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Meeting the Demand of Expanding Digital Mobile Radio Communication Networks

Given the importance of mission critical wireless communication, it is vital that these networks provide high quality voice that preserves intelligibility even with background noise, along with delivering consistency in coverage, and long range, all with minimal latency. For more than 24 years Digital Voice Systems, Inc. (DVSI)'s AMBE Vocoder® technology has been the standard in APCO P25 critical communications because it has successfully met these demands. While users often ask for more ways to communicate and share information, engineers are faced with the difficult task of designing solutions and developing new technologies that work within the established bandwidth criteria and supports interoperability with the abundance of an existing installed base.

DVSI's vocoder is the standard for APCO International Project 25 (P25) digital public safety radio systems. DVSI's vocoder was developed in two phases. Initially DVSI's IMBE® vocoder operating at 7200 bps (consisting of 4400 bps voice and 2800 bps FEC) was selected. Then as a second-generation digital radio standard, Phase 2 included several key technology advancements, such as advanced modulation methods and a two-to-one increase in spectral efficiency, DVSI's 3600 bps (consisting of 2450 bps voice and 1150 bps FEC) vocoder was developed (referred to as "half-rate" vocoder). Since Phase 2 was adopted newly manufactured radios are fully interoperable at full-rate (7200bps) or half-rate (3600bps). To allow legacy radio equipment that are only capable of working at full-rate 7200bps to interoperate with the new half-rate radios, engineers typically networks with gateways that decode to speech from one rate then encode the decoded speech to the new rate and re-transmit ("tandeming"). This method not only reduces voice quality and intelligibility but also requires additional processing as well as introduces delays. In situations where multiple tandem stages occur, the result can be severe degradation of voice quality and intelligibility. (See Figure 1)

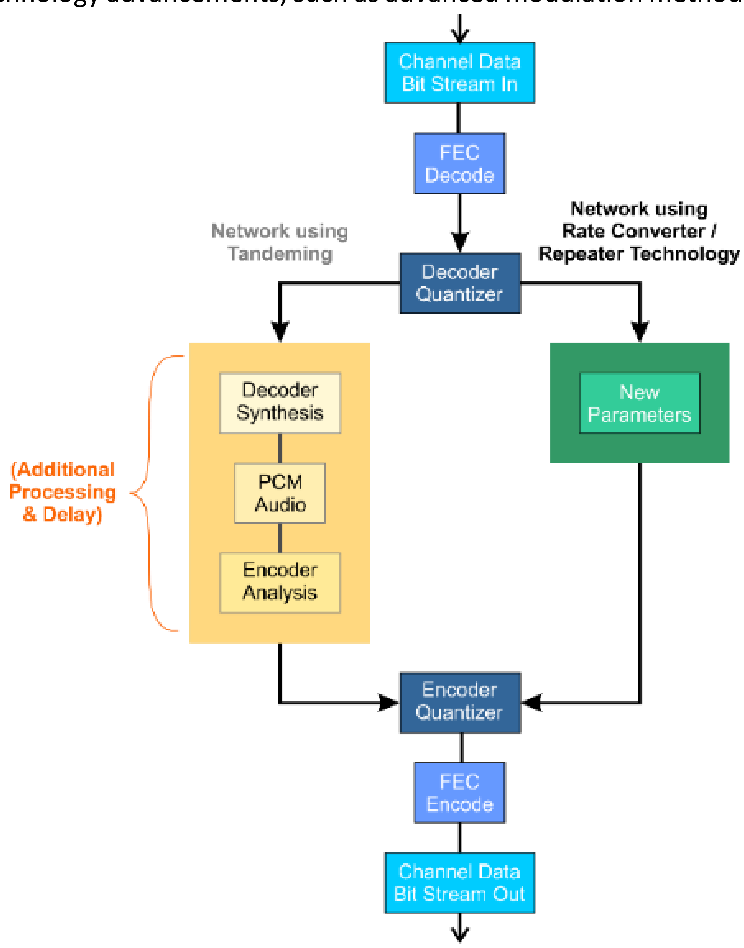

Figure 1

Alternatively, a parametric rate converter can be used to avoid the issues with tandem vocoder sequences. DVSI's parametric rate converter function allows AMBE® vocoder communication networks to interoperate independent of their respective data rates. A major advantage of employing the parametric rate converter is that the incoming data bit stream is not converted back to speech as part of the conversion process (i.e., it does not use tandeming). Instead, the analysis (i.e., extraction) of the MBE model parameters is used as the intermediate stage between bit rates, and the synthesis of speech is not performed. This approach avoids adding multiple stages of delay and much of the distortion normally associated with tandeming. A benefit of the parametric converter is that it works with any two rates supported by AMBE+2™ Vocoder Technology.

