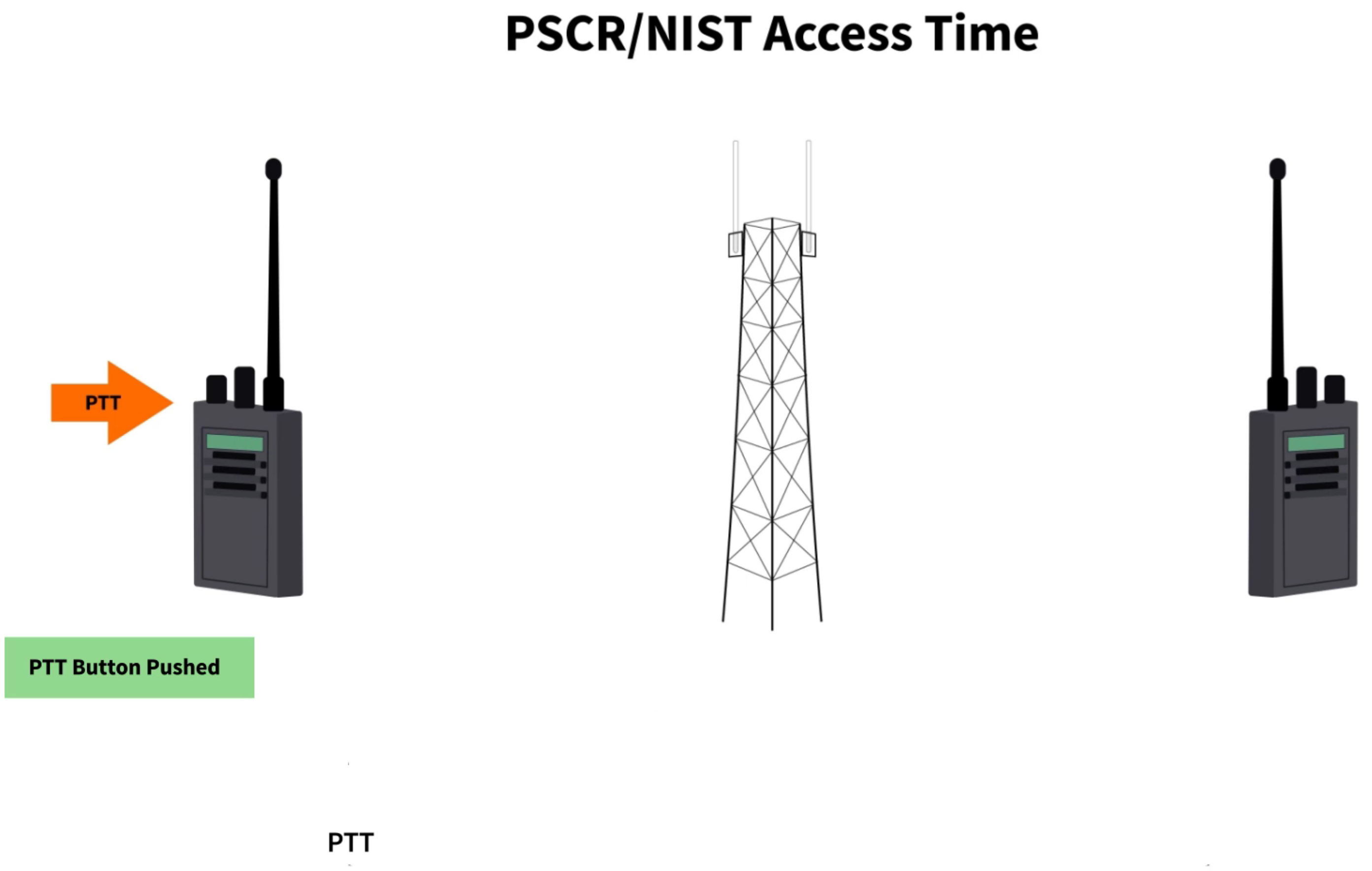
Access Time in Other Standards

Compatibility Across Technologies

- **TIA Access**
  - Analog FM LMR
    - Technically compatible
    - Not meaningful
  - P25 Direct
    - Technically compatible
    - Not meaningful
  - LTE
    - Not compatible

- **3GPP Access**
  - Analog FM LMR
    - Not applicable
  - P25 Direct
    - Not applicable
  - P25 Trunked
    - End-to-end definition is compatible and meaningful

PSCR/NIST End-to-End Access Time



User Driven Access Definition

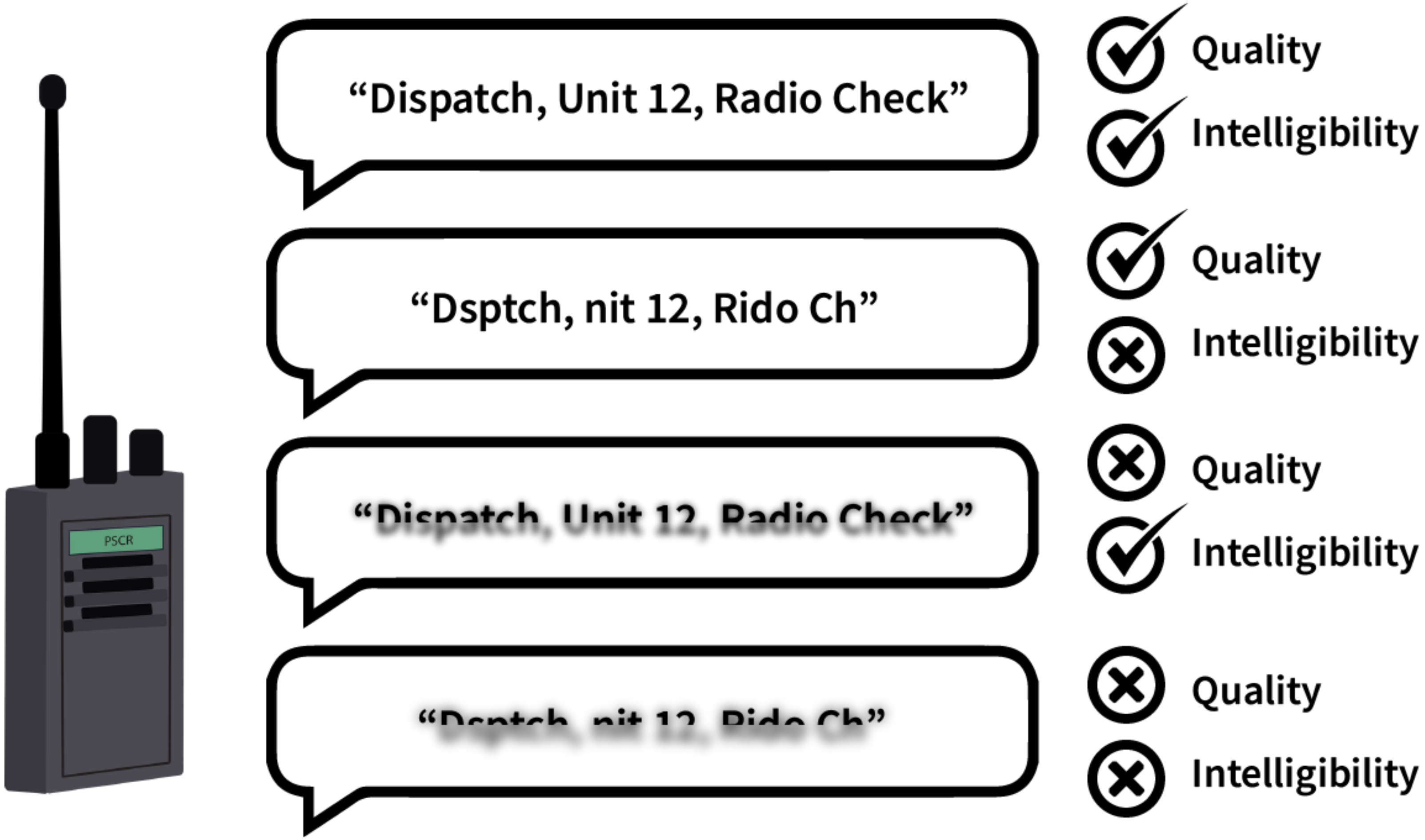
- **End-to-end Access Time**
  - *The total amount of time from when a transmitting user first presses PTT until a receiving user hears intelligible audio.*
- **Two Components:**
  - Mouth-to-ear Latency
    - *The time between speech being input into one device and its output through another*
  - Access 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

