SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS COMMUNICATION NETWORKS

Claim of Priority

[0001] A claim of priority is made to the following U.S. Provisional Applications: No. 61/059,179 entitled "ROBUST SIGNAL FOR DATA TRANSMISSION OVER IN-BAND VOICE MODEM IN DIGITAL CELLULAR SYSTEMS" filed June 5, 2008, and assigned to the assignee hereof and hereby expressly incorporated by reference herein; and No. 61/087,923 entitled "SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS (OR CELLULAR) COMMUNICATION NETWORKS" filed August 11, 2008, and assigned to the assignee hereof and hereby expressly incorporated by reference herein; and No. 61/093,657 entitled "SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS (OR CELLULAR) COMMUNICATION NETWORKS" filed September 2, 2008, and assigned to the assignee hereof and hereby expressly incorporated by reference herein; and No. 61/122,997 entitled "SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS (OR CELLULAR) COMMUNICATION NETWORKS" filed December 16, 2008, and assigned to the assignee hereof and hereby expressly incorporated by reference herein; and No. 61/151,457 entitled "SYSTEM AND METHOD FOR PROVIDING GENERAL BI-DIRECTIONAL IN-BAND MODEM FUNCTIONALITY" filed February 10, 2009, and assigned to the assignee hereof and hereby expressly incorporated by reference herein; and No. 61/166,904 entitled "SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS (OR CELLULAR) COMMUNICATION NETWORKS" filed April 6, 2009, and assigned to the assignee hereof and hereby expressly incorporated by reference herein.

RELATED APPLICATIONS

[0002] Related co-pending U.S. Patent Applications include:

"SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS COMMUNICATION NETWORKS", having Attorney Docket No. **081226U1**, filed concurrently herewith, assigned to the assignee hereof, and expressly incorporated by reference herein;

"SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS COMMUNICATION NETWORKS", having Attorney Docket No. **081226U2**, filed concurrently herewith, assigned to the assignee hereof, and expressly incorporated by reference herein;

"SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS COMMUNICATION NETWORKS", having Attorney Docket No. **081226U3**, filed concurrently herewith, assigned to the assignee hereof, and expressly incorporated by reference herein.

"SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS COMMUNICATION NETWORKS", having Attorney Docket No. **081226U4**, filed concurrently herewith, assigned to the assignee hereof, and expressly incorporated by reference herein.

"SYSTEM AND METHOD OF AN IN-BAND MODEM FOR DATA COMMUNICATIONS OVER DIGITAL WIRELESS COMMUNICATION NETWORKS", having Attorney Docket No. **081226U5**, filed concurrently herewith, assigned to the assignee hereof, and expressly incorporated by reference herein.

BACKGROUND

Field

[0003] The present disclosure generally relates to data transmission over a speech channel. More specifically, the disclosure relates to transmitting non-speech information through a speech codec (in-band) in a communication network.

Description of Related Art

[0004] Transmission of speech has been a mainstay in communications systems since the advent of the fixed line telephone and wireless radio. Advances in communications systems research and design have moved the industry toward digital based systems. One benefit of a digital communication system is the ability to reduce required transmission bandwidth by implementing compression on the data to be transferred. As a result, much research and development has gone into compression techniques, especially in the area of speech coding. A common speech compression apparatus is a "vocoder" and is also interchangeably referred to as a "speech codec" or "speech coder." The vocoder receives digitized speech samples and produces collections of data bits known as "speech packets". Several standardized vocoding algorithms exist in support of the different digital communication systems which require speech communication, and in fact speech support is a minimum and essential requirement in most communication systems today. The 3rd Generation Partnership Project 2 (3GPP2) is an example standardization organization which specifies the IS-95, CDMA2000 1xRTT (1x Radio Transmission Technology), CDMA2000 EV-DO (Evolution-Data Optimized), and CDMA2000 EV-DV (Evolution-Data/Voice) communication systems. The 3rd Generation Partnership Project is another example standardization organization which specifies the GSM (Global System for Mobile Communications), UMTS (Universal Mobile Telecommunications System), HSDPA (High-Speed Downlink Packet Access), HSUPA (High-Speed Uplink Packet Access), HSPA+ (High-Speed Packet Access Evolution), and LTE (Long Term Evolution). The VoIP (Voice over Internet Protocol) is an example protocol used in the communication systems defined in 3GPP and 3GPP2, as well as others. Examples of vocoders employed in such communication systems and protocols include ITU-T G.729 (International Telecommunications Union), AMR (Adaptive Multi-rate Speech Codec), and EVRC (Enhanced Variable Rate Codec Speech Service Options 3, 68, 70).

[0005] Information sharing is a primary goal of today's communication systems in support of the demand for instant and ubiquitous connectivity. Users of today's communication systems transfer speech, video, text messages, and other data to stay connected. New applications being developed tend to outpace the evolution of the networks and may require upgrades to the communication system modulation schemes and protocols. In some remote geographical areas only speech services may be

available due to a lack of infrastructure support for advanced data services in the system. Alternatively, users may choose to only enable speech services on their communications device due to economic reasons. In some countries, public services support is mandated in the communication network, such as Emergency 911 (E911) or in-vehicle emergency call (eCall). In these emergency application examples, fast data transfer is a priority but not always realistic especially when advanced data services are not available at the user terminal. Previous techniques have provided solutions to transmit data through a speech codec, but these solutions are only able to support low data rate transfers due to the coding inefficiencies incurred when trying to encode a non-speech signal with a vocoder.

[0006] The speech compression algorithms implemented by most vocoders utilize "analysis by synthesis" techniques to model the human vocal tract with sets of parameters. The sets of parameters commonly include functions of digital filter coefficients, gains, and stored signals known as codebooks to name a few. A search for the parameters which most closely match the input speech signal characteristics is performed at the vocoder's encoder. The parameters are then used at the vocoder's decoder to synthesize an estimate of the input speech. The parameter sets available to the vocoder to encode the signals are tuned to best model speech characterized by voiced periodic segments as well as unvoiced segments which have noise-like characteristics. Signals which do not contain periodic or noise-like characteristics are not effectively encoded by the vocoder and may result in severe distortion at the decoded output in some cases. Examples of signals which do not exhibit speech characteristics include rapidly changing single frequency "tone" signals or dual tone multiple frequency "DTMF" signals. Most vocoders are unable to efficiently and effectively encode such signals.

[0007] Transmitting data through a speech codec is commonly referred to as transmitting data "in-band", wherein the data is incorporated into one or more speech packets output from the speech codec. Several techniques use audio tones at predetermined frequencies within the speech frequency band to represent the data. Using predetermined frequency tones to transfer data through speech codecs, especially at higher data rates, is unreliable due to the vocoders employed in the systems. The vocoders are designed to model speech signals using a limited number of parameters. The limited parameters are insufficient to effectively model the tone signals. The ability of the vocoders to model the tones is further degraded when attempting to increase the

transmission data rate by changing the tones quickly. This affects the detection accuracy and results in the need to add complex schemes to minimize the data errors which in turn further reduces the overall data rate of the communication system. Therefore, a need arises to efficiently and effectively transmit data through a speech codec in a communication network.

[0008] Accordingly it would be advantageous to provide an improved system for transmitting and receiving information through a speech codec in a communications network.

SUMMARY

[0009] Embodiments disclosed herein address the above stated needs by using an in-band modem to reliably transmit and receive non-speech information through a speech codec.

[0010] In one embodiment, a method of sending non-speech information through a speech codec comprises processing a plurality of input data symbols to produce a plurality of first pulse signals, shaping the plurality of first pulse signals to produce a plurality of shaped first pulse signals, and encoding the plurality of shaped first pulse signals with a speech codec.

[0011] In another embodiment, an apparatus comprises a processor configured to process a plurality of input data symbols to produce a plurality of first pulse signals, a shaper configured to shape the plurality of first pulse signals to produce a plurality of shaped first pulse signals, and a speech codec configured to encode the plurality of shaped first pulse signals to produce a speech packet.

[0012] In another embodiment, an apparatus comprises means for processing a plurality of input data symbols to produce a plurality of first pulse signals, means for shaping the plurality of first pulse signals to produce a plurality of shaped first pulse signals, and means for encoding the shaped first pulse signals with a speech codec.

[0013] In another embodiment, a method of synchronizing non-speech frames through a speech codec comprises generating a predetermined sequence that has noise-like characteristics and is robust to speech frame errors, and sending the predetermined sequence through a speech codec.

[0014] In another embodiment, an apparatus comprises a generator configured to generate a predetermined sequence that has noise-like characteristics and is robust to

speech frame errors, and a speech codec configured to process the predetermined sequence to produce a speech packet.

[0015] In another embodiment, an apparatus comprises means for generating a predetermined sequence that has noise-like characteristics and is robust to speech frame errors, and means for sending the predetermined sequence through a speech codec.

[0016] In another embodiment, a method of obtaining non-speech data embedded in a vocoder packet comprises receiving and decoding the vocoder packet, filtering the decoded vocoder packet until a synchronization signal is detected, calculating a timing offset based on the synchronization signal, and extracting the non-speech data embedded in the decoded vocoder packet based on the timing offset.

[0017] In another embodiment, an apparatus comprises a receiver configured to receive and decode a vocoder packet, a filter configured to filter the decoded vocoder packet until a synchronization signal is detected, a calculator configured to calculate a timing offset based on the synchronization signal, and an extractor configured to extract non-speech data embedded in the decoded vocoder packet based on the timing offset.

[0018] In another embodiment, an apparatus comprises means for receiving and decoding a vocoder packet, means for filtering the decoded vocoder packet until a synchronization signal is detected, means for calculating a timing offset based on the synchronization signal, and means for extracting the non-speech data embedded in the decoded vocoder packet based on the timing offset

[0019] In another embodiment, a method of controlling source terminal transmissions from a destination terminal in an in-band communication system comprises transmitting a start signal from a destination terminal, discontinuing transmission of the start signal upon detection of a first received signal, transmitting a NACK signal from the destination terminal, discontinuing transmission of the NACK signal upon detection of a successfully received source terminal data message, transmitting a ACK signal from the destination terminal, and discontinuing transmission of the ACK signal after a predetermined number of the ACK signals have been transmitted.

[0020] In another embodiment, an apparatus comprises a processor, memory in electronic communication with the processor, instructions stored in the memory, the instructions being capable of executing the steps of transmitting a start signal from a destination terminal, discontinuing transmission of the start signal upon detection of a first received signal, transmitting a NACK signal from the destination terminal, discontinuing transmission of the NACK signal upon detection of a successfully

received source terminal data message, transmitting a ACK signal from the destination terminal, and discontinuing transmission of the ACK signal after a predetermined number of the ACK signals have been transmitted.

[0021] In another embodiment, an apparatus for controlling source terminal transmissions from a destination terminal in an in-band communication system comprises means for transmitting a start signal from a destination terminal, means for discontinuing transmission of the start signal upon detection of a first received signal, means for transmitting a NACK signal from the destination terminal, means for discontinuing transmission of the NACK signal upon detection of a successfully received source terminal data message, means for transmitting a ACK signal from the destination terminal, and means for discontinuing transmission of the ACK signal after a predetermined number of the ACK signals have been transmitted.

[0022] In another embodiment, a method of controlling source terminal transmissions from a source terminal in an in-band communication system comprises detecting a request signal at the source terminal, transmitting a synchronization signal from the source terminal upon detection of the request signal, transmitting a user data segment from the source terminal using a first modulation scheme, and discontinuing transmission of the user data segment upon detection of a first received signal.

[0023] In another embodiment, an apparatus comprises a processor, memory in electronic communication with the processor, instructions stored in the memory, the instructions being capable of executing the steps of detecting a request signal at a source terminal, transmitting a synchronization signal from the source terminal upon detection of the request signal, transmitting a user data segment from the source terminal using a first modulation scheme, and discontinuing transmission of the user data segment upon detection of a first received signal.

