US 20250260428A1

(19) **United States**

(12) **Patent Application Publication** (10) **Pub. No.: US 2025/0260428 A1**

MENDEL (43) **Pub. Date: Aug. 14, 2025**

(54) **PHASE SHIFT DETECTION AND CORRECTION FOR AUDIO-BASED DATA TRANSMISSIONS**

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(21) Appl. No.: **19/068,720**

(22) Filed: **Mar. 3, 2025**

Related U.S. Application Data

(63) Continuation of application No. 17/756,351, filed on May 23, 2022, filed as application No. PCT/US2019/062823 on Nov. 22, 2019, now Pat. No. 12,244,333.

Publication Classification

(51) **Int. Cl.**

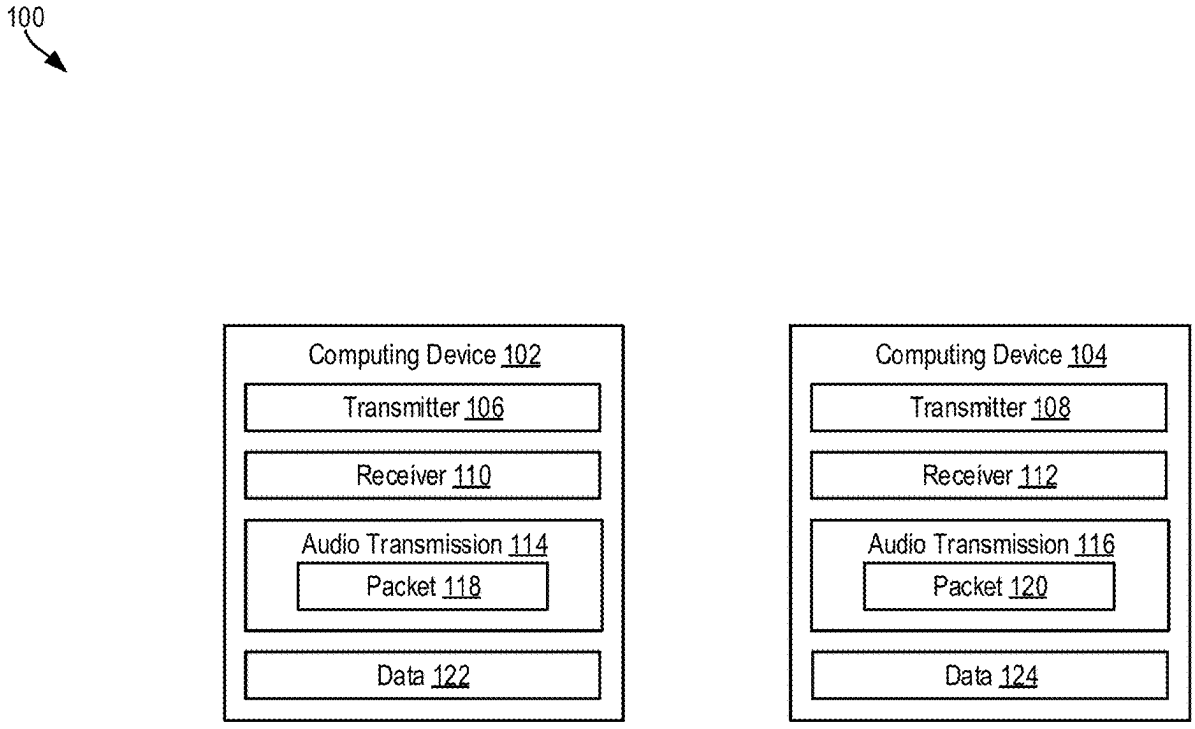
H04B 1/10	(2006.01)
H04B 11/00	(2006.01)
H04L 43/0852	(2022.01)

(52) **U.S. Cl.**

CPC ***H04B 1/1027*** (2013.01); ***H04B 11/00*** (2013.01); ***H04L 43/0858*** (2013.01)

(57) **ABSTRACT**

Methods and systems for correcting distortions of audio transmissions are provided. In one embodiment, a method is provided that includes receiving an audio transmission that includes symbols. A first portion of the audio transmission including a first subset of the symbols may be identified and compared to an expected sequence having expected symbols. One or more differences may be determined between the first subset of the symbols and the expected symbols and a movement speed between a transmitter and a receiver of the audio transmission may be determined based on the differences. A second portion of the audio transmission may be identified including a second subset of the symbols in the second subset of the symbols may be corrected based on the movement speed between the transmitter and the receiver.