Voice Quality and Intelligibility

- First Responders Require Intelligible Speech in Challenging Audio Environments
  - Background Noise: Alarms, Sirens, Helicopters, Chainsaws, Gun Shots, Etc.



Intelligibility

Modified Rhyme Test (MRT)

- Used to test intelligibility of SCBA masks[1]
- 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)
- Over lots of trials scores are generated
  - Score is value between 0 and 1
  - Corrected for guessing
- High time cost

1: NFPA 1981 Standard on open-circuit self-contained breathing apparatus (SCBA) for emergency services (2007)

Intelligibility

Intended Use Case Examples

Batch: ***fun, sun, bun, gun, run, nun***

Distortion: Background noise + system

- **Extreme**
- **Moderate**
- **Mild**
- **None**

Intelligibility

- **Articulation Band Correlated Modified Rhyme Test (ABC-MRT)**
  - Objective algorithm to provide estimates of true MRT scores
  - Developed by Stephen Voran and DJ Atkinson, ITS-NTIA
  - Most recent version is ABC-MRT16
  - Relies on temporal correlations within articulation index bands
    - Break speech into a “musical score”
    - Representation of speech in time and frequency
  - Costs: Cheaper and faster
    - Relatively low time cost
      - Can get estimated MRT scores “on demand”
    - Much lower infrastructure cost

Measurement Concept

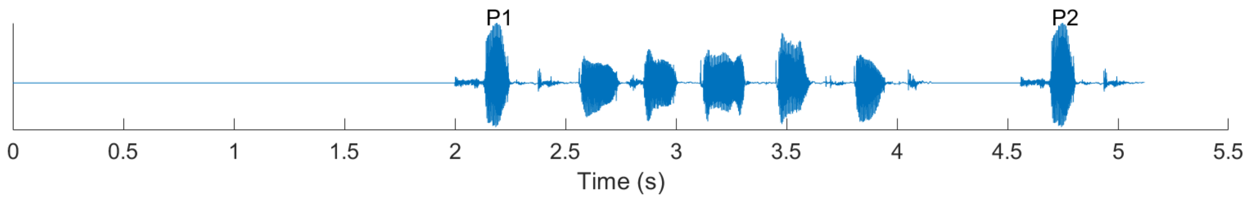
Overview

- 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

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
- Structure:
  - T seconds of silence
  - Play word, P_1
  - T seconds of speech
  - Play word again, P_2