[0024] In another embodiment, an apparatus for controlling source terminal transmissions from a source terminal in an in-band communication system comprises means for detecting a request signal at the source terminal, means for transmitting a synchronization signal from the source terminal upon detection of the request signal, means for transmitting a user data segment from the source terminal using a first modulation scheme, and means for discontinuing transmission of the user data segment upon detection of a first received signal.

[0025] In another embodiment, a method of controlling bidirectional data transmissions from a destination terminal in an in-band communication system comprises transmitting

a send signal from the destination terminal, discontinuing transmission of the send signal upon detection of a first received signal, transmitting a synchronization signal from the destination terminal, transmitting a user data segment from the destination terminal using a first modulation scheme, and discontinuing transmission of the user data segment upon detection of a second received signal.

[0026] In another embodiment, an apparatus comprises a processor, memory in electronic communication with the processor, instructions stored in the memory, the instructions being capable of executing the steps of transmitting a send signal from the destination terminal, discontinuing transmission of the send signal upon detection of a first received signal, transmitting a synchronization signal from the destination terminal, transmitting a user data segment from the destination terminal using a first modulation scheme, and discontinuing transmission of the user data segment upon detection of a second received signal.

[0027] In another embodiment, an apparatus for controlling bidirectional data transmissions from a destination terminal in an in-band communication system comprises means for transmitting a send signal from the destination terminal, means for discontinuing transmission of the send signal upon detection of a first received signal, means for transmitting a synchronization signal from the destination terminal, means for transmitting a user data segment from the destination terminal using a first modulation scheme, and means for discontinuing transmission of the user data segment upon detection of a second received signal.

[0028] In another embodiment, a system for communicating data over an in-band communication system from a vehicle containing an in-vehicle system (IVS) to a public safety answering point (PSAP) comprises one or more sensors located in the IVS for providing IVS sensor data, an IVS transmitter located in the IVS for transmitting the IVS sensor data, a PSAP receiver located in the PSAP for receiving the IVS sensor data, a PSAP transmitter located in the PSAP for transmitting PSAP command data, an IVS receiver located in the IVS for receiving the PSAP command data; wherein the IVS transmitter comprises an IVS message formatter for formatting the IVS sensor data and producing an IVS message, an IVS processor for processing the IVS message and producing a plurality of IVS shaped pulse signals, an IVS speech encoder for encoding the IVS shaped pulse signals and producing an IVS encoded signal, an IVS synchronization generator for generating an IVS synchronization signal, and an IVS transmit controller for transmitting a sequence of IVS synchronization signals and IVS

messages; wherein the PSAP receiver comprises a PSAP detector for detecting the IVS synchronization signal and producing a PSAP sync flag, a PSAP demodulator for demodulating the IVS message and producing a received IVS message; wherein the PSAP transmitter comprises a PSAP message formatter for formatting the PSAP command data and producing a PSAP command message, a PSAP processor for processing the PSAP command message and producing a plurality of PSAP shaped pulse signals, a PSAP speech encoder for encoding the PSAP shaped pulse signals and producing a PSAP encoded signal, a PSAP synchronization generator for generating a PSAP synchronization signal, and a PSAP transmit controller for transmitting a sequence of PSAP synchronization signals and PSAP command messages; wherein the IVS receiver comprises an IVS detector for detecting the PSAP synchronization signal and producing an IVS sync flag, and an IVS demodulator for demodulating the PSAP messages and producing a received PSAP message.

BRIEF DESCRIPTION OF THE DRAWINGS

[0029] The aspects and the attendant advantages of the embodiments described herein will become more readily apparent by reference to the following detailed description when taken in conjunction with the accompanying drawings wherein:

[0030] FIG. 1 is a diagram of an embodiment of source and destination terminals which use an in-band modem to transmit data through a speech codec in a wireless communication network.

[0031] FIG. 2 is a diagram of an embodiment of a transmit data modem used in an in-band communication system.

[0032] FIG. 3A is a diagram of an embodiment of a synchronization signal generator.

[0033] FIG. 3B is a diagram of another embodiment of a synchronization signal generator.

[0034] FIG. 3C is a diagram of yet another embodiment of a synchronization signal generator.

[0035] FIG. 4 is a diagram of an embodiment of a synchronization burst generator.

[0036] FIG. 5 is a diagram of an embodiment of a synchronization burst sequence.

[0037] FIG. 6A is a diagram of an embodiment of a synchronization preamble sequence.

[0038] FIG. 6B is a diagram of an embodiment of a synchronization preamble sequence with non-overlapping reference sequences.

[0039] FIG. 7A is a graph of a synchronization preamble correlation output where the preamble is comprised of non-overlapped reference sequences.

[0040] FIG. 7B is a graph of a synchronization preamble correlation output where the preamble is comprised of overlapped reference sequences.

[0041] FIG. 8A is a diagram of an embodiment of a synchronization message format.

[0042] FIG. 8B is a diagram of another embodiment of a synchronization message format.

[0043] FIG. 8C is a diagram of yet another embodiment of a synchronization message format.

[0044] FIG. 9 is a diagram of an embodiment of a transmit data message format.

[0045] FIG. 10 is a diagram of an embodiment of a composite synchronization and transmit data message format.

[0046] FIG. 11A is a graph of the power spectral density of an in-band pulse based signal versus frequency.

[0047] FIG. 11B is a graph of the power spectral density of an in-band tone based signal versus frequency.

[0048] FIG. 12 is a diagram of an embodiment of a data modulator using sparse pulses.

[0049] FIG. 13 is a diagram of an embodiment of a sparse pulse data symbol representation.

[0050] FIG. 14A is a diagram of an embodiment of a shaped pulse placement within a modulation frame using a wraparound technique.

[0051] FIG. 14B is a diagram of an embodiment of a shaped pulse placement within a modulation frame for a typical example in the art.

[0052] FIG. 15A is a diagram of an embodiment of a synchronization signal detector and receiver controller.

[0053] FIG. 15B is a diagram of another embodiment of a synchronization signal detector and receiver controller.

[0054] FIG. 16 is a diagram of an embodiment of a synchronization burst detector.

[0055] FIG. 17A is a diagram of an embodiment of a synchronization preamble detector.

[0056] FIG. 17B is a diagram of another embodiment of a synchronization preamble detector.

[0057] FIG. 18a is a diagram of an embodiment of a synchronization detector controller.

[0058] FIG. 18b is a diagram of another embodiment of a synchronization detector controller.

[0059] FIG. 19 is a diagram of an embodiment of a receive timing adjuster.

[0060] FIG. 20 is a diagram of an embodiment of a receive data modem used in an in-band communication system.

[0061] FIG. 21 is a diagram of an embodiment of an in-vehicle emergency call system.

[0062] FIG. 22 is a diagram of an embodiment of an interaction of the data request sequence transmitted on a downlink in a destination communication terminal and the data response sequence transmitted on an uplink in a source communication terminal, with the interaction initiated by the destination terminal.

[0063] FIG. 23A is a diagram of an embodiment of an interaction of the data request sequence transmitted on a downlink in a destination communication terminal and the data response sequence transmitted on an uplink in a source communication terminal, with the interaction initiated by the source terminal.

[0064] FIG. 23B is a diagram of another embodiment of an interaction of the data request sequence transmitted on a downlink in a destination communication terminal and the data response sequence transmitted on an uplink in a source communication terminal, with the interaction initiated by the source terminal.

[0065] FIG. 24A is a diagram of an embodiment of an interaction of a bi-directional data request sequence and data response sequence transmitted on both the downlink and uplink.

[0066] FIG. 24B is a diagram of another embodiment of an interaction of a bi-directional data request sequence and data response sequence transmitted on both the downlink and uplink.

[0067] FIG. 25 is a diagram of an embodiment of a user data packet format where the length of the user data length is less than the transmit packet size.

[0068] FIG. 26 is a diagram of an embodiment of a user data packet format where the length of the user data length is greater than the transmit packet size.

[0069] FIG. 27A is a diagram of an embodiment of an interaction of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size.

[0070] FIG. 27B is a diagram of another embodiment of an interaction of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size.

[0071] FIG. 27C is a diagram of yet another embodiment of an interaction of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size.

[0072] FIG. 27D is a diagram of still another embodiment of an interaction of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size.

DETAILED DESCRIPTION

[0073] FIG. 1 shows an embodiment of an in-band data communication system as might be implemented within a wireless source terminal **100**. The source terminal **100** communicates with the destination terminal **600** through the communication channels **501** and **502**, network **500**, and communication channel **503**. Examples of suitable wireless communication systems include cellular telephone systems operating in accordance with Global System for Mobile Communication (GSM), Third Generation Partnership Project Universal Mobile Telecommunication System (3GPP UMTS), Third Generation Partnership Project 2 Code Division Multiple Access (3GPP2 CDMA), Time Division Synchronous Code Division Multiple Access (TD-SCDMA), and Worldwide Interoperability for Microwave Access (WiMAX) standards. One skilled in the art will recognize that the techniques described herein may be equally applied to an in-band data communication system that does not involve a wireless channel. The communication network **500** includes any combination of routing and/or switching equipment, communications links and other infrastructure suitable for establishing a communication link between the source terminal **100** and destination terminal **600**. For example, communication channel **503** may not be a wireless link. The source terminal **100** normally functions as a voice communication device.

TRANSMITTER

[0074] The transmit baseband **200** normally routes user speech through a vocoder, but is also capable of routing non-speech data through the vocoder in response to a request

originating from the source terminal or the communication network. Routing non-speech data through the vocoder is advantageous since it eliminates the need for the source terminal to request and transmit the data over a separate communications channel. The non-speech data is formatted into messages. The message data, still in digital form, is converted into a noise-like signal comprised of shaped pulses. The message data information is built into the pulse positions of the noise-like signal. The noise-like signal is encoded by the vocoder. The vocoder is not configured differently depending on whether the input is user speech or non-speech data so it is advantageous to convert the message data into a signal which can be effectively encoded by the transmission parameter set allocated to the vocoder. The encoded noise-like signal is transmitted in-band over the communication link. Because the transmitted information is built in the pulse positions of the noise-like signal, reliable detection depends on recovery of the timing of the pulses relative to the speech codec frame boundaries. To aid the receiver in detecting the in-band transmission, a predetermined synchronization signal is generated and encoded by the vocoder prior to the transmission of message data. A protocol sequence of synchronization, control, and messages is transmitted to ensure reliable detection and demodulation of the non-speech data at the receiver.

[0075] Referring to the transmit baseband **200**, the signal input audio **S210** is input to the microphone and audio input processor **215** and transferred through the mux **220** into the vocoder encoder **270** where compressed voiced packets are generated. A suitable audio input processor typically includes circuitry to convert the input signal into a digital signal and a signal conditioner to shape the digital signal such as a low-pass filter. Examples of suitable vocoders include those described by the following reference standards: GSM-FR, GSM-HR, GSM-EFR, EVRC, EVRC-B, SMV, QCELP13K, IS-54, AMR, G.723.1, G.728, G.729, G.729.1, G.729a, G.718, G.722.1, AMR-WB, EVRC-WB, VMR-WB. The vocoder encoder **270** supplies voice packets to the transmitter **295** and antenna **296** and the voice packets are transmitted over the communication channel **501**.

[0076] A request for data transmission may be initiated by the source terminal or through the communications network. The data transmit request **S215** disables the voice path through mux **220** and enables the transmit data path. The input data **S200** is pre-processed by the data message formatter **210** and output as Tx Message **S220** to the Tx Data Modem **230**. Input data **S200** may include user interface (UI) information, user position/location information, time stamps, equipment sensor information, or other

suitable data. An example of a suitable data message formatter **210** includes circuitry to calculate and append cyclic redundancy check (CRC) bits to the input data, provide retransmission buffer memory, implement error control coding such as hybrid automatic repeat-request (HARQ), and interleave the input data. The Tx data modem **230** converts Tx Message **S220** to data signal Tx Data **S230** which is routed through mux **220** to the vocoder encoder **270**. Once the data transmission is complete the voice path may be re-enabled through mux **220**.