As an example, the DVSI's parametric rate converter can be used to convert between P25 Full-Rate (7200 bps) and P25 Half-Rate (3600 bps) bit streams. The parametric rate conversion process first de-interleaves and FEC decodes the input 7200 bps data bit stream, then determines the MBE model parameters (including the fundamental, gain, voicing decision, and spectral magnitude). These model parameters are then re-quantized and reconstructed to new bit vectors, which are FEC encoded and interleaved to produce the output bit stream (3600 bps). See Figure 1

It has been shown that the process of tandeming from one vocoder rate to another, can lead to the loss of intelligibility, and increased delays. DVSI conducted ABC-MRT tests (developed by NIST [2]) to quantify the reduction of intelligibility caused by tandeming speech. Testing was done on clean speech as well as in the presence of street background noise typically found in mission critical environments. The tests were performed in accordance with ANSI/ASA standard S3.2. The MRT results showed that tandeming had a loss of approximately 40% of intelligibility in the noise condition. The MRT results show that using the parametric converter function had less of an effect on voice intelligibility than tandeming from one rate to another. As shown in Figure 2 using the parametric converter function resulted in 12% improvement in intelligibility as compared to tandeming . In a recent study [1], [2], an MRT score of 75% was considered a minimal speech intelligibility threshold, and in the aforementioned tests this was only achieved in the test conditions of clean speech.

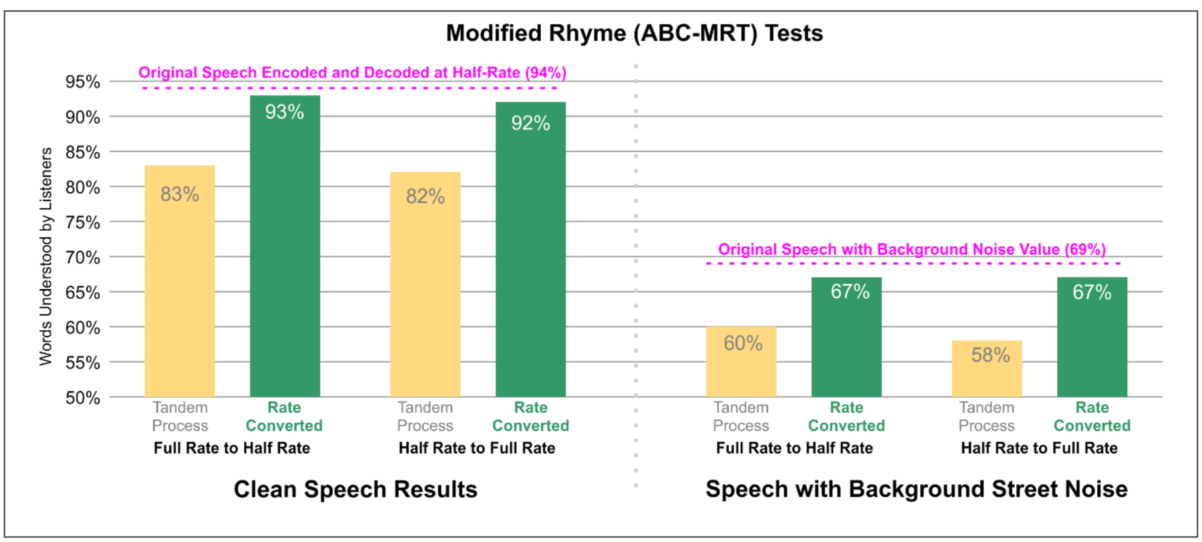

Figure 2

While the parametric rate conversion can be used to interoperate between multi rate AMBE® vocoder systems, users also require consistency in coverage, and increased communication network range. To address these requirements, DVSI developed a repeater that can take the incoming data bit stream, fix RF channel bit errors and re-transmit. This process not only provides better immunity to undesired noise signals but also allows for retransmission of data to effectively increase communication system range while leaving the speech quality intact.