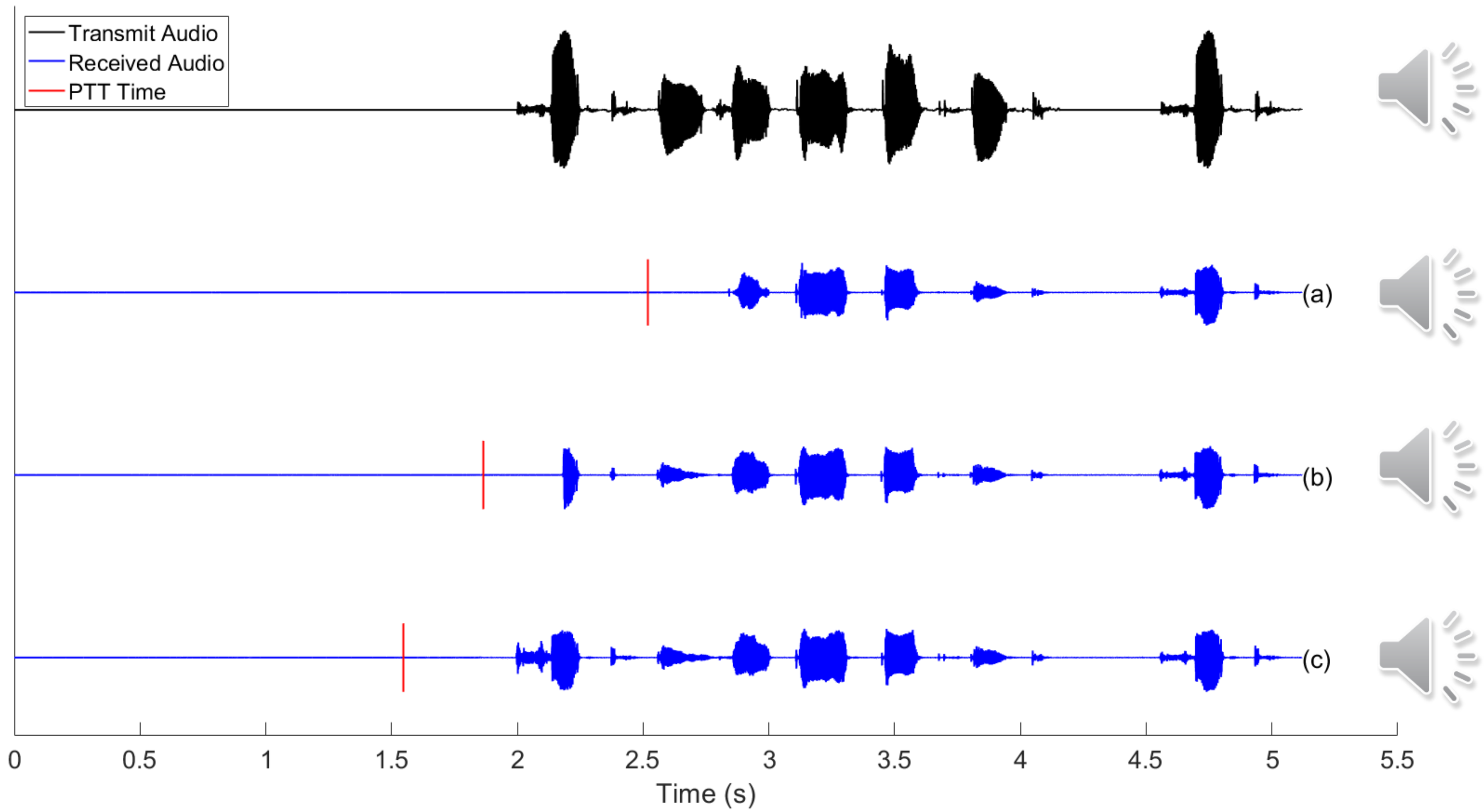


- T chosen so that system access time is less than T seconds
- Intelligibility of P_2 describes the asymptotic intelligibility, I_0
- Intelligibility of P_1 relates PTT time with intelligibility