[0077] **FIG. 2** is a suitable example block diagram of the Tx data modem **230** shown in **FIG. 1**. Three signals may be multiplexed in time through mux **259** onto the Tx data **S230** output signal; Sync Out **S245**, Mute Out **S240**, and Tx Mod Out **S235**. It should be recognized that different orders and combinations of signals Sync Out **S245**, Mute Out **S240**, and Tx Mod Out **S235** may be output onto Tx data **S230**. For example, Sync Out **S245** may be sent prior to each Tx Mod Out **S235** data segment. Or, Sync Out **S245** may be sent once prior to a complete Tx Mod Out **S235** with mute Out **S240** sent between each Tx Mod Out **S235** data segment.

[0078] Sync Out **S245** is a synchronization signal used to establish timing at the receiving terminal. Synchronization signals are required to establish timing for the transmitted in-band data since the data information is built in the pulse positions of the noise-like signal. **FIG. 3A** shows a suitable example block diagram of the Sync Generator **240** shown in **FIG. 2**. Three signals may be multiplexed in time through mux **247** onto the Sync Out **S245** signal; Sync Burst **S241**, Wakeup Out **S236**, and Sync Preamble Out **S242**. It should be recognized that different orders and combinations of Sync Burst **S241**, Wakeup Out **S236**, and Sync Preamble Out **S242** may be output onto Sync Out **S245**. For example, **FIG. 3B** shows a Sync Generator **240** comprised of Wakeup Out **S236** and Sync Preamble Out **S242** where Wakeup Out **S236** may be sent prior to each Sync Preamble Out **S242**. Alternatively, **FIG. 3C** shows a Sync Generator **240** comprised of Sync Burst **S241** and Sync Preamble Out **S242** where Sync Burst **S241** may be sent prior to each Sync Preamble Out **S242**.

[0079] Referring back to **FIG. 3A**, Sync Burst **S241** is used to establish coarse timing at the receiver and is comprised of at least one sinusoidal frequency signal having a predetermined sampling rate, sequence, and duration and is generated by Sync Burst **250** shown in **FIG. 4**. Sinusoidal Frequency1 **251** represents binary data +1 and Frequency2 **252** represents binary data -1. Examples of suitable signals include constant frequency sinusoids in the voice band, such as 395Hz, 540Hz, and 512Hz for

one sinusoidal signal and 558Hz, 1035Hz, and 724Hz for the other sinusoidal signal. The Sync Burst Sequence **253** determines which frequency signal is multiplexed through mux **254**. The information sequence modulated onto the synchronization burst should be one with good autocorrelation properties. An example of a suitable Sync Burst Sequence **253** is the Barker code of length 7 shown in **FIG. 5**. For each '+' symbol, Frequency1 Sinusoid is output on Sync Burst **S241**, and for each '-' symbol, Frequency2 Sinusoid is output.

[0080] Referring back to **FIG. 3A**, Sync Preamble Out **S242** is used to establish fine (sample based) timing at the receiver and is comprised of a predetermined data pattern known at the receiver. A suitable example of a Sync Preamble Out **S242** predetermined data pattern is Sync Preamble Sequence **241** shown in **FIG. 6A**. The composite preamble sequence **245** is generated by concatenating several periods of a pseudorandom noise (PN) sequence **242** with an overlapped and added result of the PN sequence **242** and an inverted version of the PN sequence **244**. The '+' symbols in the composite preamble sequence **245** represent binary data +1 and the '-' symbols represent binary data -1. Another suitable example inserts zero valued samples between the data bits of the PN sequence. This provides temporal distance between the data bits to account for "smearing" affects caused by the bandpass filter characteristics of the channel which tends to spread the energy of the data bit over several bit time intervals.

[0081] The previously described construction of the sync preamble using concatenated periods of a PN sequence with overlapped segments of inverted versions of the PN sequence provides advantages in reduced transmission time, improved correlation properties, and improved detection characteristics. The advantages result in a preamble which is robust to speech frame transmission errors.

[0082] By overlapping the PN segments, the resultant composite sync preamble consists of a smaller number of bits in the sequence compared to a non-overlapped version, thereby decreasing the total time required to transmit the composite preamble sequence **245**.

[0083] To illustrate the improvements in the correlation properties of the overlapped sync preamble, **FIG. 7A** and **FIG. 7B** show a comparison between the correlation of PN sequence **242** with a non-overlapped composite preamble sequence **245b**, shown in **FIG. 6B** and the correlation of PN sequence **242** with the overlapped composite sync preamble sequence **245**, shown in **FIG. 6A**. **FIG. 7A** shows the main correlation peaks, both positive and negative, as well as the minor correlation peaks located between the

main peaks for the non-overlapped composite sync preamble sequence **245b**. The negative peak **1010** results from the correlation of the PN sequence **242** with the first inverted segment of the non-overlapped composite preamble sequence **245b**. The positive correlation peaks **1011**, **1012**, **1013**, result from the correlation of the PN sequence **242** with the three concatenated segments of PN sequence **242** which make up the middle section of the non-overlapped composite preamble sequence **245b**. The negative peak **1014** results from the correlation of the PN sequence **242** with the second inverted segment of the non-overlapped composite preamble sequence **245b**. In **FIG. 7A**, the minor correlation peak **1015**, corresponding to an offset of 3 samples from the first positive correlation peak **1011** shows a magnitude of approximately 5 ($1/3^{rd}$ the magnitude of the main peaks). **FIG. 7B** shows several main correlation peaks, both positive and negative, as well as the minor correlation peaks between the main peaks for the overlapped composite sync preamble sequence **245**. In **FIG. 7B**, the minor correlation peak **1016**, corresponding to an offset of 3 PN samples from the first positive correlation peak **1011** shows a magnitude of approximately 3 ($1/5^{th}$ the magnitude of the main peaks). The smaller magnitude of the minor correlation peak **1016** for the overlapped preamble shown in **FIG. 7B** results in less false detections of the preamble main correlation peaks when compared to the non-overlapped minor peak **1015** example shown in **FIG. 7A**.

[0084] As shown in **FIG. 7B**, five major peaks are generated when correlating PN sequence **242** with the composite sync preamble sequence **245**. The pattern shown (1 negative peak, 3 positive peaks, and 1 negative peak) allows for determining the frame timing based on any 3 detected peaks and the corresponding temporal distances between the peaks. The combination of 3 detected peaks with the corresponding temporal distance is always unique. A similar depiction of the correlation peak pattern is shown in **Table 1**, where the correlation peaks are referenced by a '-' for a negative peak and a '+' for a positive peak. The technique of using a unique correlation peak pattern is advantageous for in-band systems since the unique pattern compensates for possible speech frame losses, for example, due to poor channel conditions. Losing a speech frame may result in losing a correlation peak as well. By having a unique pattern of correlation peaks separated by predetermined temporal distances, a receiver can reliably detect the sync preamble even with lost speech frames which result in lost correlation peaks. Several examples are shown in **Table 2** for the combinations of 3 detected peaks in the pattern (2 peaks are lost in each example). Each entry in **Table 2**, represents a

unique pattern of peaks and temporal distances between the peaks. Example 1 in **Table 2** shows detected peaks 3, 4, and 5 (peaks 1 and 2 were lost), resulting in the pattern '+ + -' with one predetermined distance between each peak. Examples 2 and 3 in **Table 2** also show the pattern '+ + -', however the distances are different. Example 2 has two predetermined distances between detected peak 2 and 4, while Example 3 has two predetermined distances between detected peak 3 and 5. So Examples 1, 2 and 3 each represent a unique pattern from which the frame timing may be derived. It should be recognized that the detected peaks may extend across frame boundaries, but that the unique patterns and predetermined distances still apply.

Table 1

	Correlation Peak Number				
	1	**2**	**3**	**4**	**5**
Correlation Peak Polarity	-	+	+	+	-

Table 2

		Correlation Peak Number				
		1	**2**	**3**	**4**	**5**
Detected Correlation Peaks	**Example 1**			+	+	-
	Example 2		+		+	-
	Example 3		+	+		-
	Example 4		+	+	+	
	Example 5	-			+	-
	Example 6	-		+		-
	Example 7	-		+	+	
	Example 8	-	+			-
	Example 9	-	+		+	
	Example 10	-	+	+		

[0085] One skilled in the art will recognize that a different preamble sequence resulting in a different correlation peak pattern to that shown in **FIG. 7B** and **Table 1** may be used. One skilled in the art will also recognize that multiple correlation peak patterns may be used to identify different operational modes or transmit information bits. An example of an alternate correlation peak pattern is shown in **Table 3**. The correlation peak pattern shown in **Table 3** maintains a unique pattern from which the frame timing may be derived, as described previously. Having multiple correlation peak patterns is advantageous for identifying different transmitter configurations at the receiver, such as message formats or modulation schemes.

Table 3

	Correlation Peak Number				
	1	**2**	**3**	**4**	**5**
Correlation Peak Polarity	+	-	-	-	+

[0086] Referring again to **FIG. 3A**, Wakeup Out **S236** is used to trigger the vocoder encoder **270** to wake up from a sleep state, low transmission rate state, or discontinuous transmission state. Wakeup Out **S236** may also be used to prohibit the vocoder encoder **270** from entering the sleep, low transmission, or discontinuous transmission state. Wakeup Out **S236** is generated by Wakeup Generator **256**. Wakeup signals are advantageous when transmitting in-band data through vocoders which implement sleep, discontinuous transmit functions (DTX), or operate at a lower transmission rate during inactive voice segments to minimize the startup delay which may occur in transitioning from the voice inactive state to the voice active state. Wakeup signals may also be used to identify a characteristic of the transmission mode; for example, the type of modulation scheme employed. A first example of a suitable Wakeup Out **S236** signal is a single sinusoidal signal of constant frequency in the voice band, such as 395Hz. In this first example, the Wakeup signal prohibits the vocoder encoder **270** from entering the sleep, DTX, or low rate state. In this first example, the receiver ignores the transmitted Wakeup Out signal **S236**. A second example of a suitable Wakeup Out

S236 is a signal comprised of multiple sinusoidal signals with each signal identifying a specific data modulation scheme, for example 500Hz for modulation scheme 1 and 800Hz for modulation scheme 2. In this second example, the Wakeup signal prohibits the vocoder encoder **270** from entering the sleep, DTX, or low rate state. In this second example, the receiver uses the transmitted Wakeup Out signal **S236** to identify the data modulation scheme.

[0087] An example of a composite Sync Out **S245** signal is one comprised of a multiplexed Sync Burst **S241** and Sync Preamble Out **S242** as shown in **FIG. 8A**. Tsb **701** and Tsp **702** represent the durations in time each signal is transmitted. An example of a suitable range for Tsb is 120-140 milliseconds and Tsp is 40-200 milliseconds. Another example of a composite Sync Out **S245** signal is one comprised of a multiplexed Wakeup Out **S236** and Sync Preamble Out **S242** as shown in **FIG. 8B**. Twu **711** and Tsp **702** represent the durations in time each signal is transmitted. An example of a suitable range for Twu is 10-60 milliseconds and Tsp is 40-200 milliseconds. Another example of a composite Sync Out **S245** signal is one comprised of a multiplexed Wakeup Out **S236,** Sync Burst **S241,** and Sync Preamble Out **S242** as shown in **FIG. 8C**. Twu **711**, Tsp1 **721**, Tsb **701**, Tsp2 **722** represent the durations in time each signal is transmitted. An example of a suitable range for Twu is 20 - 80 milliseconds, Tsp1 is 40-200 milliseconds, Tsb is 120-140 milliseconds, and Tsp2 is 40-200 milliseconds.