Similar to the parametric rate converter, DVSI's Repeater function does not convert the incoming data bit stream back to speech as part of the repeating process (i.e., it does not use tandeming). The "Repeater function" in the DVSI's Repeater performs just the FEC processes. When using the repeater function the MBE model parameters of the received data stream are not changed. The data is FEC Decoded to fix bit errors and then FEC encoded before transmitting the repaired frame. Without the need to process MBE model parameters and voice-decode or voice-encode there is no tandeming and no algorithmic delay that can degrade voice quality and hamper network performance. Additionally, the repeater function can be set to FEC decode only to give access to transmitted data or FEC Encode only for the injection of data into network data stream.

Converting between rates using the parametric rate converter is a great way to provide access across multiple networks of different data rates. The repeater's ability to re-transmit data without interjecting any degradation can extend network coverage to a point where you can virtually communicate between any two points. But these functions are not the only solutions needed to meet the needs of these highly demanding users and design engineers. What good is being able to communicate across networks of varying data rates across the globe if the data stream gets corrupted. The artifacts caused by data errors can lead to loss of intelligibility or transmissions with pops, cracks and hiss that effect the overall voice quality. To address these issues DVSI has designed a frame analyzer.

The DVSI Frame Analyzer function works to help stop the propagation of bit errors, whether when repeating a packet or converting from one rate to another. Once a packet is received and FEC decoded, if the frame falls below the required bit error tolerance where it cannot reasonably be corrected, (essentially too noisy to provide good copy), the Frame analyzer function will prevent the corrupted data from being FEC encoded or rate converted (depending on if it is repeating or rate converting) and force the FEC encoder or rate converter to send an "erasure frame" instead. This prevents the downstream repeater or the parametric converter from re-encoding a corrupt voice frame and passing it along to the next receiver or voice decoder (See Figure 3). Without the Frame analyzer function a previously corrupted voice frame may arrive without further channel errors at a n endpoint's FEC decoder which would think it is good data and ultimately pass it to the voice decoder which would produce distorted sounds. When an erasure frame is present it will signal to the voice decoder to initiate a frame repeat thereby, maintaining voice quality. It is better for an endpoint to do a frame repeat on a frame that was detected as bad upstream rather than retransmitting cascading frame repeats in the middle of the link which may result in a long sequence of repeated frames. Thus, in some extreme environments with high BER it may be desirable to pause from using the repeater's erasure frame feature to allow for the muting that normally would occur after four bad frames.

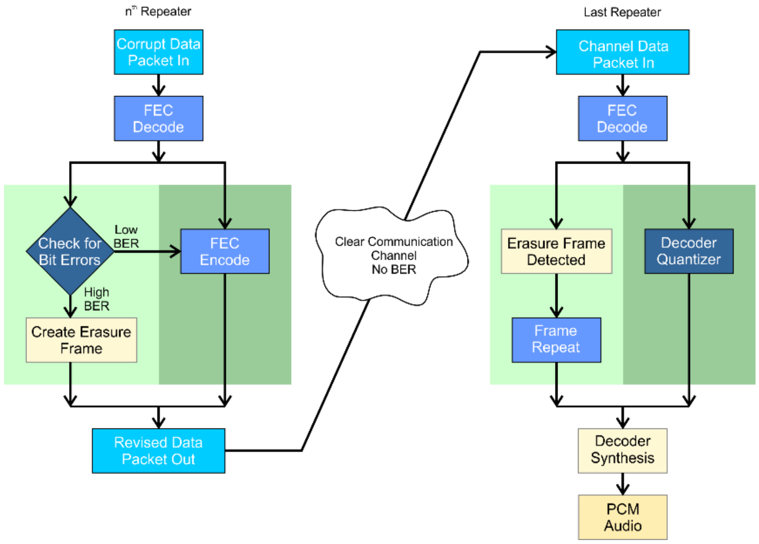

Figure 3

The erasure frame is even compatible in legacy communication networks/endpoints, because even if the endpoint doesn't have the erasure frame detector in the FEC decoder, the erasure frame sent by the upstream "erasure frame capable" repeater will be decoded by the legacy FEC decoder as a high BER frame, and it will signal to the voice decoder to frame repeat. If the erasure frame gets passed from the FEC decoder to the voice decoder it will be detected there, as invalid, and the voice decoder will frame repeat.

DVSI's parametric rate converter, vocoder repeater and frame analyzer meet the digital mobile radio user's Demand for Expanding Communication Networks. Ultimately this demand cannot be realized without engineers and manufacturers embedding AMBE® Vocoder technology into their products. As DVSI makes advances in new vocoder technology and development, engineers and manufacturers are working on using advanced software implementation techniques and simplified hardware designs to provide a better alternative to the decoding and reencoding of tandeming typically required to seamlessly transition between different communication network configurations.