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*



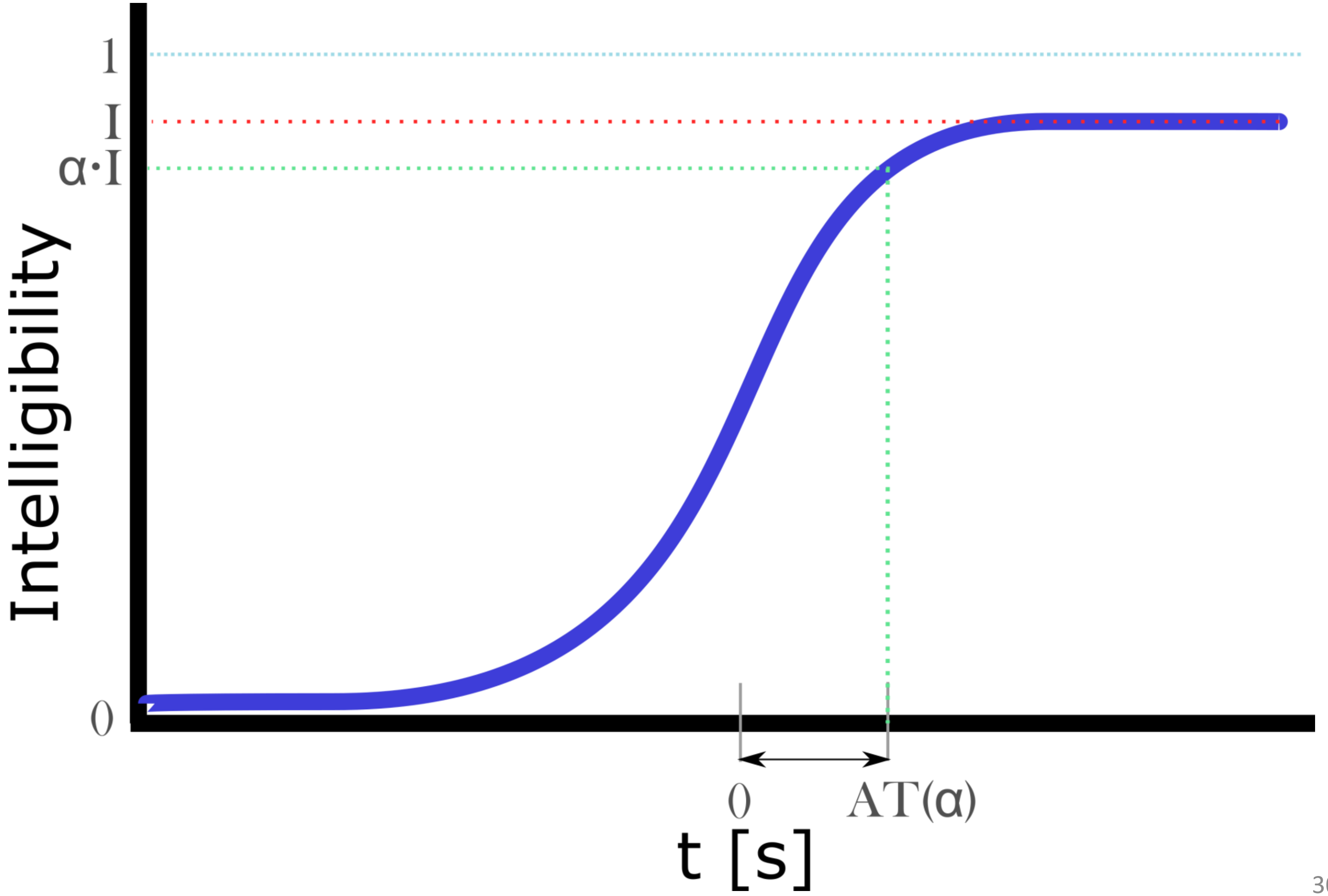
Measurement Concept

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

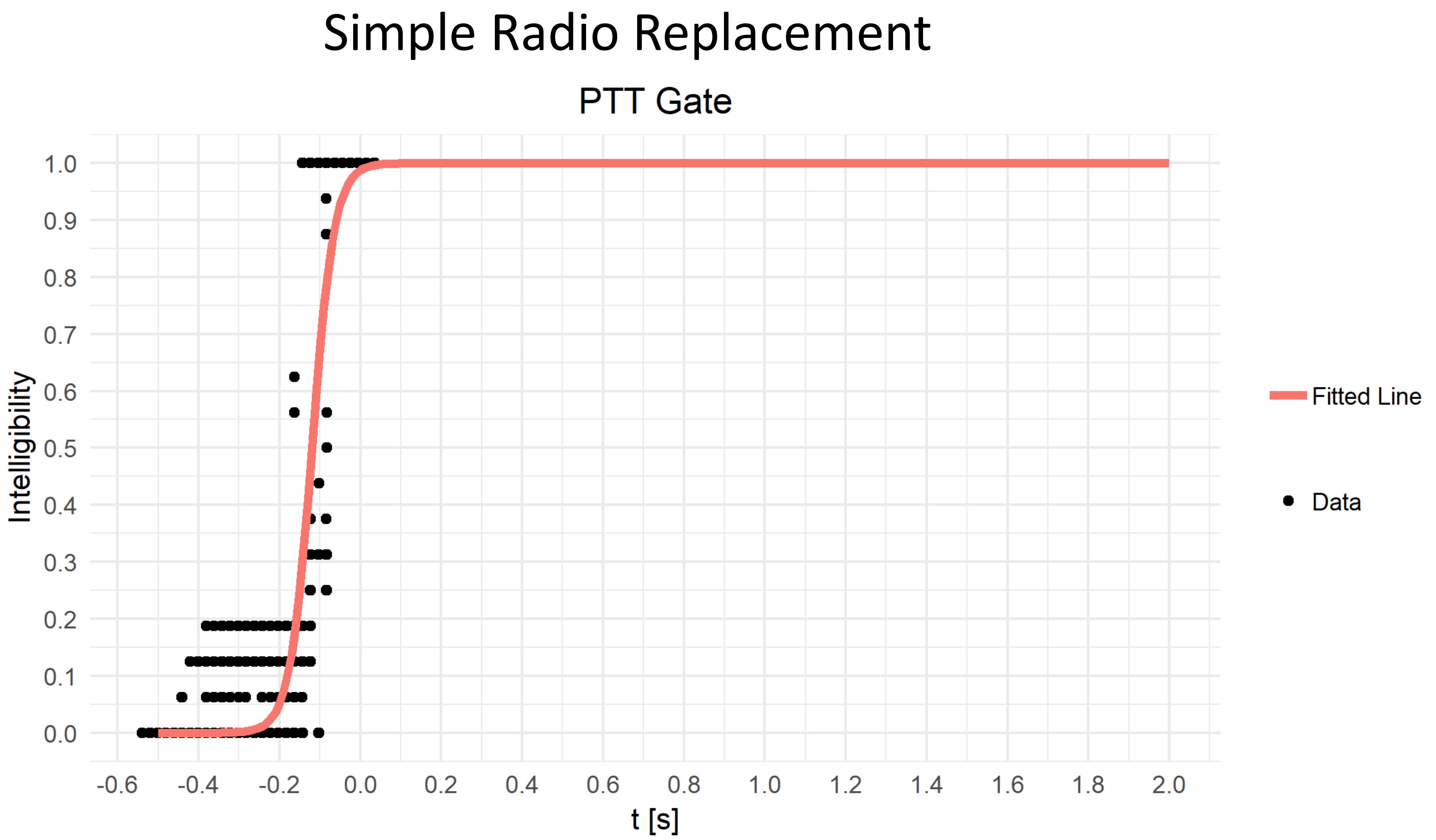
$$I(t) = \frac{I_0}{1 + e^{(t-t_0)/\lambda}}$$