[0088] Referring back to **FIG. 2**, a suitable example of Tx Mod Out **S235** is a signal generated by the Modulator **235** using pulse-position modulation (PPM) with special modulation pulse shapes. This modulation technique results in low distortion when encoded and decoded by different types of vocoders. Additionally, this technique results in good autocorrelation properties and can be easily detected by a receiver matched to the waveform. Further, the shaped pulses do not have a tonal structure; instead the signals appear noise-like in the frequency spectrum domain as well as retain a noise-like audible characteristic. An example of the power spectral density of a signal based on shaped pulses is shown in **FIG. 11A.** As can be seen in **FIG. 11A**, the power spectral density displays a noise-like characteristic over the in-band frequency range (constant energy over the frequency range). Conversely, an example of the power spectral density of a signal with a tonal structure is shown in **FIG. 11B**, where the data is represented by tones at frequencies approximately 400Hz, 600Hz, and 1000Hz. As

can be seen in **FIG. 11B**, the power spectral density displays "spikes" of significant energy over the in-band frequency range at the tone frequencies and its harmonics.

[0089] **FIG. 12** is an example block diagram of the Modulator **235** shown in **FIG. 2**. The Sparse Pulse Generator **238** produces pulses corresponding to input Tx Message **S220** using pulse position modulation and then the Pulse Shaper **239** shapes the pulses to create the signal for better coding quality in the vocoder encoder. A suitable example of a Sparse Pulse is shown in **FIG. 13**. The time axis is divided into modulation frames of duration T_{MF}. Within each such modulation frame, a number of time instances t_0, t_1 ,..., t_{m-1} are defined relative to the modulation frame boundary, which identify potential positions of a basic pulse $p(t)$. For example, the Pulse **237** at position t_3 is denoted as $p(t-t_3)$. The Tx Message **S220** information bits input to the Modulator **235** are mapped to symbols with corresponding translation to pulse positions according to a mapping table. The pulse may also be shaped with a polarity transform, $\pm p(t)$. The symbols may therefore be represented by one of $2m$ distinct signals within the modulation frame where m represents the number of time instances defined for the modulation frame and the multiplication factor, 2, represents the positive and negative polarity.

[0090] An example of a suitable pulse position mapping is shown in **Table 4.** In this example, the modulator maps a 4-bit symbol for each modulation frame. Each symbol is represented in terms of the position k of the pulse shape p(n-k) and the sign of the pulse. In this example, T_{MF} is 4 milliseconds resulting in 32 possible positions for an 8KHz sample rate. The pulses are separated by 4 time instances resulting in the assignment of 16 different pulse position and polarity combinations. In this example, the effective data rate is 4 bits per symbol in a 4 millisecond period or 1000 bits/second.

Table 4

Symbol		Pulse
decimal	binary	
0	0000	*p(n-0)*
1	0001	*p(n-4)*

2	0010	*p(n-8)*
3	0011	*p(n-12)*
4	0100	*p(n-16)*
5	0101	*p(n-20)*
6	0110	*p(n-24)*
7	0111	*p(n-28)*
8	1000	*-p(n-28)*
9	1001	*-p(n-24)*
10	1010	*-p(n-20)*
11	1011	*-p(n-16)*
12	1100	*-p(n-12)*
13	1101	*-p(n-8)*
14	1110	*-p(n-4)*
15	1111	*-p(n-0)*

[0091] Another example of a suitable pulse position mapping is shown in **Table 5**. In this example, the modulator maps a 3-bit symbol for each modulation frame. Each symbol is represented in terms of the position k of the pulse shape p(n-k) and the sign of the pulse. In this example, T_{MF} is 2 milliseconds resulting in a 16 possible positions for an 8KHz sample rate. The pulses are separated by 4 time instances resulting in the assignment of 8 different pulse position and polarity combinations. In this example, the effective data rate is 3 bits per symbol in a 2 millisecond period or 1500 bits/second.

Table 5

Symbol		Pulse
decimal	binary	
0	000	*p(n)*
1	001	*p(n-4)*
2	010	*p(n-8)*
3	011	*p(n-12)*
4	100	*-p(n-12)*
5	101	*-p(n-8)*
6	110	*-p(n-4)*
7	111	*-p(n)*

[0092] To increase robustness in poor channel conditions, the Modulator **235** may increase the duration of the modulation frame T_{MF} while maintaining a constant number of time instances $t_0, t_1, \ldots, t_{m-1}$. This technique serves to place more temporal distance between the pulses resulting in a more reliable detection. An example of a suitable pulse position mapping includes a T_{MF} of 4 milliseconds resulting in 32 possible positions for an 8KHz sample rate. As in the previous example, if the pulses are separated by 4 time instances, the mapping results in the assignment of 16 different pulse position and polarity combinations. However, in this example, the separation between time instances is increased by a factor of 2 from the previous example, resulting in 8 different pulse position and polarity combinations. In a suitable example, the Modulator **235** may switch between different pulse position maps or modulation frame durations depending on a feedback signal indicating channel conditions or transmission success. For example, the Modulator **235** may start transmitting using T_{MF} of 2 milliseconds then switch to T_{MF} of 4 milliseconds if the channel conditions are determined to be poor.

[0093] To increase robustness with certain vocoders, the Modulator **235** may change the initial time offset in the pulse position map. An example of a suitable pulse position mapping is shown in **Table 6**. In this example, the modulator maps a 3-bit symbol per modulation frame. Each symbol is represented in terms of the position k of the pulse shape p(n-k) and the sign of the pulse. In this example, T_{MF} is 2 milliseconds resulting in a 16 possible positions for an 8KHz sample rate. The initial offset is set to 1 time instance and the pulses are separated by 4 time instances resulting in the assignment of 8 different pulse position and polarity combinations as shown in the table.

Table 6

Symbol		Pulse
decimal	binary	
0	000	*p(n-1)*
1	001	*p(n-5)*
2	010	*p(n-9)*
3	011	*p(n-13)*
4	100	*-p(n-13)*
5	101	*-p(n-9)*
6	110	*-p(n-5)*
7	111	*-p(n-1)*

[0094] It should be recognized that reducing the number of separation time instances would result in an increased number of bits per symbol and thus higher data rates. For example, if T_{MF} is 4 milliseconds the resulting number of possible positions for an 8KHz sample rate is 32 with plus or minus polarity for each resulting in 64 different signals if no separation is included. For a 64 position map, the number of supported bits per symbol is 6 and the resulting effective data rate is 1500 bits per second. It should

also be recognized that different combinations of T_{MF} and sample rate may be used to achieve a desired effective bit rate.

[0095] An example of a suitable Pulse Shaper **239** is a root-raised cosine transform of the form:

$$r(t) = \begin{cases} 1-\beta+\dfrac{4\beta}{\pi}, & t=0 \\ \dfrac{\beta}{\sqrt{2}}\left[\left(1+\dfrac{2}{\pi}\right)\sin\left(\dfrac{\pi}{4\beta}\right)+\left(1-\dfrac{2}{\pi}\right)\cos\left(\dfrac{\pi}{4\beta}\right)\right], & t=\pm\dfrac{T_s}{4\beta} \\ \dfrac{\sin\left[\pi\dfrac{t}{T_s}(1-\beta)\right]+4\beta\dfrac{t}{T_s}\cos\left[\pi\dfrac{t}{T_s}(1+\beta)\right]}{\pi\dfrac{t}{T_s}\left[1-\left(4\beta\dfrac{t}{T_s}\right)^2\right]}, & otherwise \end{cases}$$

where β is the roll-off factor, $1/T_s$ is the maximum symbol rate, and t is the sampling time instance.

For the previous example with 32 possible pulse positions (time instances), the following transform generates the root raised cosine pulse shape where the number of zeros prior to the first nonzero element of the pulse determines the exact position of the pulse within the frame.

$r(n) =$ [0 0 0 40

-200 560 -991 -1400

7636 15000 7636 -1400

-991 560 -200 40

0 0 0 0

0 0 0 0

0 0 0 0

0 0 0 0]

It should be recognized that the transform may be shortened or lengthened for different variants of modulation fame sizes.

[0096] FIG. 14A is an example of the placement of a pulse within a modulation frame to generate a particular entry in the modulation alphabet. In **FIG. 14A**, a pulse is represented by 13 samples shown as P0 – P12 where each sample represents the non-zero elements of r(n) shown in the previous example. **FIG. 14B** is an example of the typical implementation in the art. In **FIG. 14B**, a pulse is positioned at offset 7 within modulation frame $T_{MF}(n)$ **1003**, and the "tail" portion of the pulse extends into the next modulation frame $T_{MF}(n+1)$ **1004** by 4 samples (P9 – P12). Samples from modulation frame $T_{MF}(n)$ **1003** extending into the next modulation frame $T_{MF}(n+1)$ **1004** as shown in **FIG. 14B** would result in intersymbol interference if the pulse samples for frame $T_{MF}(n+1)$ are positioned in any of the first 4 samples of frame $T_{MF}(n+1)$, since an overlap of samples would occur. Alternatively, in the "wraparound" technique shown in **FIG. 14A**, the tail samples which would have extended into the next modulation frame, $T_{MF}(n+1)$ **1004,** are placed at the beginning of the current modulation frame, $T_{MF}(n)$ **1003**. The samples (P9 – P12) are wrapped around to the beginning of $T_{MF}(n)$ at samples 0 – 3. Using a wraparound technique for the generation of a modulation alphabet eliminates the cases where the shaped pulse samples extend into the next modulation frame. The wraparound technique is advantageous since it results in reduced intersymbol interference that would occur if the shaped pulse samples in the present frame extend into the next frame and overlap with the shaped pulse samples in the next frame. One skilled in the art would recognize that the wraparound technique could be used for any pulse position in the modulation frame which would result in samples extending in the next modulation frame. For example, a pulse positioned at offset 8 within modulation frame $T_{MF}(n)$ **1003** would wraparound samples (P8 – P12).

[0097] Another example of a suitable Pulse Shaper **239** is an amplitude transform signal of the form:

$$r(n) \cdot p(n-t)$$

An example of a 32 sample amplitude transform signal is of the form:

$$r(n) = [\ -2000 \quad 0 \quad 6000 \quad -2000$$
$$0 \quad 0 \quad 0 \quad 0$$
$$0 \quad 0 \quad 0 \quad 0$$
$$0 \quad 0 \quad 0 \quad 0$$
$$0 \quad 0 \quad 0 \quad 0$$
$$0 \quad 0 \quad 0 \quad 0$$
$$0 \quad 0 \quad 0 \quad 0$$
$$0 \quad 0 \quad 0 \quad 0\ ]$$

[0098] Another example of a suitable Pulse Shaper **239** is a linear prediction synthesis filter. The response of an example recursive LPC synthesis filter is defined by its impulse response

$$h(n) = \delta(n) + \sum_{i=1}^{10} a_i h(n-i)$$

and coefficients: $a(i)$ = {-6312, 5677, -2377, 1234, -2418, 3519, -2839, 1927, -629, 96}/4096, i = 1,…, 10. Linear prediction filters are well known in the art. The residual signal $r(n)$ is first created by the input symbols according to the pulse mapping tables above. The actual modulation pulse shape then results from filtering the modulated signal $r(n)$ with $h(n)$.

[0099] One skilled in the art will recognize that the techniques described herein may be equally applied to different pulse shapes and transforms. The length of the waveforms and the modulation schemes applied to these waveforms may also vary. Moreover, the pulse shapes may use completely uncorrelated (or orthogonal) waveforms to represent different symbols. In addition to polarity of the shaped pulse, amplitude of the shaped pulse may also be used to carry information.