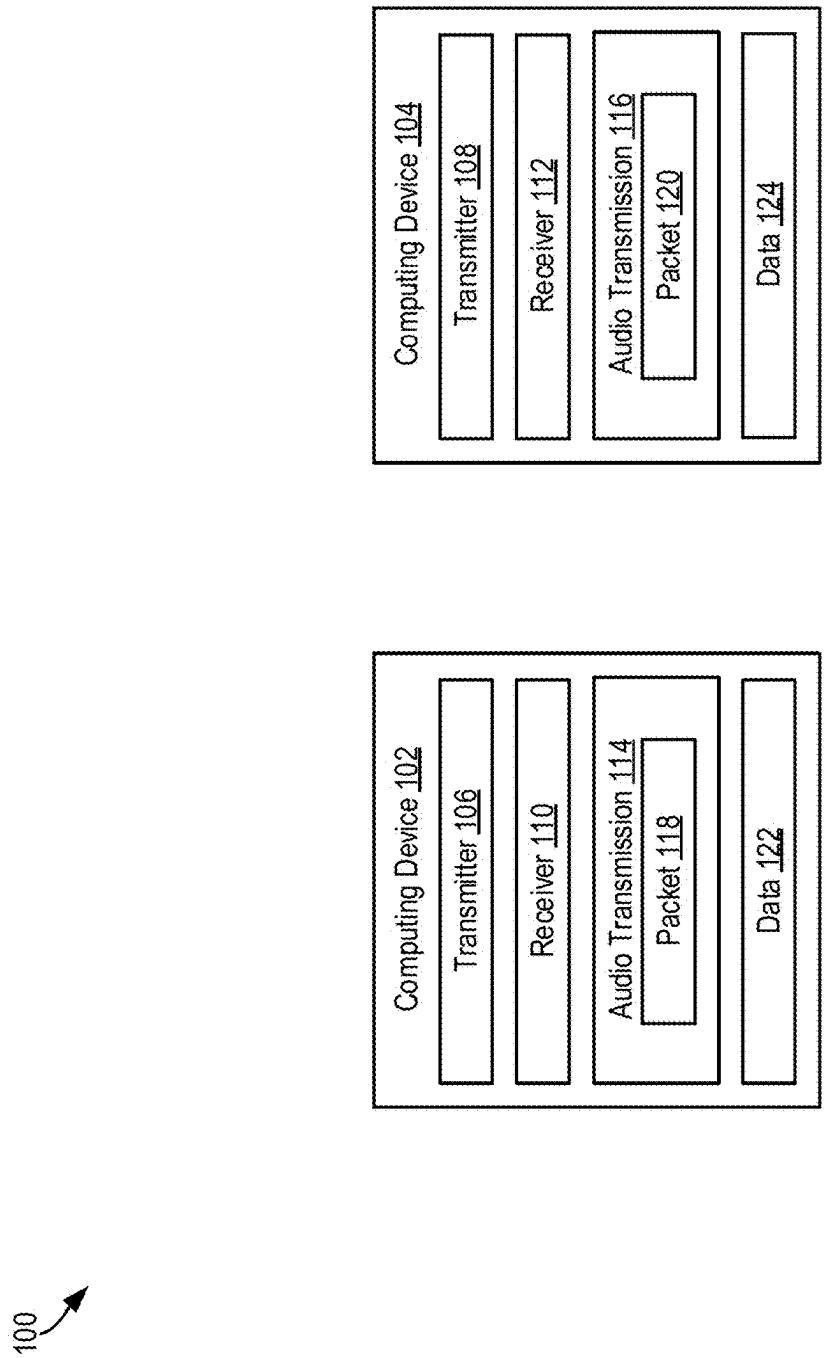

100
Computing Device 102
Transmitter 106
Receiver 110
Audio Transmission 114
Packet 118
Data 122
Computing Device 104
Transmitter 108
Receiver 112
Audio Transmission 116
Packet 120
Data 124

FIG. 1

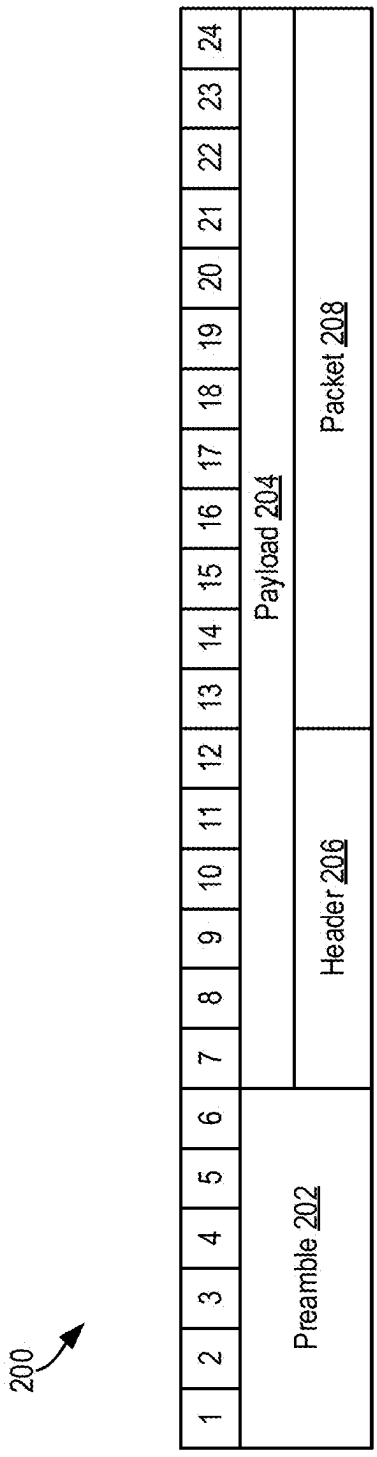

200
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
17
18
19
20
21
22
23
24
Preamble 202
Header 206
Payload 204
Packet 208