- λ: Steepness of intelligibility transition
- t_0: 50% intelligibility point

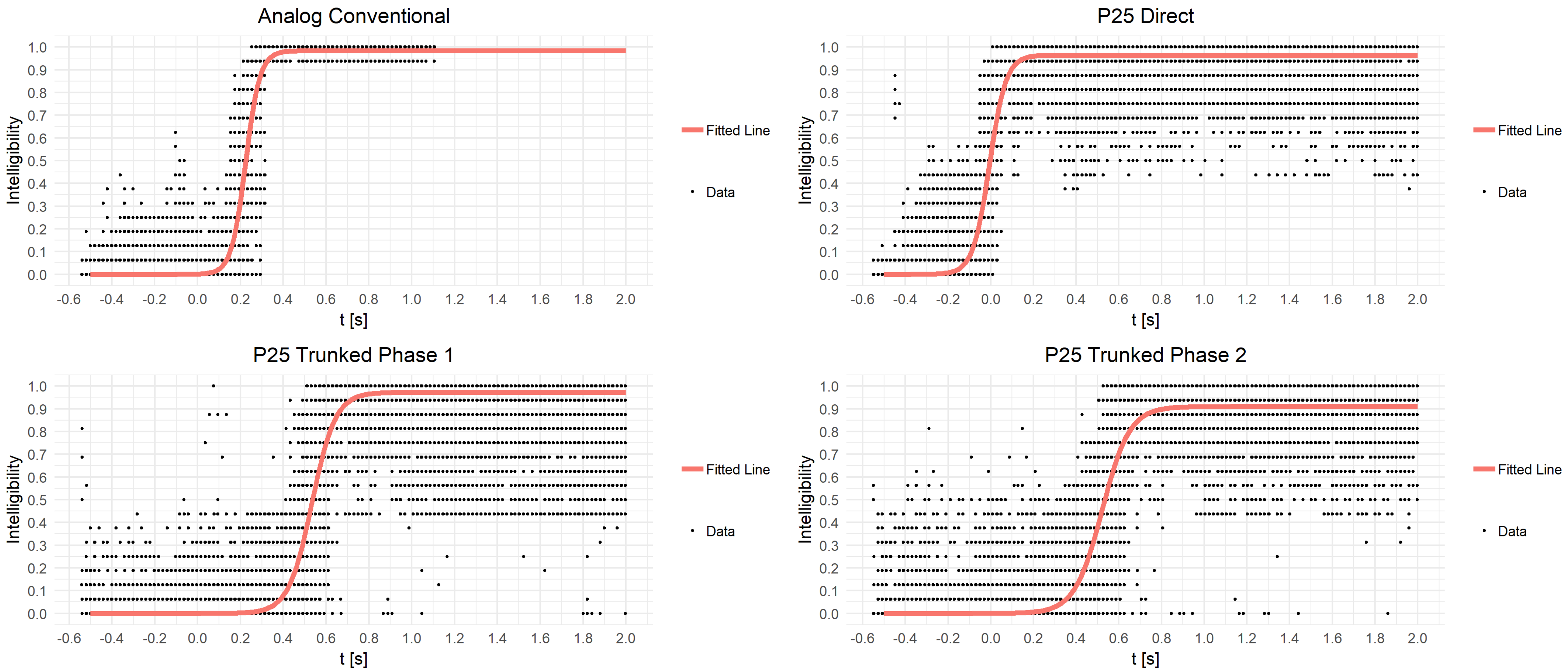
Intelligibility Curve



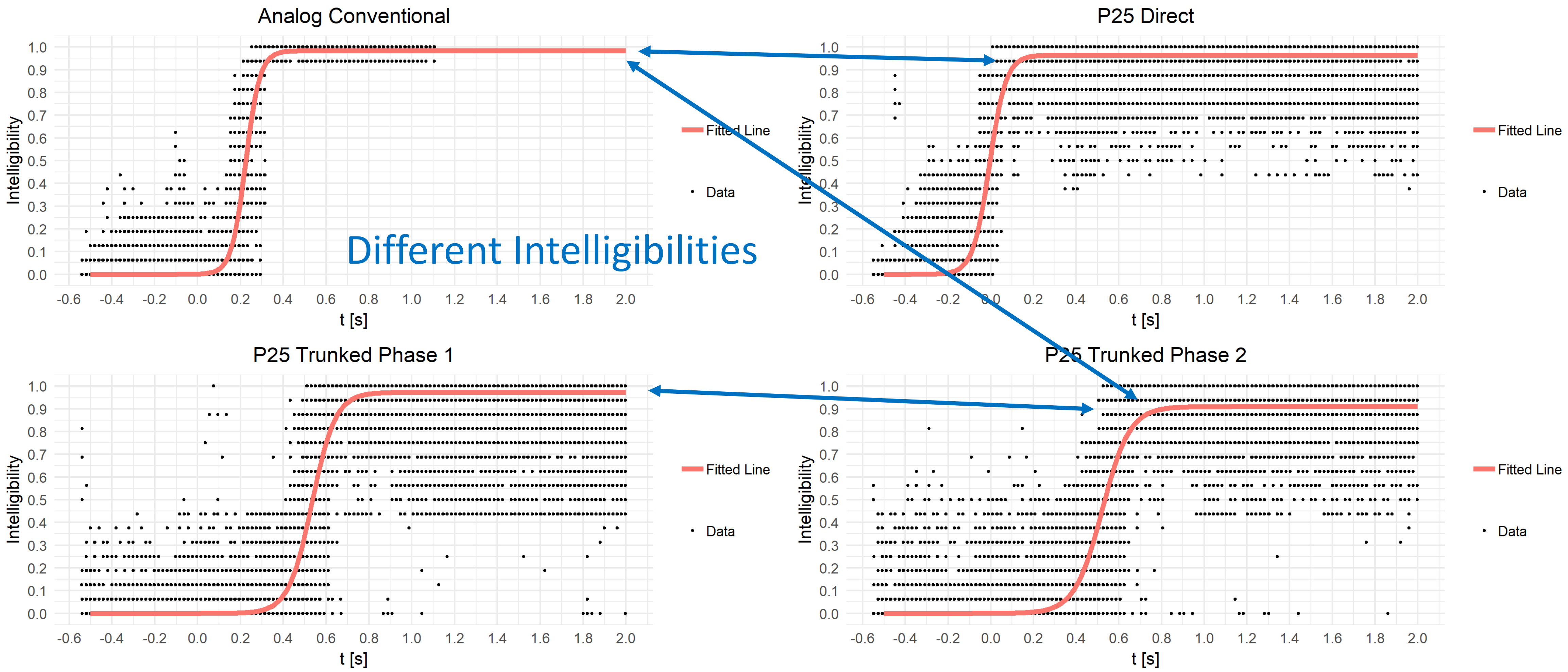
Measurement Concept



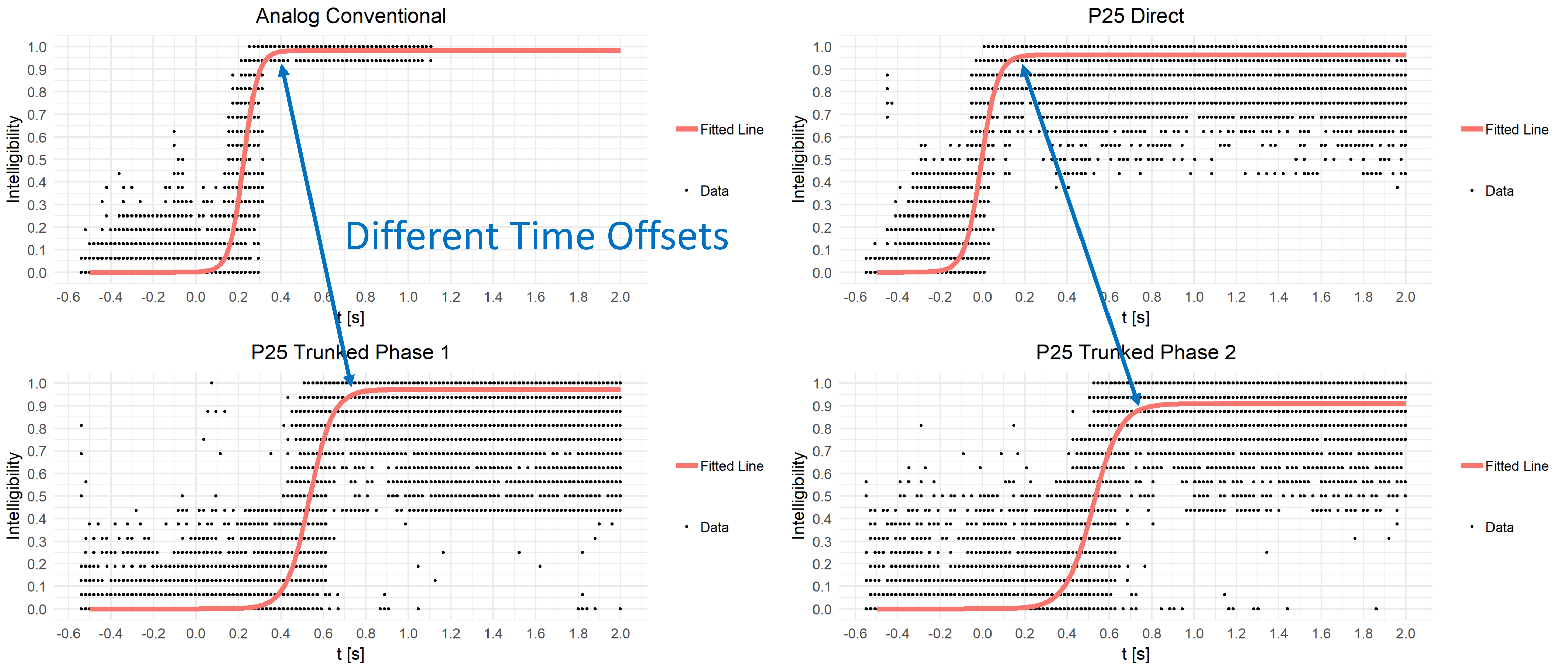
Intelligibility Curves for PTT Technologies