[00100] Referring again to **FIG. 2**, Mute Out **S240** is a signal used to separate the Tx message transmissions and is generated by the Muting Generator **255**. An example of a suitable composite Tx Data **S230** signal comprised of a multiplexed Tx Mod Out **S235** and Mute Out **S240** is shown in **FIG. 9**. Tmu1 **731**, Td1 **732**, Tmu2 **733**, Td2 **734**, Tmu3 **735**, Td3 **736**, and Tmu4 **737** represent the durations in time each signal is transmitted. An example of a suitable range for Tmu1, Tmu2, Tmu3, and Tmu4 is 10-

60 milliseconds and Td1, Td2, and Td3 is 300-320 milliseconds for normal operation and 600-640 milliseconds for robust operation. Examples of a suitable muting generator sequence may be an all-zero sequence signal or a sinusoidal frequency signal. Another suitable example of a signal used to separate the Tx message transmissions is shown in **FIG. 10**. In this example, the Wakeup Out **S236** signal and Sync Preamble Out **S242** precede each transmission of Tx Mod Out **S235**. One skilled in the art will recognize that different combinations of the Sync Preamble Out **S242**, Mute Out **S240**, and Tx Mod Out **S235** may be equally applied. For example Tx Mod Out **S235** in **FIG. 10** may be preceded and followed by Mute Out **S240**.

RECEIVER

[00101] Referring to **FIG. 1**, the receive baseband **400** normally routes decoded voice packets from the vocoder to an audio processor, but is also capable of routing the decoded packets through a data demodulator. Because the non-speech data was converted to a noise-like signal and encoded by the vocoder at the transmitter, the receiver's vocoder is able to effectively decode the data with minimal distortion. The decoded packets are continually monitored for an in-band synchronization signal. If a synchronization signal is found, the frame timing is recovered and the decoded packet data is routed to a data demodulator. The decoded packet data is demodulated into messages. The messages are deformatted and output. A protocol sequence comprising synchronization, control, and messages ensures reliable detection and demodulation of the non-speech data.

[00102] Voice packets are received over the communication channel **502** in the receiver **495** and input to the vocoder decoder **390** where decoded voice is generated then routed through the de-mux **320** to the audio out processor and speaker **315** generating output audio **S310**.

[00103] Once a synchronization signal is detected in Vocoder Decoder Output **S370** by the Sync Detector **350**, the Rx De-Mux Control **S360** signal switches to the Rx data path in the Rx De-Mux **320**. The vocoder packets are decoded by the vocoder decoder **390** and routed by the Rx De-Mux **320** to the Rx Timing **380** then the Rx data modem **330**. The Rx data is demodulated by the Rx data modem **330** and forwarded to the data message deformatter **301** where output data **S300** is made available to the user or interfaced equipment.

[00104] An example of a suitable data message deformatter **301** includes circuitry to deinterleave the Rx Message **S320** data, implement error control decoding such as hybrid automatic repeat-request (HARQ), and calculate and check the cyclic redundancy check (CRC) bits. Suitable output data **S300** may include user interface (UI) information, user position/location information, time stamps, equipment sensor information, or other suitable data.

[00105] **FIG. 15A** is a suitable example block diagram of the Sync Detector and Receiver Controller **350** shown in **FIG. 1**. Signal Vocoder Decoder Output **S370** is input to the Sync Burst Detector **360** and the Sync Preamble Detector **351**. The Sync Burst Detector **360** detects the transmitted Sync Burst signal in the Vocoder Decoder Output **S370** and generates the Burst sync index **S351**. The Sync Preamble Detector **351** detects the transmitted Sync Preamble Out signal in the Vocoder Decoder Output **S370** and generates Preamble sync index **S353**. Signals Burst sync index **S351** and Preamble sync index **S353** are input to the Sync Detector Controller **370**. The Sync Detector Controller **370** generates output signals Rx De-Mux Control **S360** which routes the Vocoder Decoder Output **S370** to the data path **S326** or the audio path **S325**, Audio Mute Control **S365** which enables or disables the output audio signal **S310,** and Timing Offset **S350** which provides bit timing information to the Rx Timing **380** to align the Rx Data **S326** for demodulation.

[00106] Another example of a suitable Sync Detector **350** is shown in **FIG. 15B**. Signal Vocoder Decoder Output **S370** is input to the Memory **352** and the Sync Preamble Detector **351**. The Memory **352** is used to store the latest Vocoder Decoder Output **S370** samples which includes the received Wakeup Out signal. A suitable example of the Memory **352** is a First-In-First-Out (FIFO) or Random Access Memory (RAM). The Sync Preamble Detector **351** detects the transmitted Sync Preamble Out signal in the Vocoder Decoder Output **S370** and outputs the SyncFlag **S305** signal. Signals Modulation Type **S306** and SyncFlag **S305** are input to the Sync Detector Controller **370**. The Sync Detector Controller **370** generates the Modulation Search **S307** signal which is used to access the Memory **352**, find the received Wakeup Out signal based on the Timing Offset **S350**, and evaluate the Wakeup Out Signal to determine the type of modulation used in the transmission. The resulting detected modulation type is output from the Memory **352** as Modulation Type **S306**. The Sync Detector Controller **370** also generates output signals Rx De-Mux Control **S360** which routes the Vocoder Decoder Output **S370** to the data path or the audio path, Audio Mute

Control **S365** which enables or disables the output audio signal **S310,** and Timing Offset **S350** which provides bit timing information to Rx Timing **380** to align the Rx Data **S326** for demodulation.

[00107] An example of a suitable Sync Burst Detector **360** is shown in **FIG. 16**. Signal Vocoder Decoder Output **S370** is input to the Power calculator **361**. Examples of a suitable Power calculator **361** include an input squaring function or absolute value function calculated on the input signal. The Vocoder Decoder Output **S370** signal is also input to mixer functions **362** where it is multiplied by the in-phase and quadrature components of reference Frequency Sinusoid 1 **363** and Frequency Sinusoid 2 **364** to generate downconverted signal components at frequency 0Hz. The mixer **362** outputs are low pass filtered by the LPF **365** to eliminate the high frequency multiplier products in the mixed output. An example transfer function of a suitable LPF **365** is of the form:

$$H_{IIR}(z) = c \cdot \frac{1 + a_1 z^{-1} + a_2 z^{-2}}{1 + b_1 z^{-1} + b_2 z^{-2}}$$

where c = 0.0554, a_1 = 2, a_2 = 1, b_1 = −1.9742, b_2 = 0.9744. The magnitude of in-phase and quadrature outputs of the LPF **365** are calculated by the Magnitude **366** and summed in the Adder **367**. The output of the Adder **367** is input to the Matched Filter **368** which is a matched to the transmitted Sync Burst Sequence. Matched filters are well known in the art. The output of the Matched Filter **368** is searched for the maximum peak in the Max Search **369.** Once the maximum is found in the Max Search **369**, the index corresponding to the time offset of the maximum is output in signal Burst sync index **S351**.

[00108] An example of a suitable Sync Preamble Detector **351** is shown in **FIG. 17A**. Signal Vocoder Decoder Output **S370** is processed by the Matched Filter **368** which is matched to the Sync Preamble Sequence. The Matched Filter **368** output is then input to the Max Search **369** which searches for the maximum peak. Once the maximum is found in the Max Search **369**, the index corresponding to the time offset of the maximum is output in Preamble sync index **S353**.

[00109] Another example of a suitable Sync Preamble Detector **351** is shown in **FIG. 17B**. Signal Vocoder Decoder Output **S370** is processed by the filter in step **452**. A suitable example of the filter in step **452** is a sparse filter with coefficients based on the band-pass filtered impulse response of the Sync Preamble Sequence. A sparse filter has a finite-impulse-response structure with some of the coefficients set to zero and

results in a reduction in the computational complexity based on fewer required multipliers due to the zero coefficients. Sparse filters are well known in the art. In step **453** the filter output is searched for the maximum positive and negative correlation peaks which match an expected pattern based on the negative and positive correlation peak distance. For example, 5 peaks should be found in step **453** based on Sync Preamble Sequence **245**, 3 positive peaks corresponding to correlation with the pseudorandom noise (PN) sequence **243** and 2 negative peaks corresponding to correlation with the inverted version of the PN sequence **244**. In a suitable example, the sync detector should find at least 2 peaks in order to declare that the sync preamble is detected. In step **461**, the number of peaks detected is counted and if a majority of peaks is detected, then a sync indicator flag is set True in step **460**, indicating the preamble sync has been detected. A suitable example of a majority of peaks detected is 4 out of 5 peaks which match the expected pattern. If a majority of peaks is not detected then control passes to step **454**, where the temporal distance between the positive peaks found in step **453** is compared against the expected distance, PeakDistT1. The PeakDistT1 is set to be a function of the period of the PN sequence **242** since filtering the received preamble against PN sequence **242** should yield a temporal distance between the correlation peaks which is equal to some multiple of the period. If the temporal distance between the positive peaks is found to be within a range of PeakDistT1, the positive peaks amplitudes are then checked against a threshold PeakAmpT1 in step **455**. A suitable range for PeakDistT1 is plus or minus 2 samples. The PeakAmpT1 is a function of the amplitudes of the previous peaks found. In a suitable example, the PeakAmpT1 is set such that the peaks found in step **453** do not differ in amplitude by more than a factor of 3 and the average peak amplitude does not exceed half the maximum peak amplitude observed up to that point. If either the positive peak temporal distance check in step **454** or the amplitude check in step **455** fails then the negative peak temporal distance is checked in step **456.** If the negative peak temporal distance is within a range of PeakDistT2 then the negative peak amplitudes are checked against a threshold PeakAmpT2 in step **457**. A suitable range for PeakDistT2 is plus or minus 2 samples. PeakDistT2 is set to be a function of the period of the PN sequence **242** and the PeakAmpT2 is set to be a function of the amplitudes of the previous peaks found. If either the positive peak temporal distance check in step **454** and the positive peak amplitude check in step **455** or the negative peak temporal distance check in step **456** and the negative peak amplitude check in step

457 pass then a sync indicator flag is set True in step **460**, indicating the preamble sync has been detected. If either the negative peak temporal distance check in step **456** or negative peak amplitude check in step **457** fails then the sync indicator flag is set False in step **458**, indicating the preamble sync has not been detected. It should be recognized that different orders and combinations of the steps will achieve the same result. For example, detecting the majority peaks in step **461** of may be done after the positive peak check of steps **454** and **455**.

[00110] An example of a suitable Sync Detector Controller **370** is shown in **FIG. 18a**. Step **407** is the entry point in the controller which initializes the memory buffers and configures the initial state of the receiver. In step **406**, the sync search type is checked indicating whether the sync signal is being searched in the Rx data or Rx audio path. Step **372** is entered if the Rx audio path is being searched for sync. Using Burst sync index **S351**, the maximum sync burst and index are searched over a number of processing frames, N1 in step **372**. Step **373** determines if the maximum sync burst and index searched in step **372** passes a successful search criterion. An example of a suitable search decision criterion in step **373** is of the form:

$$(s_{max\,max} \geq Th_{SB}) \text{ and } (i_{smax} \leq N_{\text{sync}} - N_{\text{guard}})$$

where $s_{max\,max}$ is the maximum of the sync bursts found over the N1 processing frames, Th_{SB} is the sync burst detection threshold, i_{smax} is the maximum sync burst index, N_{sync} is the number of processing frames searched and N_{guard} is a latency period in processing frames. If a sync burst is not found, control is passed back to step **406** and the search is restarted. If a sync burst is found, control passes to step **374** where signal Audio Mute Control **S365** is generated to prevent the audio path from being output on the speaker. In step **375** using Preamble sync index **S353**, the maximum sync preamble and index are searched over a number of processing frames, N2. Step **376** determines if the maximum sync preamble and index searched in step **375** passes a successful search criterion. An example of a suitable search decision criterion in step **376** is of the form:

$$\left(c_1 \cdot \left(s_{\max\max} / P(i_{s\max})\right)^2 + c_2 \cdot z^2_{\max\max}\right) \geq Th_{PD}$$

where $s_{max\,max}$ is the maximum of the sync bursts found over the N1 processing frames, c_1 and c_2 are scaling factors, $z_{\max\max}$ is the maximum of the outputs of the matched filter **368** in Sync the Preamble Detector **351**, $P(i_{s\max})$ is the maximum power input to the Max Search **369** in the Sync Burst Detector **360** at the maximum sync burst index, i_{smax}.