FIG. 2

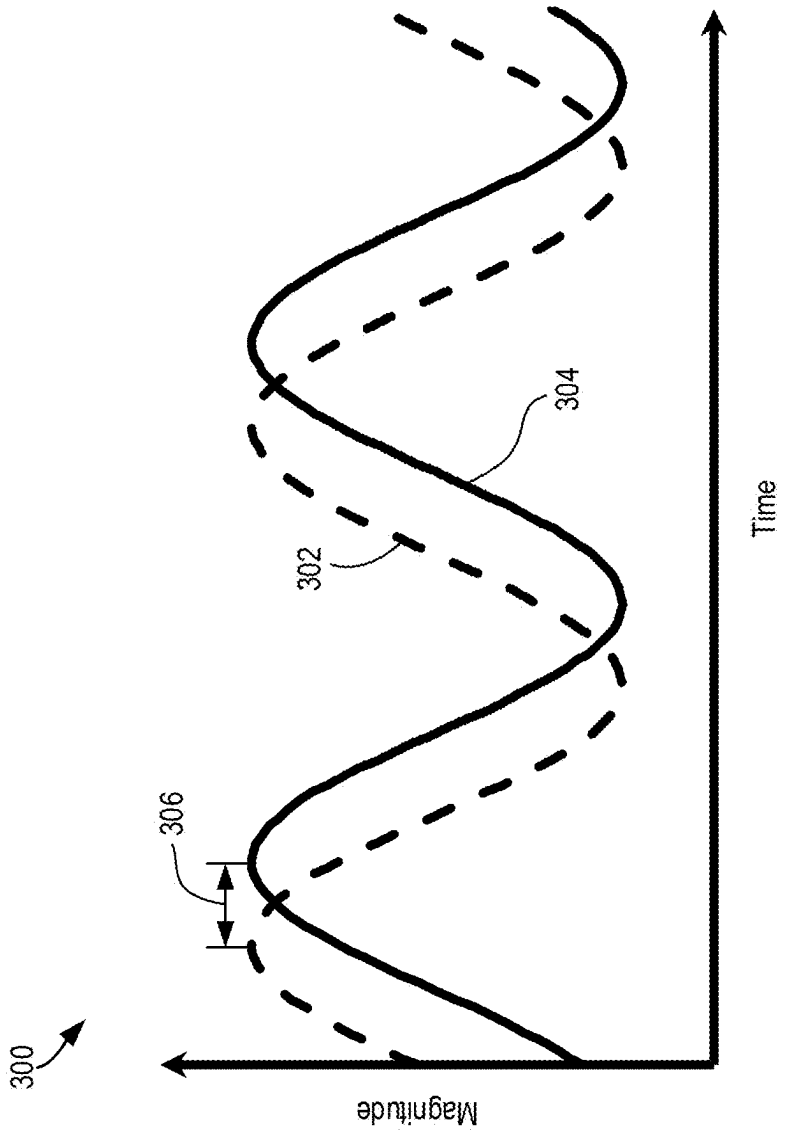


FIG. 3

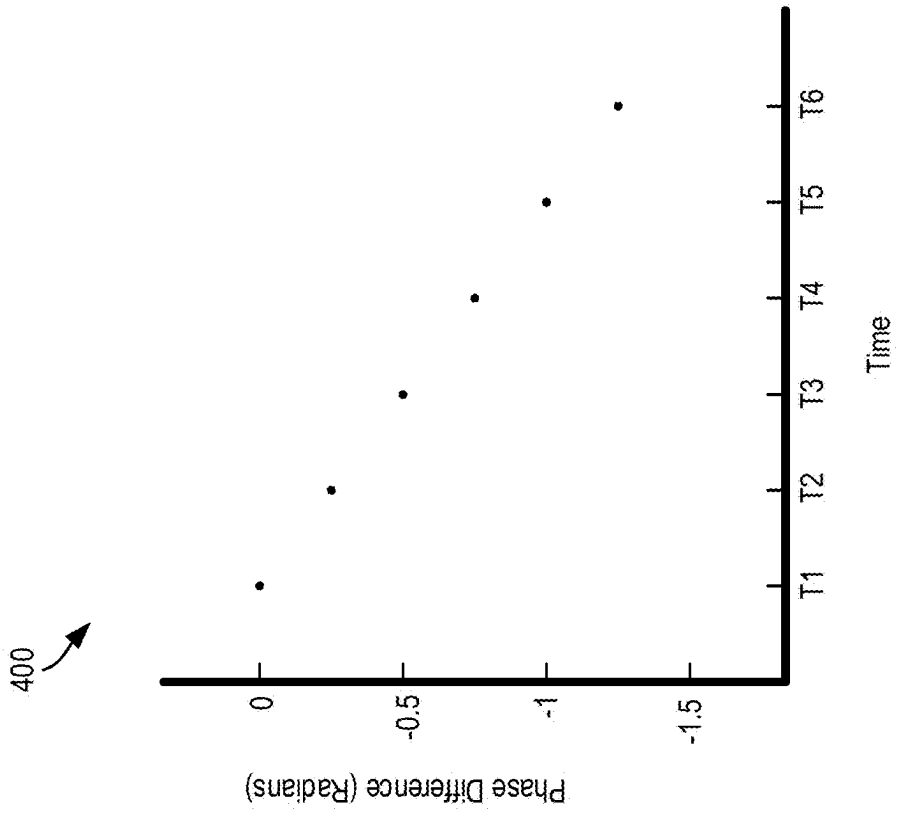


FIG. 4

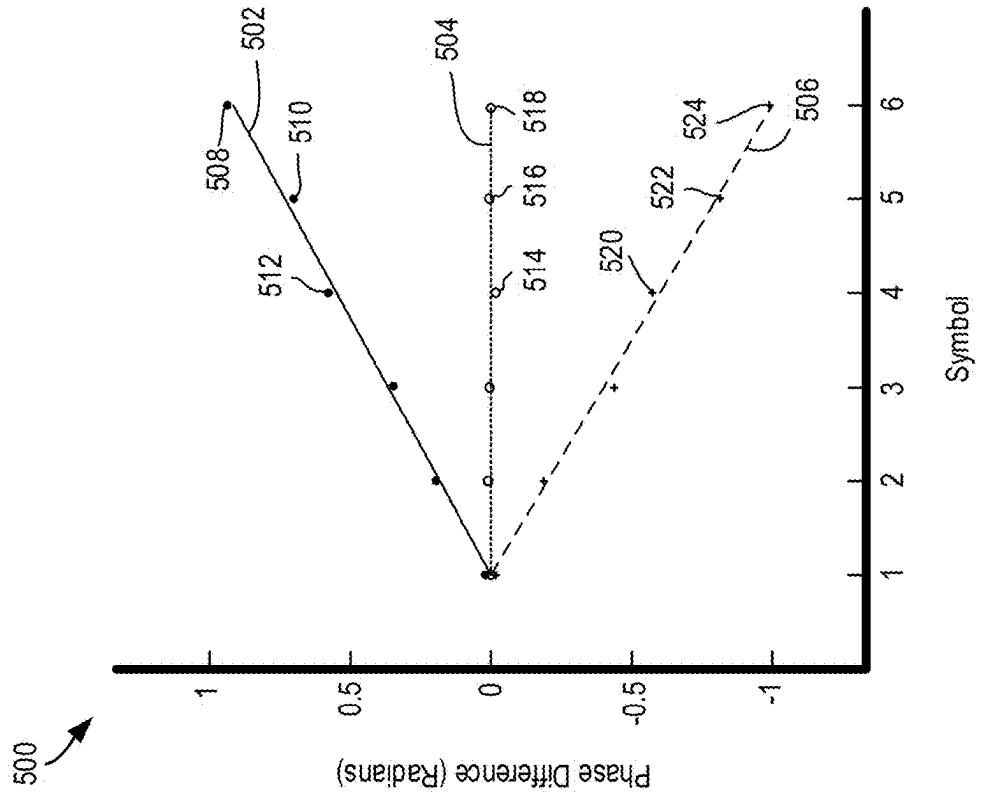

500
Phase Difference (Radians)
