Addressing Differences in Vocoder Technologies when Interfacing TIA-102 (P25) LMR Systems to Broadband Networks

John Evans

Senior Scientist

Harris Corporation - PSPC

Overview

- P25 systems will be bridged to LTE systems and transcoding of P25 to/from AMR-NB and AMR-WB will be needed
- PESQ scores are a quantitative, repeatable indicator of voice quality in the face or errors and transcoding
  - But the absolute value of the PESQ is not a direct predictor of listener MOS score since ‘listener’ expectations set the bar for what is the norm
- Public Safety uses the P25 vocoder modes for mission critical voice every day
  - Bridging that voice to users on LTE systems will not compromise the mission

Outline

- TIA-102 LMR Systems & the MBE vocoder family
- Broadband (LTE) Systems & the AMR vocoder family
- Bridging Broadband to TIA-102 systems
- Transcoding Overview
- Transcoding to interface Broadband to TIA-102
- PESQ & PESQ-Loss
- Sample PESQ-Loss scores

LMR Systems & AMBE Vocoder [1]

- In N. America, a significant portion of the Public Safety radio systems are based on the TIA-102 standards widely referred to as P25.
- These systems all use a narrowband (8 KHz sample rate) vocoder technology based upon the Multi-Band Excitation vocoder technology.
  - P25 FDMA working channels use the full rate vocoder
    - **4.4k info-bits/sec** + 2.8 FEC-bits/sec = 7200 bps
  - P25 TDMA working channels use the half rate vocoder
    - **2.45k info-bits/sec** + 1.15 FEC-bits/sec = 3600 bps
- One key advantage of the AMBE vocoder family is the robustness of the voice in the face of fading errors even with low bit rates (3600 bps for Info + FEC bits).

1 AMBE, AMBE+ and AMBE+2 are trademarks of Digital Voice Systems, Inc.

Broadband PTT Systems & AMR [1]

- In N. America (& the world), a significant change is ongoing in public safety to use broadband data systems based on LTE networks & technology for PTT applications
- The Advanced Multi-Rate (AMR) family is the vocoder mode used in Voice Over LTE (VoLTE) networks
  - AMR-NB (8KHz voice sample rate) for switched voice services
    - Info-bits-rate range from 4.75 kbps to 12.2 kbps
  - AMR-WB (16 KHz voice sample rate) for VOIP & 'HD voice' calls
    - Info-bits-rate range from 6.6 kbps to 23.85 kbps

1 AMR codecs incorporate several patents of Nokia, Ericsson, NTT and VoiceAge.

Bridging Broadband to LMR Systems

- Vocoders
  - TIA-102 systems use P25-FR and P25-HR vocoders based on DVSI AMBE+2 technology
    - The vocoder mode is embedded in the air interface and cannot be switched to some low bit rate variant of AMR
  - Broadband systems are cutting over to AMR-WB (HD Voice) and the users in general will not be willing to use narrowband, low bit rate vocoders unless they are interoperating with LMR systems

The focus of this paper is the impact on voice quality of bridging the vocoders (transcoding).

Transcoding & Re-sampling

- **Transcoding** is the direct analog-to-analog or digital-to-digital conversion of one encoding to another, such as for movie data files, audio files, or character encoding.
- Transcoding typically can result in some degradation of quality
- Rate conversion within a vocoder family (e.g. P25-FR to P25-HR) results in very minor quality degradation
- Transcoding between vocoder families requires decoding the input to a linear format (i.e. 16-bit PCM) and then re-encoding the output of the other vocoder mode into the desired vocoder mode
  - When converting between LMR and HD voice you have to also do the Up (AMBE to HD) or Down (HD to AMBE) rate sampling of discrete signals (re-sampling)

This paper provides quantitative data on the loss in audio quality due to the need to bridge the two diverse networks.

Evaluating Voice Quality

- Use ITU-T P.862 PESQ algorithm averaged over 64 files
  - Consistent indicator of changes in voice quality due to bit errors and transcoding
  - PESQ-Loss == {1- AVG(MeasPESQ)/AVG(PredPESQ}%
- TIA Project 25 used a set of 32 standard phrases to evaluate different vocoder modes
  - 4 male + 4 female speakers
  - 4 recordings per speaker
  - Each file is encoded at -28 dBov (normal voice level)
- These were modified for this study as follows
  - 32 recordings split into 64 files
  - (Most) Silence removed
  - Average duration is 2.9 seconds

AMR Modes

AMR-NB

Index	Mode	Class A bits	Total speech bits	Adaptive Half-Rate Speech (AHS)	Adaptive Full-Rate Speech (AFS)
0	AMR 4.75	42	95	x	x
1	AMR 5.15	49	103	x	x
2	**AMR 5.9**	**55**	**118**	**D**	**x**
3	AMR 6.7	58	134	d	x
4	AMR 7.4	61	148	d	D
5	AMR 7.95	75	159	d	d
6	AMR 10.2	65	204	-	d
7	AMR 12.2	81	244	-	d
8	AMR SID	39	39	x	x

Mode 2 is the default for Adaptive Half Rate Speech of AMR-NB.