If a sync preamble is not found in step **376**, control is passed back to step **406** and the search is restarted. If a sync preamble is found, signal Rx De-Mux Control **S360** is generated in step **378** to switch to the Rx data path in De-Mux **320**. Control is then passed to step **377** where signal Timing Offset **S350** is calculated. An example of a suitable Timing Offset calculation is of the form:

$$Timing\ Offset = ((\ i_{zmax} - N_{\text{sync}} - 1\ ) \cdot N_{\text{samp}}\ ) + (\ k_{max} \cdot i_{zmax}\ )$$

where i_{zmax} is the index at the maximum of the output of the matched filter **368** in the Sync Preamble Detector **351** over one frame, N_{sync} is the number of processing frames searched, N_{samp} is the number of samples in one frame, and k_{max} is the phase of the maximum of the output of the matched filter **368** in the Sync Preamble Detector **351** over one frame. Control is then passed to step **418** where the Rx Modem **330** is enabled via signal Rx Modem Enable **S354**, then finally passed back to step **406** and the search is restarted. Step **372a** is entered if the Rx data path is being searched for sync. Steps **372a**, **373a**, **375a**, and **376a** function the same as steps **372**, **373**, **375**, and **376** respectively; the main difference being that the audio path is not muted and the De-Mux is not switch from Rx Audio to Rx data when the Sync Search Type checked in step **406** is Rx Data.

[00111] Another example of a suitable Sync Detector Controller **370** is shown in **FIG. 18b**. Step **407** is the entry point in the controller which initializes the memory buffers and configures the initial state of the receiver. In step **406**, the sync search type is checked indicating whether the sync signal is being searched in the Rx data or Rx audio path. Control then passes to step **411** where the Preamble Detector **351** is enabled. Step **412** checks the signal SyncFlag **S305**, indicating a Sync Preamble has been found, then confirms it by repeatedly checking for a SyncFlag **S305** a total of N times. A suitable value for N is 1 (that is; only 1 preamble detected without confirmation) for the Destination Terminal **600** and 3 for the Source Terminal **100**. If a sync preamble is found, signal Audio Mute Control **S365** is generated to prevent the audio path from being output to the speaker. Signal Rx De-Mux Control **S360** is then generated in step **378** to switch from the Rx audio path to the Rx data path in De-Mux **320**. Control is then passed to step **377** where signal Timing Offset **S350** is calculated. An example of a suitable Timing Offset calculation is of the form:

$$Timing\ Offset = PulsePosition + PeakDistance$$

PulsePosition is a time distance from the positive correlation peak to a first reference time instance, and may be a positive or negative value. *PeakDistance* is a time distance between the positive correlation peak and negative correlation peak. An example of a suitable first reference time instance may be a certain sample position relative to the current received speech frame. Another example of a suitable Timing Offset calculation is of the form:

$$Timing\ Offset = PulsePosition$$

PulsePosition is a time distance from the negative correlation peak to a second reference time instance, and may be a positive or negative value. An example of a suitable second reference time instance may be a certain sample position relative to the current received speech frame. Control is then passed to step **414** where the Modulation Type is determined via signal Modulation Search **S307** by searching in the Memory **352** at a predetermined position where the received Wakeup Out signal should be stored. Control is then passed to step **418** where the Rx Modem **330** is enabled via the signal Rx Modem Enable **S354**. The demodulation scheme used in Rx Modem Enable **S354** is determined in step **418** by the Modulation Type **S306** input signal. Control is finally passed back to step **406** and the search is restarted. Step **411a** is entered if the Rx data path is being searched for sync. Steps **411a**, and **412a** function the same as steps **411**, and **412** respectively; the main difference being that the audio path is not muted and the De-Mux is not switch from Rx Audio to Rx data when the Sync Search Type checked in step **406** is Rx Data. It should be recognized that different orders and combinations of the steps will achieve the same result. For example, steps Mute Audio Path **374** and the path switch step **378** may be swapped with no effect on the overall sync detection.

[00112] **FIG. 19** is a suitable example block diagram of Rx Timing **380** shown in **FIG. 1**. The Rx Timing **380** is used to align the modulation frame boundary in the data output from the vocoder decoder **390** so that demodulation in the Rx data modem **330** can occur. Signal Rx Data **S326** is input to Buffer **381** where several samples are stored. Suitable examples of Buffer **381** include first-in-first-out (FIFO) memory or random access memory (RAM). The samples from the Buffer **381** are input to the Variable Delay **382** where a time delay is applied to align the modulation frame boundary corresponding to the Timing offset **S350** control signal. A suitable delay applied in Variable Delay **382** may be any number of samples from zero to the frame size - 1. The delayed signal is output as Adjusted Rx Data **S330**.

[00113] **FIG. 20** is a suitable example block diagram of the Rx data modem **330** shown in **FIG. 1**. Two signals are de-multiplexed in time from the Adjusted Rx Data **S330** input signal through Rx Data Modem De-mux **331**; De-Mux Mute **S332**, and De-Mux Rx Data **S333**. De-Mux mute **S332** is a separation or muting period which may exist between successive received messages and is stripped from the Adjusted Rx Data **S330** signal if the separation or muting signal has been applied at the transmitter. De-Mux Rx Data **S333** is the received modulated message signal input to the Demodulator **335**. The Demodulator **335** demodulates the received message information bits from the adjusted Rx Data **S330.** The Rx data modem **330** uses the demodulation frame boundary determined by the Rx Timing **380** and the demodulation type indicator determined by the Sync Detector Controller **370** to determine a data signal pulse position and calculate an output data symbol based on the data signal pulse position. An example of a suitable demodulator is a matched filter correlator matched to all allowed cyclic shifts of the modulation pulse shape applied by the transmit data modulator. Another example of a suitable demodulator is a matched filter correlator matched to a bandpass filtered version of the pulse applied by the transmit data modulator where the bandpass filter represents the transmission characteristics of the channel.

SYSTEM

[00114] **FIG. 21** is an example use case of the system and methods disclosed herein. The diagram represents a typical example of the in-vehicle emergency call (eCall) system. A vehicle incident **950** is shown as an accident between two vehicles. Other suitable examples for vehicle incident **950** include multiple vehicle accident, single vehicle accident, single vehicle flat tire, single vehicle engine malfunction or other situations where the vehicle malfunctions or the user is in need of assistance. The In-Vehicle System (IVS) **951** is located in one or more of the vehicles involved in the vehicle incident **950** or may be located on the user himself. The In-Vehicle System **951** may be comprised of the source terminal **100** described herein. The In-Vehicle System **951** communicates over a wireless channel which may be comprised of an uplink communications channel **501** and downlink communications channel **502**. A request for data transmission may be received by the In-Vehicle System through the communications channel or may be automatic or manually generated at the In-Vehicle System. A wireless tower **955** receives the transmission from the In-Vehicle System

951 and interfaces to a wireline network comprised of a wireline uplink **962** and wireline downlink **961**. A suitable example of a wireless tower **955** is a cellular telephone communications tower comprised of antennas, transceivers, and backhaul equipment, all well-known in the art, for interfacing to the wireless uplink **501** and downlink **502**. The wireline network interfaces to a Public Safety Answering Point (PSAP) **960**, where emergency information transmitted by the In-Vehicle System **951** may be received and control and data transmitted. The Public Safety Answering Point **960** may be comprised of the destination terminal **600** described herein. The communication between the In-Vehicle System **951** and the Public Safety Answering Point **960** is accomplished using the interaction diagrams described in the following sections.

[00115] **FIG. 22** is an example interaction diagram of the synchronization and data transmission sequences between the Source Terminal **100** and the Destination Terminal **600**. In this example, the Uplink Transmission sequence **810** is initiated by the Destination Terminal **600**. The Downlink Transmission sequence **800** is the transmission of sync and data messages from the Destination Terminal **600** to the Source Terminal **100** and the Uplink Transmission sequence **810** is the transmission of sync and data messages from the Source Terminal **100** to the Destination Terminal **600**. The Downlink Transmission sequence **800** is initiated at time t0 **850** by the Destination Terminal **600** with a sync sequence **801**. Suitable examples of the sync sequence **801** are those described in **FIG. 8A**, **FIG. 8B**, and **FIG. 8C**. Following the sync sequence **801**, the Destination Terminal **600** transmits a "Start" message **802** to command the Source Terminal **100** to begin transmitting its Uplink Transmission **810** sequence. The Destination Terminal **600** continues to transmit an alternating sync **801** and "Start" message **802** and waits for a response from the Source Terminal **100**. At time t1 **851** the Source Terminal **100,** having received the "Start" message **802** from the Destination Terminal **600**, begins transmitting its own sync sequence **811**. Suitable examples of the sync sequence **811** are those described in **FIG. 8A**, **FIG. 8B**, and **FIG. 8C**. Following the sync sequence **811**, the Source Terminal **100** transmits a minimum set of data or "MSD" message **812** to the Destination Terminal **600**. A suitable example of data comprising the MSD message **812** includes sensor or user data formatted by a data message formatter **210**. At time t2 **852** the Destination Terminal **600**, having received the sync message **811** from the Source Terminal **100,** begins transmitting a negative acknowledgement or "NACK" message **803** to the Source Terminal **100.** The

Destination Terminal **600** continues to transmit an alternating sync **801** and "NACK" message **803** until it successfully receives the MSD message **812** from the Source Terminal **100.** A suitable example of successfully receiving the MSD message **812** includes verifying a cyclic redundancy check performed on the MSD message **812**. At time t3 **853**, the Destination Terminal **600**, having successfully received the MSD message, begins transmitting an alternating sync **801** and acknowledge or "ACK" message **804.** The Source Terminal **100** may attempt to send the MSD message **812** multiple times (**813**, **814**) until it receives the "ACK" message **804.** In a suitable example, if the Source Terminal **100** attempts to send the MSD message more than 8 times wherein each attempt is a different redundancy version, it switches to a more robust modulation scheme identified by the Wakeup signal **S236**. A suitable example of a more robust modulation scheme includes increasing the duration of the modulation frame T_{MF} while maintaining a constant number of time instances as described previously. At time t4 **854** the Source Terminal **100,** having received the "ACK" message **804** from the Destination Terminal **600** discontinues transmission of the MSD message **814**. In a suitable example, a retransmission is requested by the Destination Terminal **600** via transmitting the start messages **802** again after a predetermined number of "ACK" messages **804** have been sent by the Destination Terminal **600**.

[00116] **FIG. 23A** is another example interaction diagram of the synchronization and data transmission sequences between the Source Terminal **100** and the Destination Terminal **600**. In this case, the Uplink Transmission sequence **810** is initiated by the Source Terminal **100**. The Uplink Transmission sequence **810** is initiated at time t0 **850a** by the Source Terminal **100** with Voice data **815** by configuring the Source Terminal **100** Transmit baseband **200** to the Tx audio path **S225**. At time t1 **851a**, the Source Terminal **100** configures Transmit baseband **200** to the Tx data path **S230** and begins transmitting its sync sequence **811** followed by the MSD message **812**. At time t2 **852a** the Destination Terminal **600**, having received the sync message **811** from the Source Terminal **100,** begins transmitting an alternating sync **801** and "NACK" message **803** to the Source Terminal **100.** The Destination Terminal **600** continues to transmit an alternating sync **801** and "NACK" message **803** until it successfully receives the MSD message from the Source Terminal **100.** At time t3 **853**, the Destination Terminal **600**, having successfully received the MSD message **813**, begins transmitting an alternating sync **801** and acknowledge or "ACK" message **804.** The Source Terminal **100** may attempt to send the MSD message **812** multiple times until it receives

the "ACK" message **804**, wherein each attempt is a different redundancy version. At time t4 **854** the Source Terminal **100,** having received the "ACK" message **804** from the Destination Terminal **600** discontinues transmission of the MSD message **814.**

[00117] **FIG. 23B** is another example interaction diagram of the synchronization and data transmission sequences between the Source Terminal **100** and the Destination Terminal **600**. In this case, the Uplink Transmission sequence **810** is initiated by the Source Terminal **100**. Instead of transmitting voice data on the uplink to initiate the transmission, the Source Terminal **100** transmits an alternating sync **811** and "SEND" message **805** at time t0 **850b**. At time t1 **851b** the Destination Terminal **600**, having received the SEND message **805** from the Source Terminal **100,** transmits an alternating sync **801** and "Start" message **802**. At time t2 **852b** the Source Terminal **100,** having received the "Start" message **802** from the Destination Terminal **600**, transmits a sync sequence **811** followed by an MSD message **812** to the Destination Terminal **600**. At time t3 **853b** the Destination Terminal **600**, having received the sync message **811** from the Source Terminal **100,** transmits an alternating sync **801** and "NACK" message **803** to the Source Terminal **100.** At time t4 **854b**, the Destination Terminal **600**, having successfully received the MSD message, transmits an alternating sync **801** and "ACK" message **804.** Upon receiving the "ACK" message **804** from the Destination Terminal **600**, the Source Terminal **100** discontinues transmission of the MSD message.