1
0.5
0
-0.5
-1
Symbol
1
2
3
4
5
6
502
504
506
508
510
512
514
516
518
520
522
524

FIG. 5

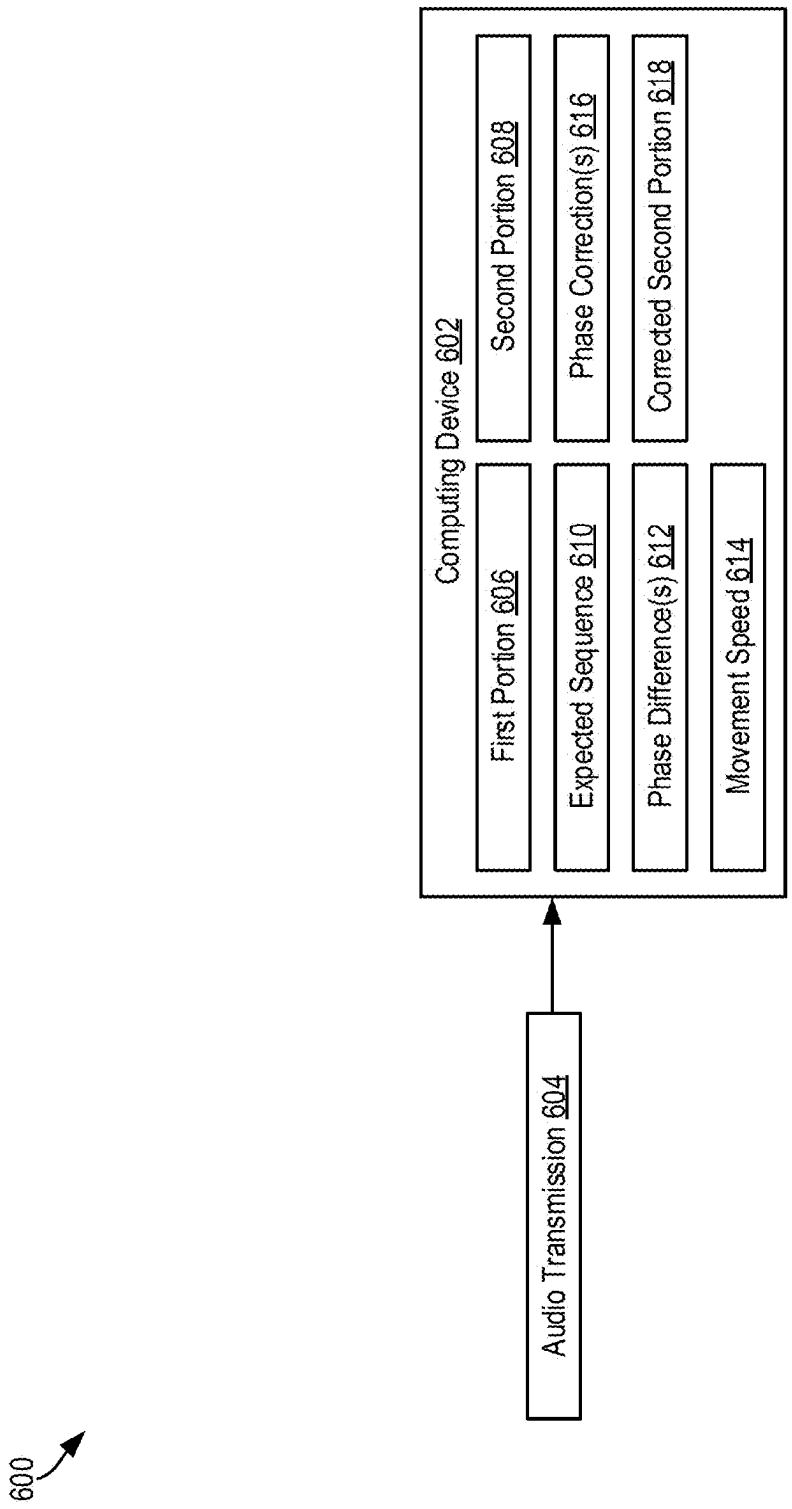

600
Audio Transmission 604
Computing Device 602
First Portion 606
Expected Sequence 610
Phase Difference(s) 612
Movement Speed 614
Second Portion 608
Phase Correction(s) 616
Corrected Second Portion 618