AMR-WB (HD Voice)

Index	Mode	Class A bits	Total speech bits
0	AMR 6.6	54	132
1	AMR 8.85	64	177
2	**AMR 12.65(M)**	**72**	**253**
3	AMR 14.25	72	285
4	AMR 15.85	72	317
5	AMR 18.25	72	365
6	AMR 19.85	72	397
7	AMR 23.05	72	461
8	AMR 23.85	72	477

Mode 2 is the main anchor bit rate mode for all WB modes.

AMR-NB-M2	(0% BER)
Average PESQ	3.352
Average, Male Only	3.39
Average, Female Only	3.31

AMR-WB-M2	(0% BER)
Average PESQ	3.974
Average, Male Only	4.02
Average, Female Only	3.93

P25 Mode

- The P25 Half Rate vocoder mode was chosen for this study
  - PESQ scores of P25-HR ~ P25-FR
- The effects of fading consistent with DAQ 3.4 were included when transcoding from P25-HR to AMR to simulate the effects of bit errors through the transcoding process

P25-HR	(0% BER)	(2.5% BER)	PESQ-Loss @ 2.5% BER Compared to 0%BER
Average PESQ	2.953	2.553	13.5%
Average, Male Only	3.01	2.60	13.5%
Average, Female Only	2.90	2.50	13.6%

High Level View

- Barring the physical limitations of SmartPhone Mics and speakers compared to LMR radios…
  - The vocoder modes of AMR used on LTE systems (e.g. Mode 2 and above) have better PESQ scores than the P25 mode
  - AMR-WB-M2 ~4, AMR-NB-M2 ~3.5 and P25-HR ~ 3
  - So a user on the LTE system accustomed to calls on AMR that hears a call from a P25 radio will probably judge the audio quality as reduced compared to normal before any fading or transcoding effects.
- Similarly, since AMR-WB is ~4 & AMR-NB ~3.5
  - the effect of transcoding from P25-HR to AMR-WB is ~ 0 on the PESQ score

Cases Presented

- AMR-NB (Mode 2) to P25-HR (Strong Signal)
- AMR-WB (Mode 2) to P25-HR (Strong Signal)
- P25-HR (Faded) to AMR-NB (Mode 2)
- P25-HR (Faded) to AMR-WB (Mode 2)

AMR-NB to P25-HR

ENCODE	AMR-NB-M2			P25-HR	AMR-NB-M2
DECODE	AMR-NB-M2			P25-HR	AMR-NB-M2
XCODE to	None	P25-HR		None	P25-HR
P25 Link BER	0% BER				
	PESQ Score	PESQ Score	%-Loss to LTE Listener	PESQ Score	%-Loss to P25 Listener
Average	3.35	2.84	15.3%	2.95	3.8%
Average, Male Only	3.39	2.88	15.1%	3.01	4.2%
Average, Female Only	3.31	2.80	15.5%	2.90	3.3%

AMR-WB to P25-HR

ENCODE	AMR-WB-M2			P25-HR	AMR-WB-M2
DECODE	AMR-WB-M2			P25-HR	AMR-WB-M2
XCODE to	None	P25-HR		None	P25-HR
P25 Link BER	0% BER				
	PESQ Score	PESQ Score	%-Loss to HD-Voice Listener	PESQ Score	%-Loss to P25 Listener
Average	3.97	2.92	26.6%	2.95	1.2%
Average, Male Only	4.02	2.95	26.5%	3.01	1.8%
Average, Female Only	3.93	2.88	26.7%	2.90	0.5%