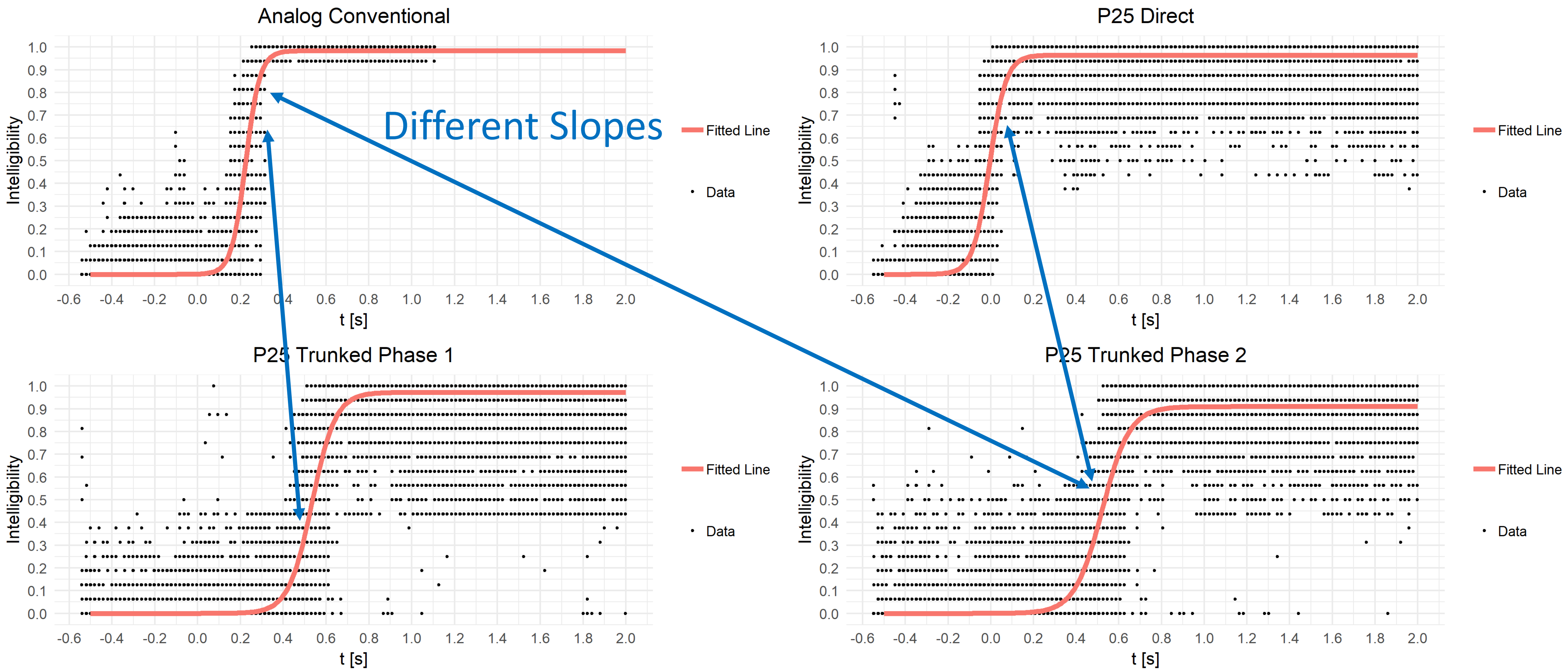
Intelligibility Curves for PTT Technologies



Intelligibility Curves for PTT Technologies



Intelligibility Curves for PTT Technologies



Measurement Concept

Access Delay Function

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

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:

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

Measurement Concept

Uncertainty of Access Delay

For an access delay estimate, $\hat{t}$, for some choice of α:

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

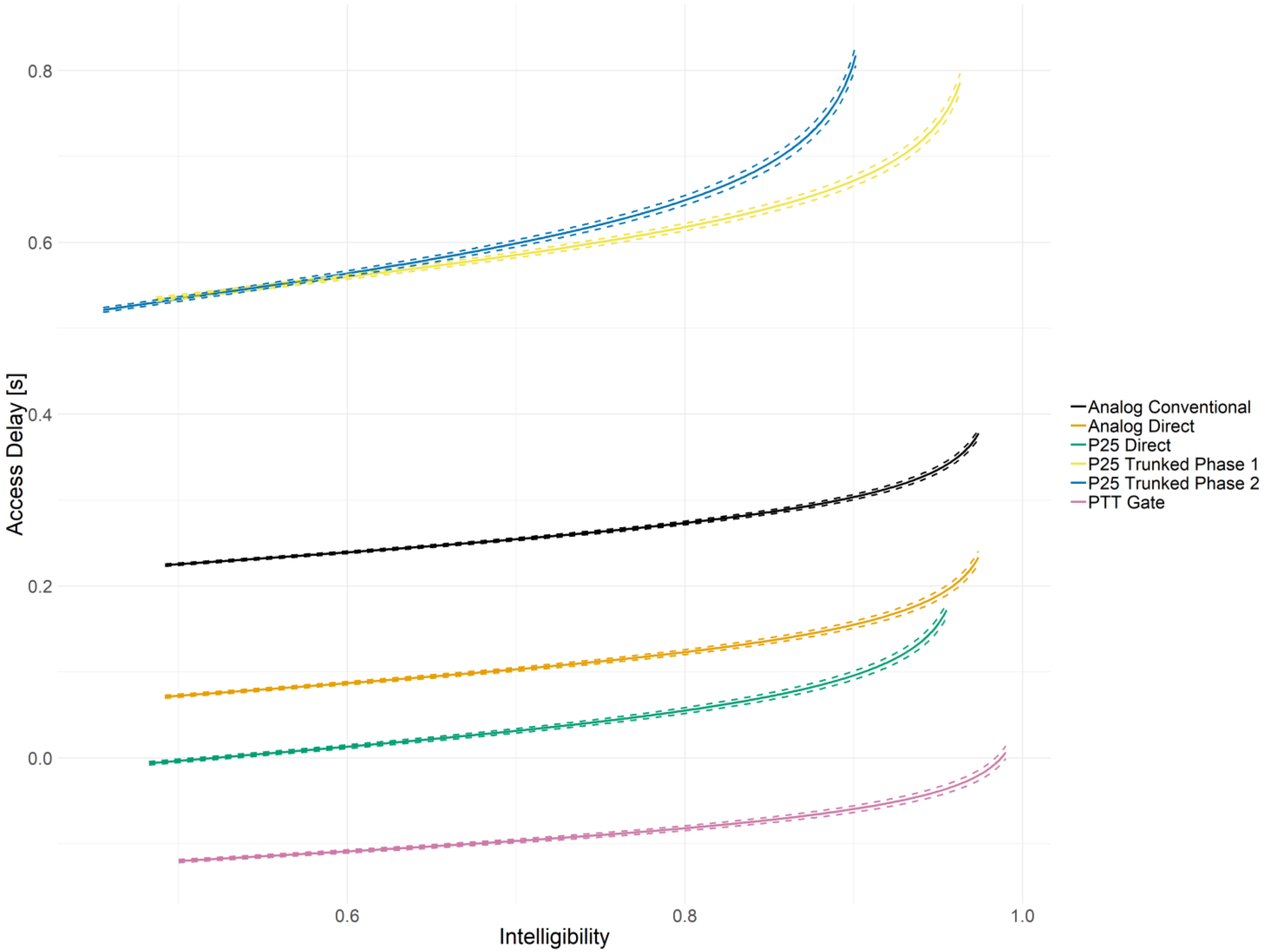
Let $C = \ln\left(\frac{1-\alpha}{\alpha}\right)$

Uncertainty from variance of estimate:

$$\mathrm{Var}(\hat{t}) = C^2\mathrm{Var}(\hat{\lambda}) + \mathrm{Var}(\widehat{t_0}) + 2C \cdot \mathrm{Cov}(\hat{\lambda}, \widehat{t_0})$$