To facilitate the delivery of innovative products that support AMBE® vocoder communication systems DVSI developed the USB-3000™ RC (See Figure 4). The USB-3000™ RC employs several features that have been deployed in systems using DVSI's software products for more than 15 years. The USB-3000™ RC is a USB device that incorporates a parametric rate converter, a vocoder repeater and frame analyzer. The parametric rate converter promotes seamless interoperability between AMBE® vocoder communication networks such as, wireless radio or satellite links, wire connected phone lines, and Ethernet networks including the Internet. The USB-3000™ RC vocoder repeater can extend the effective transmission range and avoid gaps in

Figure 4

coverage area as well as remove unwanted errors in data stream. Its frame analyzer function helps propagate efficient data transmission.

DVSI's patented AMBE+2™ Voice Compression technology is the heart of USB-3000™ RC. It has the flexibility to convert to/from or repeat virtually any data rate between 2000 bps and 9600 bps. The versatility of speech and/or FEC rates permits optimization within custom system requirements while delivering and maintaining excellent voice quality along with superior robustness to bit errors without adding significant delays.

The USB-3000™ RC uses the same technology as the successful USB-3000™. The USB-3000™ has been implemented into critical applications such as digital mobile radio, satellite communication systems and in other wireless communication devices for more than ten years. Both devices allow user to connect to a USB port on a Windows or Linux based PC, to transmit/receive speech and compressed data packets, as well as configure vocoder repeater / rate converter and FEC options and monitor status information.

Like the USB-3000™ the USB-3000™ RC is configured so that all speech and channel data to/from USB port is formatted into packets. This packet-mode interface allows the USB-3000™ RC to process the incoming packets as soon as they are received and output the resulting response packet with minimal delay. The fast baud rate of the USB-3000™ RC helps keep the delay as small as possible. The algorithmic delay of the repeater is zero. There are other non-zero processing and buffering delays caused by the PC hardware and the OS, as well as what drivers are employed by the system.

The USB interface helps keep infrastructure costs low and allows for flexible implementation into a variety of configurations. A three channel USB-3003™ RC model can convert rates of multiple channels at one time to expand the network size without requiring increased processing power, without adding latency and without the need to vocoder decode / encode tandeming. USB-3000™ RC can also be used to process stored compressed voice data offline.

Efficiently and effectively expanding digital mobile radio communication networks depends greatly on the voice compression vocoder capabilities and how it handles wireless transmission conditions and background environmental noise. DVSI is continuously advancing voice compression technology and its ability to provide high quality intelligible voice in a variety of conditions and background noise environments. With DVSI's parametric rate converter / repeater technology there is no need to employ encoding/decoding tandeming that could result in severe degradation in performance, increased processing delays and losses in voice quality and intelligibility.

DVSI's USB-3000™ RC can play and integral role in expanding communication networks by providing a parametric rate converter, a vocoder repeater and frame analyzer that satisfies the needs of its users. The USB interface of the USB-3000™ RC provides the design engineer and the manufacturer with a low-cost method to implement AMBE® Vocoder technology and rate converter into their products.

Mission critical wireless communication is not segregated solely to law enforcement and emergency first responders. Any industry that relies on digital wireless communication, from energy/utilities, to large university campuses or transportation systems, or manufacturing facilities and even amateur radio demand high quality voice and intelligibility. It is considered mission critical to them. These communication systems employ different standards such as DMR, DpMR, Globastar, Terrastar, Full Rate and Half Rate– P25, NXDN at various data rates. However, the one thing they have in common is they all implement the AMBE® Vocoder technology. When there is a need to expand or communicate between any of these systems, the best way to avoid the detrimental effect of encoder/decoder tandeming is to employ a parametric rate converter/repeater.

[1] Letowski, T.R. & Scharine, A.A. (2017). *Correlational Analysis of Speech Intelligibility Test and Metrics for Speech Transmission ARL-TR-8227*. Retrieved from: https://www.arl.army.mil/arlreports/2017/ARL-TR-8227.pdf

[2] Webpage of the Institute for Telecommunication Sciences *ABC-MRT16 and AMC-MRT* Retrieved from: https://www.its.bldrdoc.gov/resources/audio-quality-research/abc-mrt.aspx