P25-HR to AMR-NB

ENCODE	P25-HR					AMR-NB-M2	P25-HR
DECODE	P25-HR					AMR-NB-M2	P25-HR
XCODE to	None			AMR-NB-M2		None	AMR-NB-M2
P25 Link BER	0% BER	2.5% BER				0% BER	2.5% BER
	PESQ Score	PESQ Score	%-Loss	PESQ Score	%-Loss to P25 Listener	PESQ Score	%-Loss to LTE Listener
Average	2.95	2.55	13.5%	2.50	2.1%	3.35	25.4%
Average, Male Only	3.01	2.60	13.5%	2.53	2.9%	3.39	25.5%
Average, Female Only	2.90	2.50	13.6%	2.47	1.2%	3.31	25.3%

P25-HR to AMR-WB

ENCODE	P25-HR					AMR-WB-M2	P25-HR
DECODE	P25-HR					AMR-WB-M2	P25-HR
XCODE to	None			AMR-WB-M2		None	AMR-WB-M2
P25 Link BER	0% BER	2.5% BER				0% BER	2.5% BER
	PESQ Score	PESQ Score	%-Loss	PESQ Score	%-Loss to P25 Listener	PESQ Score	%-Loss to HD-Voice Listener
Average	2.95	2.55	13.5%	2.55	0.2%	3.97	35.9%
Average, Male Only	3.01	2.60	13.5%	2.58	0.8%	4.02	35.8%
Average, Female Only	2.90	2.50	13.6%	2.51	-0.4%	3.93	36.0%

Summary

- P25 systems will be bridged to LTE systems and transcoding of P25 to/from AMR-NB and AMR-WB will be needed in cases
- PESQ scores are a quantitative, repeatable indicator of voice quality in the face or errors and transcoding
  - But the absolute value of the PESQ is not a direct predictor of listener MOS score since ‘listener’ expectations set the bar for what is the norm

Contact Information

John Evans

Senior Scientist

Harris Corporation

Public Safety & Professional Communications

(http://pspc.harris.com)

221 Jefferson Ridge Parkway

Lynchburg, VA 24501-6952

john.evans@harris.com

Acknowledgements

- AMBE, AMBE+ and AMBE+2 are trademarks of Digital Voice Systems, Inc.
  - The fixed point vocoder simulator used in this study was provided by DVSI, Inc. and is bit-exact with the APCO V1.6 release.
- AMR codecs incorporate several patents of Nokia, Ericsson, NTT and VoiceAge
  - The floating point vocoder simulators used in this study were provided by VoiceAge
    - Open AMR Initiative, July 2007

Related Study

- PSCR conducted a very similar study
  - D.J. Atkinson, “P25/VoLTE Interconnection: Initial Voice Performance Indicators”, 1/24/2012, Sponsored by DHS/OIC.

Parametric Rate Conversion

- Parametric Rate Conversion is a special case of transcoding where the underlying model is the same
  - E.g. Multi-Band Estimation as used in P25 vocoders or ACELP as used in AMR vocoders
  - Different Rates use different numbers of bits per parameter
  - So rate conversion involves simply mapping the bits between the different rates
- The transcoding loss for rate conversion is generally very small compared to the loss between families of vocoders
  - Particularly when transcoding from a low bit-rate vocoder to a high-bit rate AND higher sampling rate vocoder (e.g. 16 KHz to 8 KHz)

Parametric Rate Conversion Example – FR to HR

ENCODE	P25-FR		
DECODE	P25-FR	None	
PRC to	None	P25-HR	
P25 Link BER	0% BER		
	PESQ Score	PESQ Score	%-Loss to P25 Listener
Average	3.12	3.02	3.3%
Average, Male Only	3.20	3.09	3.7%
Average, Female Only	3.04	2.95	2.8%

Parametric Rate Conversion Example – HR to FR

ENCODE	P25-HR		
DECODE	P25-FR	None	
PRC to	None	P25-FR	
P25 Link BER	0% BER		
	PESQ Score	PESQ Score	%-Loss to P25 Listener
Average	3.09	3.01	2.6%
Average, Male Only	3.17	3.07	3.1%
Average, Female Only	3.01	2.94	2.1%

Acronyms

- ACELP — Algebraic Code-Excited Linear Prediction
- AMBE — Advanced Multi-Band Estimation
- AMR — Adaptive Multi-Rate vocoder
- DAQ — Delivered Audio Quality
- FDMA — Frequency Division Multiple Access
- FEC — Forward Error Correction
- ITU-T — International Telecommunication Union-Telecommunication
- LMR — Land Mobile Radio
- LTE — Long Term Evolution
- MBE — Multi-Band Estimation
- P25 — Project 25
- PESQ — Perceptual Evaluation Speech Quality
- TDMA — Time Division Multiple Access
- TIA — Telecommunications Industry Association
- VoLTE — Voice over LTE