Measurement Concept

Access Curves

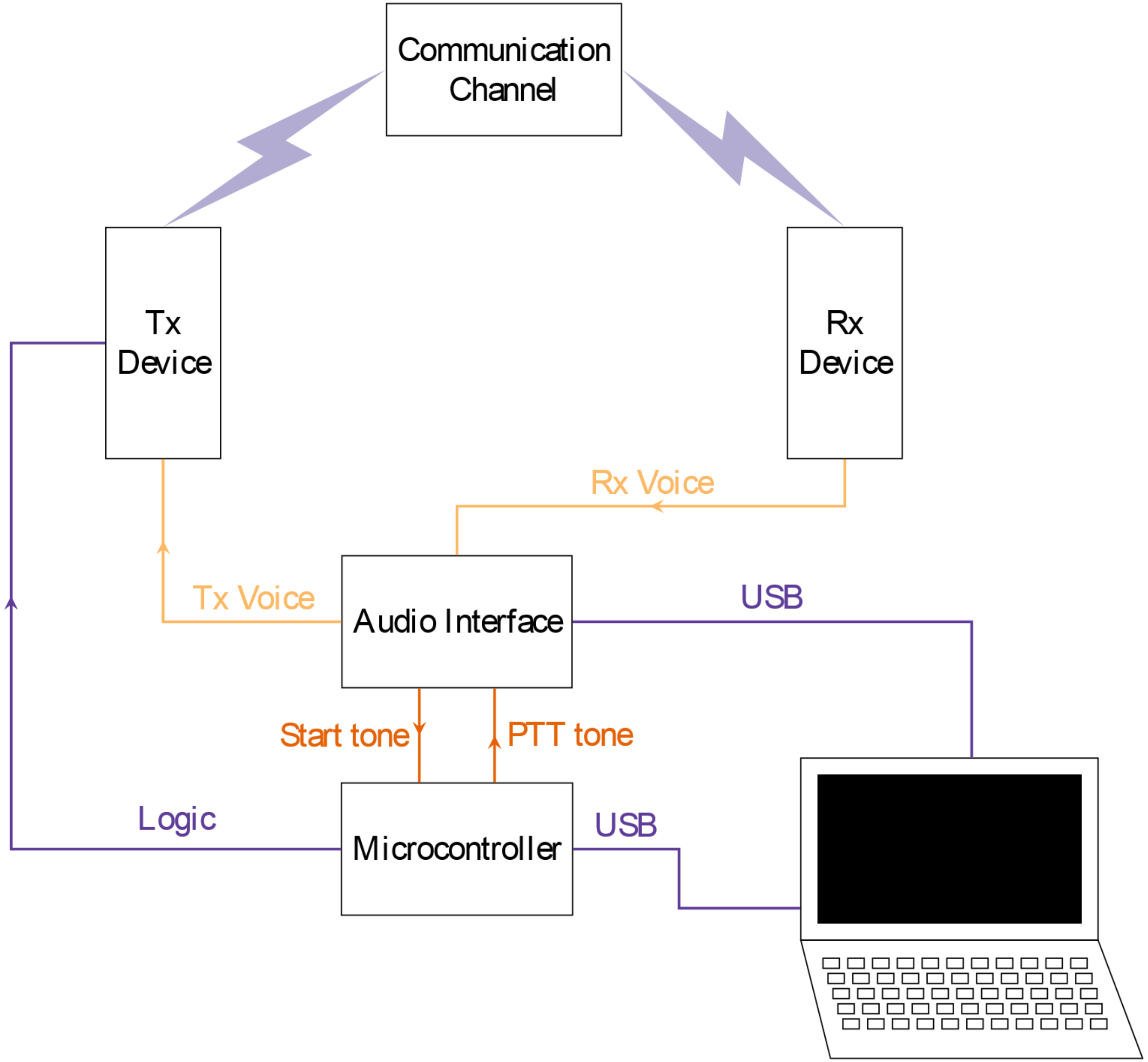


End-to-end Access Time Results for 85% Intelligibility

PTT Technology*	M2E Latency (ms)	Access Delay (ms)	End-to-End Access Time (ms)
Analog Direct	76.5 ± 0.3	136.5 ± 3.3	213.1 ± 3.3
Analog Conventional	78.5 ± 0.3	286.1 ± 2.5	364.7 ± 2.5
P25 Direct	220.9 ± 0.3	71.6 ± 4.1	292.4 ± 4.1
P25 Trunked (Phase 1 – FDMA)	356.6 ± 3.8	640.1 ± 5.1	996.7 ± 6.3
P25 Trunked (Phase 2 – TDMA)	575.9 ± 8.1	692.2 ± 7.1	1268.1 ± 10.7

*Analog Conventional operates in VHF band.
All P25 technologies operating in 700 MHz band.