[00118] **FIG. 24A** is an example interaction diagram of the synchronization and data transmission sequences between the Source Terminal **100** and the Destination Terminal **600**. In this case, data is requested and transmitted by both the Source Terminal **100** and the Destination Terminal **600** on the Uplink and Downlink respectively in support of bidirectional data transmission. The Downlink Transmission sequence **800** is initiated at time t0 **850** by the Destination Terminal **600** with alternating sync sequence **801** and "Start" message **802**. At time t1 **851** the Source Terminal **100,** having received the "Start" message **802** from the Destination Terminal **600**, begins transmitting its sync sequence **811** followed by data **812.** At time t2 **852**, The Destination Terminal **600** transmits an alternating sync **801** and "NACK" message **803** until it successfully receives the data **812** from the Source Terminal **100**, upon which then the Destination Terminal **600** sends an alternating sync sequence **801** and "ACK" message **804.** At time t4 **854** the Source Terminal **100,** having received the "ACK" message **804** from the Destination Terminal **600** discontinues its data transmission. At time t5 **855**, the Destination Terminal **600** transmits an alternating sync sequence **801**

and "SEND" message **805** indicating a request to transmit data on the downlink. At time t6 **856**, the Source Terminal **100** upon detecting the "SEND" message **805**, responds with an alternating sync sequence **811** and "Start" message **816**. At time t7 **857**, the Destination Terminal **600**, upon detecting the "Start" message **816**, responds with a sync sequence **801** followed by data **806**. At time t8 **858**, the Source Terminal **100** transmits an alternating sync sequence **811** and "NACK" message **817** until it successfully receives the data **806** from the Destination Terminal **600**, upon which at time t9 **859** the Source Terminal **100** sends an alternating sync sequence **811** and "ACK" message **818.** At time t10 **860** the Destination Terminal **600,** having received the "ACK" message **818** from the Source Terminal **100** discontinues transmission of its data **806.** One skilled in the art will recognize that the interactions described herein are symmetric and may be initiated by the Source Terminal **100**. One skilled in the art will also recognize that the sync sequence, Start message, NACK message, and ACK message may each be the same or different sequences between those transmitted on the downlink and uplink.

[00119] **FIG. 24B** is a another example interaction diagram of the synchronization and data transmission sequences between the Source Terminal **100** and the Destination Terminal **600**, wherein data is requested and transmitted by both the Source Terminal **100** and the Destination Terminal **600** on the Uplink and Downlink respectively. The difference between the interactions of **FIG. 24B** and **FIG. 24A** occurs at t3 **853**. In this example, an alternating sync **801** and "SEND" message **805** is transmitted by the Destination Terminal **600** instead of an alternating sync and "ACK" message. In this example, the "SEND" message **805** serves to indicate that the Destination Terminal **600** has successfully received the Source Terminal **100** data **812,** and results in the Source Terminal **100** discontinuing its data transmission at t4 **854.** The "SEND" message also indicates a request from the Destination Terminal **600** to send data on the Downlink.

[00120] **FIG. 25** is an example diagram of the composition of a transmit data packet whereby the length of the user data is less than the transmit data packet length. The user data segment **900** is assembled into the transmit data packet **806** or **812** along with a preceding length indicator **910** and a following sequence of pad bits **911** which served to fill out the data to the end of transmit data packet. A suitable example for the length indicator **910** is a 1 to 3 byte value indicating the length of the user data segment **900**. A suitable example of the transmit data packet length **806** or **812** may be 100 –

200 bytes. A suitable example of pad bits **911** include the binary "0" value. One skilled in the art will recognize that the pad bits **911** may be comprised of the binary "1" value or may be comprised of a pattern of binary "1" and "0" values.

[00121] **FIG. 26** is an example diagram of the composition of a transmit data packet whereby the length of the user data is greater than the transmit data packet length. The user data **900** is split into multiple segments such that the first segment plus the length indicator is equal to the transmit data packet length and subsequent segments are equal to the transmit data packet length. If the user data is not an integer multiple of the transmit data packet length, then the last segment contains a pad. In the example of **FIG. 26**, the user data is split into two segments. The first user data segment **901** is assembled into the transmit data packet **806** or **812** along with a preceding length indicator **910**. The second user data segment **902** is assembled into the transmit data packet **806** or **812**, and because the segment is smaller than the transmit data packet length a pad **911** is used to fill out the data to the end of the transmit data packet.

[00122] **FIG. 27A** is an example interaction diagram of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size. Initiated by the Start messages of the requesting terminal in either the downlink transmission **800** or the uplink transmission **810**, at time t20 **870**, the first transmit data packet **806** or **812** comprised of a length indicator **910** and first user data segment **901** is transmitted by the responding terminal. At time t21 **871**, since the responding terminal has not yet received the ACK message, it begins transmitting the user data again in a second attempt **903**. At time t22 **872**, the responding terminal, having received the ACK message, discontinues transmission of the first data packet **806** or **812**. At time t23 **873**, the requesting terminal, after evaluating the length indicator **910** to determine how many segments are expected, requests the next transmit data packet **806** or **812** by transmitting start messages to the responding terminal. At time t24 **874**, the responding terminal, having received the start message from the requesting terminal, begins transmitting the next transmit data packet **806** or **812** comprised of a next user data segment **902** and pad **911** (in this example the next transmit data packet is the last data packet). At time t25 **875**, the responding terminal, having received the ACK message, discontinues its data transmission. One skilled in the art will recognize that the interactions described herein are symmetric whereby the requesting and responding terminals may be either the Source Terminal **100** or the

Destination Terminal **600**. One skilled in the art will also recognize that the user data may span more than two transmit data packets **806** or **812**.

[00123] **FIG. 27B** is another example interaction diagram of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size. In this example, after the first transmit data packet **806** or **812** is requested via Start messages transmitted by the requesting terminal, the subsequent transmit data packets **806** or **812** are automatically transmitted by the responding terminal based on receiving the ACK message from the requesting terminal. In this example, the requesting terminal does not transmit Start messages to initiate transmission of the subsequent transmit data packet **806** or **812** from the responding terminal. At time t31 **881,** the responding terminal, having received the ACK message, discontinues the transmission of the first data packet then immediately begins transmitting the next transmit data packet **806** or **812** separated only by a sync sequence. At time t32 **882**, the requesting terminal, having received the sync sequence, begins transmitting NACK messages until it successfully receives the transmit data packet **806** or **812.** At time t33 **883**, having successfully received the transmit data packet **806** or **812**, the requesting terminal begins transmitting the ACK messages. At time t34 **884**, the responding terminal having received the ACK message discontinues transmission of the transmit data packet **806** or **812.**

[00124] **FIG. 27C** is yet another example interaction diagram of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size. In this example, after the first transmit data packet **806** or **812** is requested via Start messages transmitted by the requesting terminal, the subsequent transmit data packets **806** or **812** are automatically transmitted by the responding terminal based on receiving the ACK message from the requesting terminal. In this example, the requesting terminal does not transmit Start messages to initiate transmission of the transmit data packet **806** or **812** from the responding terminal nor does the requesting terminal transmit NACK messages. At time t41 **891**, the responding terminal, having received the ACK message, discontinues the transmission of the first data packet then immediately begins transmitting the next transmit data packet **806** or **812** separated only by a sync sequence. At time t42 **892**, having successfully received the transmit data packet **806** or **812**, the requesting terminal begins transmitting the ACK messages. Once the responding terminal receives the ACK messages, it discontinues transmission of the transmit data packet **806** or **812**.

[00125] **FIG. 27D** is still another example interaction diagram of the transmit data request sequence and transmit data response sequence, wherein the user data length is greater than the transmit packet size. **FIG. 27D** is an alternate to the example interaction diagram shown in **FIG. 27B**. In the example of **FIG. 27D**, the time gap at t32 **882** between the requesting terminal ACK message for the first user data segment **903** and the NACK for the next user data segment **902** is eliminated. This helps to maintain timing at the responding terminal such that it would not need to resynchronize to the requesting terminal sync sequence.

[00126] One skilled in the art would recognize that the responding terminals may automatically transmit data packets subsequent to the first data packet without transmitting the sync sequence separator. In this case the sync sequence is sent once prior to the first transmit data packet **806** or **812**, then upon receiving the ACK messages the responding terminal automatically transmits the subsequent data packet without sending a sync. One skilled in the art would also recognize that a length indicator **910** could also be transmitted with other data segments in addition to the first one.

[00127] In the interaction diagrams disclosed herein, there may be error conditions which should be responded to and handled in a predetermined manner. The following sections provide examples on the error condition handling corresponding to the interaction diagrams disclosed herein. In each example, the error condition is stated along with the corresponding response description. One skilled in the art will recognize that the error handling described herein may be equally applied to the source or destination terminal in both unidirectional and bidirectional embodiments.

[00128] An example error condition occurs when the Source Terminal does not detect a transmitted sync preamble. In an example response, the Source Terminal delays the transmission of the MSD message until a predetermined number of sync preambles have been detected.

[00129] Another example error condition occurs when the Source Terminal incorrectly detects a sync preamble. In an example response, the Source Terminal delays the transmission of the MSD message until a predetermined number of detected sync preambles yield the same sample offset.

[00130] Another example error condition occurs when the Source Terminal falsely detects a sync preamble although there was none actually transmitted. In an example response, the Source Terminal ignores the falsely detected sync preambles.

The Source Terminal would only trigger the MSD transmission if a predetermined number of detected sync preambles yield the same sample offset estimate.

[00131] Another example error condition occurs when the Destination Terminal does not detect a transmitted sync preamble. In an example response, the Destination Terminal does not start decoding the MSD message, but continues transmitting START messages so as to trigger the Source Terminal to reinitiate the MSD transmission after a predetermined number of START messages is received (including the sync preamble sequence).

[00132] Another example error condition occurs when the Destination Terminal incorrectly detects a sync preamble. In an example response, the Destination Terminal decodes the received MSD data incorrectly throughout all redundancy versions. Based on the incorrectly decoded data, the Destination Terminal may reinitiate the MSD transmission by sending START messages to the Source Terminal.

[00133] Another example error condition occurs when the Destination Terminal falsely detects a sync preamble although there was none actually transmitted. There is no response since the probability of this happening is very low. The Destination Terminal does not start monitoring its received signal until it expects a sync preamble from the Source Terminal.

[00134] Another example error condition occurs when the Source Terminal misinterprets a START message as a NACK message. In an example response, if the MSD transmission has not started, the Source Terminal delays the MSD transmission until it receives a START message. In another example response, if the MSD transmission is ongoing, the Source Terminal delays the reinitialization of the transmission.