FIG. 6

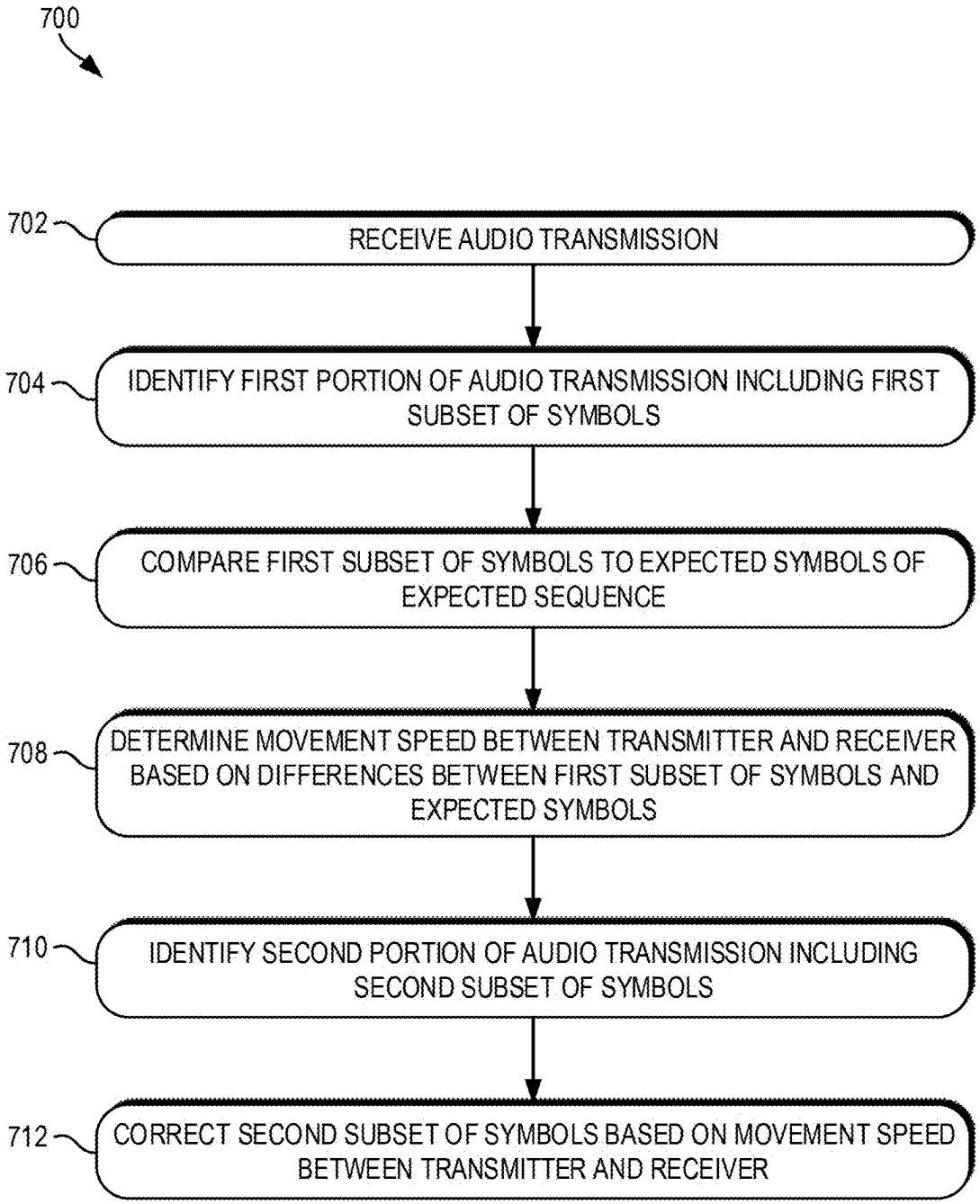

700
702
RECEIVE AUDIO TRANSMISSION
704
IDENTIFY FIRST PORTION OF AUDIO TRANSMISSION INCLUDING FIRST SUBSET OF SYMBOLS
706
COMPARE FIRST SUBSET OF SYMBOLS TO EXPECTED SYMBOLS OF EXPECTED SEQUENCE
708
DETERMINE MOVEMENT SPEED BETWEEN TRANSMITTER AND RECEIVER BASED ON DIFFERENCES BETWEEN FIRST SUBSET OF SYMBOLS AND EXPECTED SYMBOLS
710
IDENTIFY SECOND PORTION OF AUDIO TRANSMISSION INCLUDING SECOND SUBSET OF SYMBOLS
712
CORRECT SECOND SUBSET OF SYMBOLS BASED ON MOVEMENT SPEED BETWEEN TRANSMITTER AND RECEIVER

FIG. 7

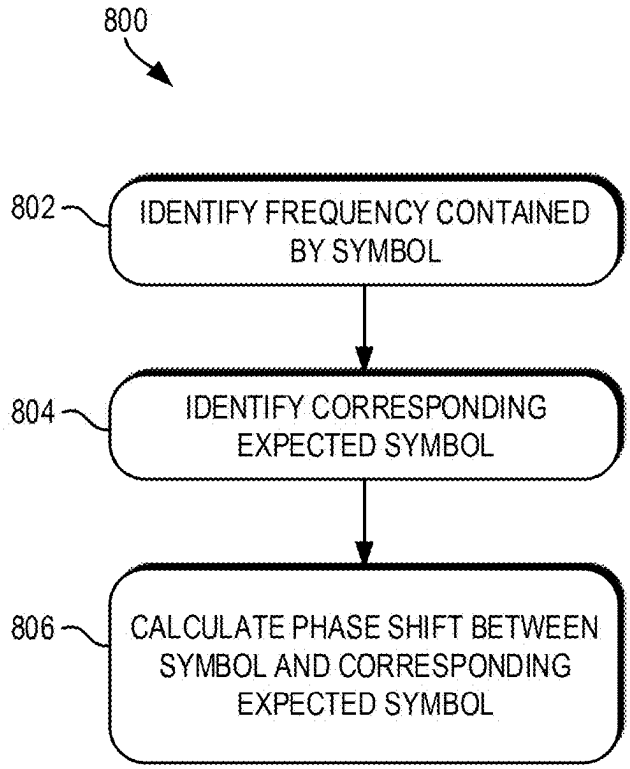

800
802
IDENTIFY FREQUENCY CONTAINED BY SYMBOL
804
IDENTIFY CORRESPONDING EXPECTED SYMBOL
806
CALCULATE PHASE SHIFT BETWEEN SYMBOL AND CORRESPONDING EXPECTED SYMBOL