End-to-End Access Time Test Setup Diagram

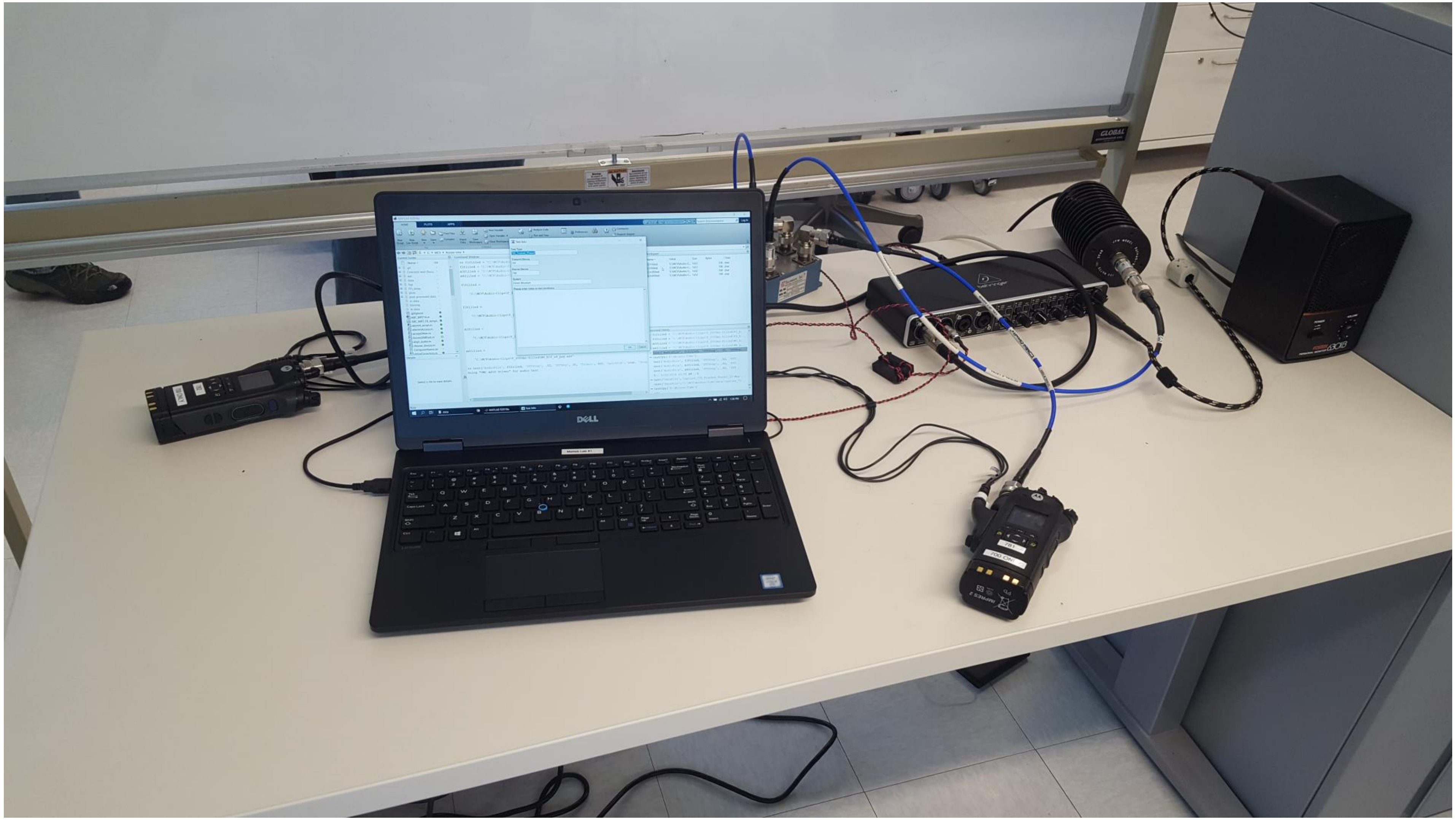


End-to-End Access Time Measurement Devices

NIST

- Behringer UMC 204/404HD Audio Interface
- Audio Interface Settings
  - Sampling rate, buffer size, and USB Streaming Mode values chosen to prevent data over/under runs and audio glitches
- Audio Interface Device Characterization
  - Latency: 21.85 ms (± 0.07 ms measurement uncertainty)
    - Time offset between play and record
- MATLAB
  - Audio System Toolbox
    - Used to play and record audio samples
    - Used to automatically key the PTT button via the microcontroller
- R Software
  - Used to quantify end-to-end access time

Test Setup (Cabled RF)



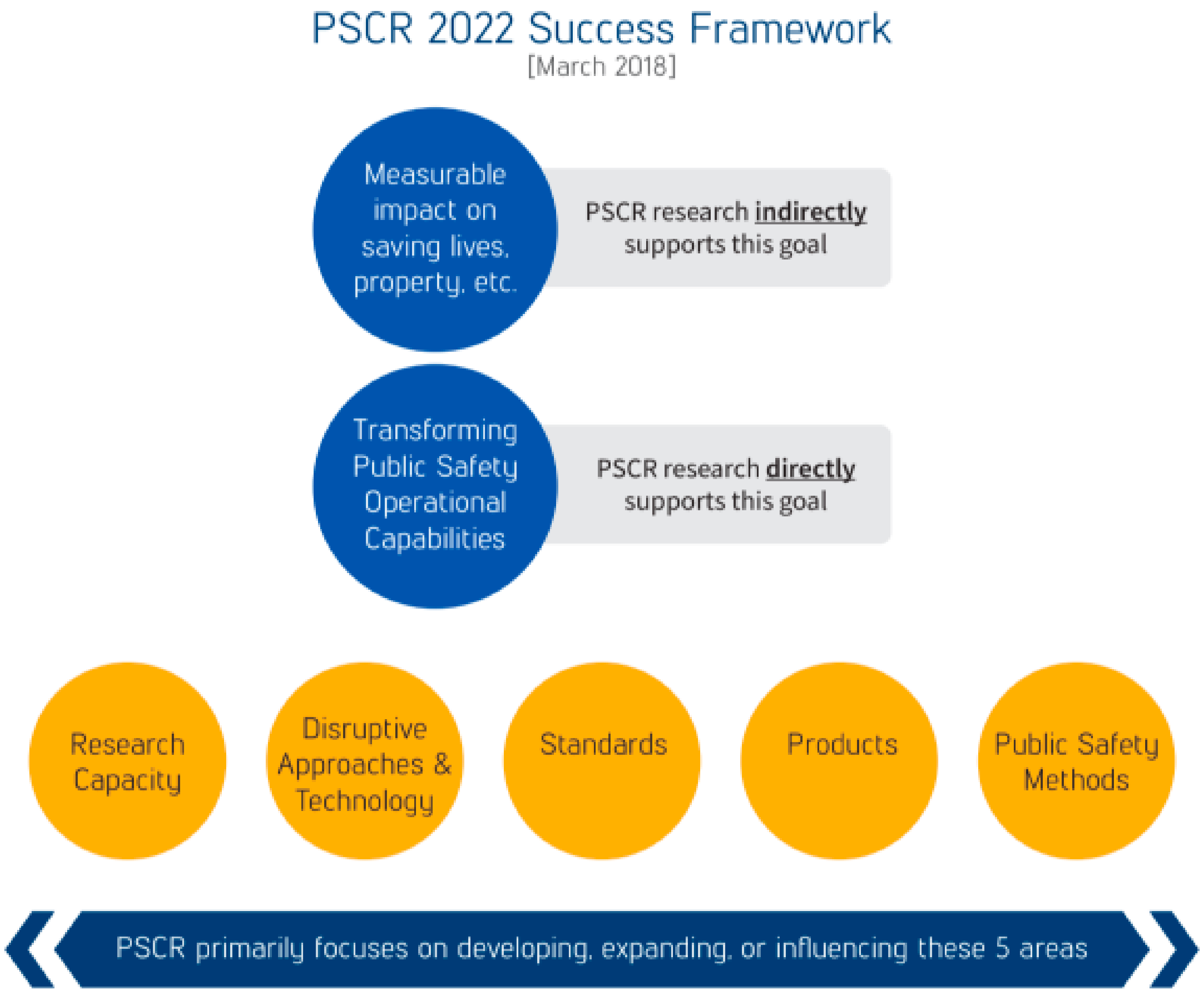
Future Work/Direction

- End-to-End Access Time Measurement Method
  - Requires Further Development
    - Collect more specific human intelligibility data
    - Validate current system
    - Explore more accurate potential models
    - Jaden Pieper to Lead with Assistance from the PSCR MCV Team
  - Validate Measurement Method on MCV Systems in the PSCR Lab
    - PTT over LTE
    - FirstNet LTE
    - DHS Interworking Capability
    - Field testing
    - LMR-LTE Interconnected Systems (Long-term Goal)
    - Tim Thompson to Lead with Assistance from the PSCR MCV Team
- Audio Quality/Intelligibility
- Access/Retention Probability

Team Members

- Back Row
  - Steve Voran
  - Tim Thompson
  - Jesse Frey
  - Zainab Soetan
- Front Row
  - Hossein Zarrini
  - Don Bradshaw
  - Chelsea Greene
  - Jaden Pieper

PSCR Success Framework



THANK YOU