[00135] Another example error condition occurs when the Source Terminal misinterprets a START message as an ACK message. In an example response, if the MSD transmission has not started, the Source Terminal ignores any ACK message. In another example response, the Source Terminal ignores the ACK if the previous messages have been interpreted as a START message. In yet another example response, if the previous messages were NACK messages, the Source Terminal puts itself on hold and terminates the MSD transmission if the next message is also interpreted as an ACK. In still another example response, if the previous message has been interpreted as an ACK, the Source Terminal terminates the MSD transmission erroneously. The

probability of this event is low, however, if it does occur, the Destination Terminal may reinitiate the transmission again by sending a request with START messages.

[00136] Another example error condition occurs when the Source Terminal misinterprets a NACK message as a START message. In an example response, a single NACK that is interpreted as a START does not have any effect on the MSD transmission. In another example response, a series of NACK messages that are all interpreted as START messages may cause the Source Terminal transmitter to reinitiate the MSD. The Destination Terminal would not expect this and would fail receiving the incoming data, realizing this by incorrectly decoded data. Based on the incorrectly decoded data, the Destination Terminal may request the Source Terminal to reinitiate the transmission by sending START messages.

[00137] Another example error condition occurs when the Source Terminal misinterprets a NACK message as an ACK message. In an example response, if the previous message has been interpreted as a START message, the Source Terminal ignores any ACK message. In another example response, if the previous message has been interpreted as a NACK message, the Source Terminal waits for another ACK. If the following message is not another ACK, the current ACK is ignored. In yet another example response, if the previous message has also been erroneously detected as an ACK message, the Source Terminal may terminate the MSD transmission although the Destination Terminal has not yet received the MSD correctly. The probability of this event is low, however, if it does occur, the Destination Terminal may reinitiate the transmission again by sending a request with START messages.

[00138] Another example error condition occurs when the Source Terminal misinterprets an ACK message as a START message. In an example response, the Source Terminal would not abort the transmission of additional redundancy versions of the MSD, since the usual abort condition is the reception of a predetermined number of ACK messages. If more subsequent messages are interpreted as START messages, the Source Terminal may reinitiate the MSD transmission. Eventually, the Destination Terminal would stop transmitting messages. The Source Terminal would eventually determine that the Destination Terminal is no longer transmitting sync frames and reset itself, thereby stopping further transmissions.

[00139] Another example error condition occurs when the Source Terminal misinterprets an ACK message as a NACK message. In an example response, the Source Terminal would continue transmitting redundancy versions until the ACK

messages are detected correctly. Eventually, the Destination Terminal would stop transmitting messages. The Source Terminal would eventually determine that the Destination Terminal is no longer transmitting sync frames and reset itself, thereby stopping further transmissions.

[00140] Another example error condition occurs when the Source Terminal determines that a received message is unreliable. In an example response, if the received messages are START messages, the Source Terminal continues to count the unreliable messages but with a lower weighting factor than if the messages were received with a reliable determination. The subsequent trigger of an event based on the count of received messages will require a larger predetermined number of unreliable messages received versus if the messages were received with a reliable determination. In another example response, if the unreliable received messages are NACK messages or ACK messages, the Source Terminal may ignore the messages.

[00141] Another example error condition occurs when the Destination Terminal is unable to detect the transmitted MSD due to noise or other channel distortions. In an example response, after attempting to decode a predetermined number of redundancy versions, the Destination Terminal may request the Source Terminal reinitiate the transmission by sending START messages. In the reinitiated transmission, the Source Terminal may use the robust modulator, which is less prone to noise and other channel distortions.

[00142] Another example error condition occurs when the Destination Terminal cannot evaluate the wakeup signal correctly. In an example response, if the Destination Terminal considers the wakeup signal detection unreliable, it chooses the fast (or normal) modulation mode for the first trial of demodulating the MSD data. For any other set of a predetermined number of received redundancy versions of the MSD data, the Destination Terminal may use the robust modulation mode to demodulate the data.

[00143] Thus, disclosed herein is an apparatus and method of reliably and efficiently transmitting data in-band through a speech codec in a wireless communication system. Those of skill in the art would understand that information and signals may be represented using any of a variety of different technologies and techniques. For example, data, instructions, commands, information, signals, bits, and symbols that may be referenced throughout the above description may be represented by voltages, currents, electromagnetic waves, magnetic fields or particles, optical fields or particles, or any combination thereof. Also, though the embodiments are described

primarily in terms of a wireless communication system, the described techniques may be applied to other in-band data communication systems that are fixed (non-portable) or do not involve a wireless channel.

[00144] Those of skill would further appreciate that the various illustrative logical blocks, modules, circuits, and algorithm steps described in connection with the embodiments disclosed herein may be implemented as electronic hardware, computer software, or combinations of both. To clearly illustrate this interchangeability of hardware and software, various illustrative components, blocks, modules, circuits, and steps have been described above generally in terms of their functionality. Whether such functionality is implemented as hardware or software depends upon the particular application and design constraints imposed on the overall system. Skilled artisans may implement the described functionality in varying ways for each particular application, but such implementation decisions should not be interpreted as causing a departure from the scope of the present invention.

[00145] The various illustrative logical blocks, modules, and circuits described in connection with the embodiments disclosed herein may be implemented or performed with a general purpose processor, a digital signal processor (DSP), an application specific integrated circuit (ASIC), a field programmable gate array (FPGA) or other programmable logic device, discrete gate or transistor logic, discrete hardware components, or any combination thereof designed to perform the functions described herein. A general purpose processor may be a microprocessor, but in the alternative, the processor may be any conventional processor, controller, microcontroller, or state machine. A processor may also be implemented as a combination of computing devices, e.g., a combination of a DSP and a microprocessor, a plurality of microprocessors, one or more microprocessors in conjunction with a DSP core, or any other such configuration.

[00146] The steps of a method or algorithm described in connection with the embodiments disclosed herein may be embodied directly in hardware, in a software module executed by a processor, or in a combination of the two. A software module may reside in RAM memory, flash memory, ROM memory, EPROM memory, EEPROM memory, registers, hard disk, a removable disk, a CDROM, or any other form of storage medium known in the art. A storage medium is coupled to the processor such the processor can read information from, and write information to, the storage medium. In the alternative, the storage medium may be integral to the processor. The processor

and the storage medium may reside in an ASIC. In the alternative, the processor and the storage medium may reside as discrete components in a user terminal.

[00147] The previous description of the disclosed embodiments is provided to enable any person skilled in the art to make or use the present invention. Various modifications to these embodiments will be readily apparent to those skilled in the art, and the generic principles defined herein may be applied to other embodiments without departing from the spirit or scope of the invention. Thus, the present invention is not intended to be limited to the embodiments shown herein but is to be accorded the widest scope consistent with the principles and novel features disclosed herein.

WHAT IS CLAIMED IS:

1. A method of controlling bidirectional data transmissions from a destination terminal in an in-band communication system, the method comprising:
   transmitting a send signal from the destination terminal;
   discontinuing transmission of the send signal upon detection of a first received signal, wherein the first received signal indicates a successful reception of the send signal from a source terminal;
   transmitting a synchronization signal from the destination terminal;
   transmitting a user data segment from the destination terminal using a first modulation scheme; and
   discontinuing transmission of the user data segment upon detection of a second received signal, wherein the second received signal indicates a successful reception of the user data segment from the source terminal.

2. The method of claim 1, wherein the transmitting a send signal is preceded by:
   transmitting a start signal from the destination terminal;
   discontinuing transmission of the start signal upon detection of a third received signal, wherein the third received signal indicates a successful reception of the start signal from the source terminal;
   transmitting a NACK signal from the destination terminal, whereby the source terminal is constrained to respond in a first predetermined manner;
   discontinuing transmission of the NACK signal upon detection of a successfully received source terminal data message;
   transmitting a ACK signal from the destination terminal, whereby the source terminal is constrained to respond in a second predetermined manner; and
   discontinuing transmission of the ACK signal after a predetermined number of the ACK signals have been transmitted.

3. The method of claim 1 wherein the send signal is comprised of a synchronization signal followed by a send message.

4. The method of claim 2 wherein the start signal is comprised of a synchronization signal followed by a start message.

5. The method of claim 2 wherein the NACK signal is comprised of a synchronization signal followed by a NACK message.

6. The method of claim 2 wherein the ACK signal is comprised of a synchronization signal followed by an ACK message.

7. The method of claim 2 wherein the successfully received source terminal data message is the data message verified by a cyclic redundancy check.

8. The method of claim 1 further comprising switching to a second modulation scheme if the destination terminal receives a predetermined number of a fourth received signal, wherein the fourth received signal indicates an unsuccessful reception of the user data segment from the source terminal.

9. An apparatus for controlling bidirectional data transmissions from a destination terminal in an in-band communication system comprising:

a processor;

memory in electronic communication with the processor; and

instructions stored in the memory, the instructions being capable of executing the steps of:

transmitting a send signal from the destination terminal;

discontinuing transmission of the send signal upon detection of a first received signal, wherein the first received signal indicates a successful reception of the send signal from a source terminal;

transmitting a synchronization signal from the destination terminal;

transmitting a user data segment from the destination terminal using a first modulation scheme; and

discontinuing transmission of the user data segment upon detection of a second received signal, wherein the second received signal indicates a successful reception of the user data segment from the source terminal.

10. The apparatus of claim 9 wherein the memory further comprises instructions, the instructions being capable of executing the steps, preceding the step of transmitting a send signal, of:

transmitting a start signal from the destination terminal;

discontinuing transmission of the start signal upon detection of a third received signal, wherein the third received signal indicates a successful reception of the start signal from the source terminal;

transmitting a NACK signal from the destination terminal, whereby the source terminal is constrained to respond in a first predetermined manner;

discontinuing transmission of the NACK signal upon detection of a successfully received source terminal data message;

transmitting a ACK signal from the destination terminal, whereby the source terminal is constrained to respond in a second predetermined manner; and

discontinuing transmission of the ACK signal after a predetermined number of the ACK signals have been transmitted.

11. The method of claim 9 wherein the send signal is comprised of a synchronization signal followed by a send message.

12. The apparatus of claim 10 wherein the start signal is comprised of a synchronization signal followed by a start message.

13. The method of claim 10 wherein the NACK signal is comprised of a synchronization signal followed by a NACK message.

14. The method of claim 10 wherein the ACK signal is comprised of a synchronization signal followed by an ACK message.

15. The method of claim 10 the successfully received source terminal data message is the data message verified by a cyclic redundancy check.

16. The method of claim 9 further comprising switching to a second modulation scheme if the destination terminal receives a predetermined number of a fourth received signal, wherein the fourth received signal indicates an unsuccessful reception of the user data segment from the source terminal.

17. An apparatus for controlling bidirectional data transmissions from a destination terminal in an in-band communication system comprising:

means for transmitting a send signal from the destination terminal;

means for discontinuing transmission of the send signal upon detection of a first received signal, wherein the first received signal indicates a successful reception of the send signal from a source terminal;

means for transmitting a synchronization signal from the destination terminal;

means for transmitting a user data segment from the destination terminal using a first modulation scheme; and

means for discontinuing transmission of the user data segment upon detection of a second received signal, wherein the second received signal indicates a successful reception of the user data segment from the source terminal.

18. The apparatus of claim 17, wherein the means for transmitting a send signal is preceded by:

means for transmitting a start signal from the destination terminal;

means for discontinuing transmission of the start signal upon detection of a third received signal, wherein the third received signal indicates a successful reception of the start signal from the source terminal;

means for transmitting a NACK signal from the destination terminal, whereby the source terminal is constrained to respond in a first predetermined manner;

means for discontinuing transmission of the NACK signal upon detection of a successfully received source terminal data message;

means for transmitting a ACK signal from the destination terminal, whereby the source terminal is constrained to respond in a second predetermined manner; and

means for discontinuing transmission of the ACK signal after a predetermined number of the ACK signals have been transmitted.

19. The apparatus of claim 17, further comprising means for switching to a second modulation scheme if the destination terminal receives a predetermined number of a fourth received signal, wherein the fourth received signal indicates an unsuccessful reception of the user data segment from the source terminal.