FIG. 8

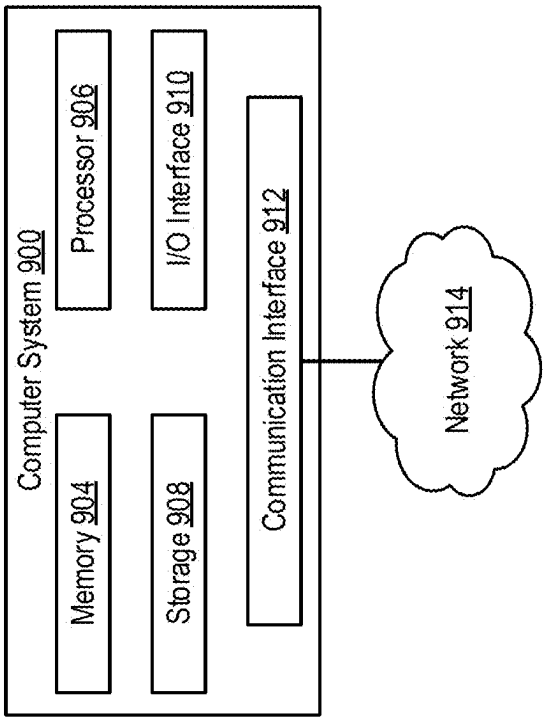

Computer System 900
Processor 906
I/O Interface 910
Memory 904
Storage 908
Communication Interface 912
Network 914

FIG. 9

PHASE SHIFT DETECTION AND CORRECTION FOR AUDIO-BASED DATA TRANSMISSIONS

CROSS-REFERENCE TO RELATED APPLICATIONS

[0001] The present application is a continuation of U.S. patent application Ser. No. 17/756,351 filed May 23, 2022, which is a national phase of International Pat. App. PCT/US2019/062823 filed Nov. 22, 2019. The content of each application is incorporated herein by reference.

BACKGROUND

[0002] Data often needs to be transmitted between computing devices without connecting both devices to the same computing network. For example, in certain applications, a computing network may not exist near the computing devices, or it may be too cumbersome (e.g., may take too long) to connect one or both of the computing devices to a nearby computing network. Therefore, data may be transmitted directly from one computing device to another computing device.

SUMMARY

[0003] The present disclosure presents new and innovative methods and systems for correcting distortions of audio signals. In one embodiment, a method is provided comprising receiving an audio transmission including symbols, at least a portion of the symbols corresponding to data modulated onto a carrier signal for transmission by the audio transmission and identifying a first portion of the audio transmission including a first subset of the symbols, the first portion of the audio transmission corresponding to an expected sequence having expected symbols. The method may further include comparing the first subset of the symbols to the expected symbols to identify one or more differences between the first subset of the symbols and the expected symbols and determining, based on the one or more differences between the first subset of the symbols and the expected symbols, a movement speed between a transmitter of the audio transmission and a receiver of the audio transmission. The method may also include identifying a second portion of the audio transmission different from the first portion of the audio transmission, the second portion of the audio transmission including a second subset of the symbols and correcting the second subset of the symbols based on the movement speed between the transmitter and the receiver.

[0004] In a second aspect according to the first aspect, identifying the one or more differences between the first subset of the symbols and the expected symbols comprises identifying a phase difference between at least one of the first subset of the symbols and at least one of the expected symbols.

[0005] In a third aspect according to the second aspect, the expected symbols contain expected frequencies. Comparing the first subset of the symbols to the expected symbols to identify one or more differences between the first subset of the symbols and the expected symbols may further comprise, for each symbol of the first subset of the symbols identifying a first frequency contained by the symbol, identifying a corresponding expected symbol from among the expected symbols that contains an expected frequency with the same or similar frequency as the first frequency, and calculating a phase difference between the symbol and the corresponding expected symbol.

[0006] In a fourth aspect according to any of the second and third aspects correcting the second subset of the symbols comprises calculating, based on the phase difference between the at least one of the first symbol and the expected symbols, one or more phase corrections for the second subset of the symbols and correcting a phase of at least one of the second subset of the symbols according to the phase correction.

[0007] In a fifth aspect according to the fourth aspect, calculating one or more phase corrections for the second subset of the symbols comprises calculating a phase drift between consecutive symbols of the expected symbols and calculating the one or more phase corrections for the second subset of the symbols based on the phase drift.

[0008] In a sixth aspect according to the fifth aspect, the phase drift is calculated such that the phase corrections change linearly for consecutive symbols of the expected symbols.

[0009] In a seventh aspect according to any of the first through sixth aspects, determining the movement speed comprises determining a correlation between the differences and determining the movement speed based on the correlation.

[0010] In an eighth aspect according to any of the first through seventh aspects, the movement speed is determined to represent movement of at least one of the transmitter and the receiver along an axis extending between the transmitter and the receiver.

[0011] In a ninth aspect according to any of the first through eighth aspects, the transmitter initially generates the first portion of the audio transmission to be identical to the expected sequence.

[0012] In a tenth aspect according to the ninth aspect, the first portion of the audio transmission is a preamble of the audio transmission indicating a beginning of the audio transmission.

[0013] In an eleventh aspect according to the ninth aspect, the first portion of the audio transmission is a training sequence of the audio transmission different from a preamble of the audio transmission indicating a beginning of the audio transmission.

[0014] In a twelfth aspect according to any of the first through eleventh aspect, the second portion of the audio transmission includes the portion of the symbols corresponding to the data.

[0015] In a thirteenth aspect, a system is provided comprising a processor and a memory. The memory may store instructions which, when executed by the processor, cause the processor to receive an audio transmission including symbols, at least a portion of the symbols corresponding to data modulated onto a carrier signal for transmission by the audio transmission and identify a first portion of the audio transmission including a first subset of the symbols, the first portion of the audio transmission corresponding to an expected sequence having expected symbols. The memory may store further instructions which, when executed by the processor, cause the processor to compare the first subset of the symbols to the expected symbols to identify one or more differences between the first subset of the symbols and the expected symbols and determine, based on the one or more differences between the first subset of the symbols and the

expected symbols, a movement speed between a transmitter of the audio transmission and a receiver of the audio transmission. The memory may store still further instructions which, when executed by the processor, cause the processor to identify a second portion of the audio transmission different from the first portion of the audio transmission, the second portion of the audio transmission including a second subset of the symbols and correct the second subset of the symbols based on the movement speed between the transmitter and the receiver.

[0016] In a fourteenth aspect according to the thirteenth aspect, the memory stores further instructions which, when performed by the processor while identifying the one or more differences between the first subset of the symbols and the expected symbols, cause the processor to identify a phase difference between at least one of the first subset of the symbols and at least one of the expected symbols.

[0017] In a fifteenth aspect according to the fourteenth aspect, the expected symbols contain expected frequencies. The memory may store further instructions which, when performed by the processor while comparing the first subset of the symbols to the expected symbols to identify one or more differences between the first subset of the symbols and the expected symbols cause the processor to, for each symbol of the first subset of the symbols identify a first frequency contained by the symbol, identify a corresponding expected symbol from among the expected symbols that contains an expected frequency with the same or similar frequency as the first frequency, and calculate a phase difference between the symbol and the corresponding expected symbol.

[0018] In a sixteenth aspect according to any of the fourteenth and fifteenth aspects, the memory stores further instructions which, when performed by the processor while correcting the second subset of the symbols, cause the processor to calculate, based on the phase difference between the at least one of the first symbol and the expected symbols, one or more phase corrections for the second subset of the symbols and correct a phase of at least one of the second subset of the symbols according to the phase correction.

[0019] In the seventeenth aspect according to the sixteenth aspect, the memory stores further instructions which, when performed by the processor while calculating one or more phase corrections for the second subset of the symbols, cause the processor to calculate a phase drift between consecutive symbols of the expected symbols and calculate the one or more phase corrections for the second subset of the symbols based on the phase drift.

[0020] In an eighteenth aspect according to any of the thirteenth through seventeenth aspects, the memory stores further instructions which, when performed by the processor while determining the movement speed, cause the processor to determine a correlation between the differences and determine the movement speed based on the correlation.

[0021] In a nineteenth aspect according to any of the thirteenth through eighteenth aspects, the movement speed is determined to represent movement of at least one of the transmitter and the receiver along an axis extending between the transmitter and the receiver.

[0022] In a twentieth aspect, a non-transitory, computer-readable medium is provided storing instructions which, when executed by a processor, cause the processor to receive an audio transmission including symbols, at least a portion of the symbols corresponding to data modulated onto a carrier signal for transmission by the audio transmission and identify a first portion of the audio transmission including a first subset of the symbols, the first portion of the audio transmission corresponding to an expected sequence having expected symbols. The non-transitory, computer-readable medium may store further instructions which, when executed by a processor, cause the processor to compare the first subset of the symbols to the expected symbols to identify one or more differences between the first subset of the symbols and the expected symbols and determine, based on the one or more differences between the first subset of the symbols and the expected symbols, a movement speed between a transmitter of the audio transmission and a receiver of the audio transmission. The non-transitory, computer-readable medium may store still further instructions which, when executed by a processor, cause the processor to identify a second portion of the audio transmission different from the first portion of the audio transmission, the second portion of the audio transmission including a second subset of the symbols and correct the second subset of the symbols based on the movement speed between the transmitter and the receiver.

[0023] The features and advantages described herein are not all-inclusive and, in particular, many additional features and advantages will be apparent to one of ordinary skill in the art in view of the figures and description. Moreover, it should be noted that the language used in the specification has been principally selected for readability and instructional purposes, and not to limit the scope of the disclosed subject matter.

BRIEF DESCRIPTION OF THE FIGURES

[0024] FIG. **1** illustrates a system according to an exemplary embodiment of the present disclosure.

[0025] FIG. **2** illustrates an audio transmission according to an exemplary embodiment of the present disclosure.

[0026] FIG. **3** illustrates a plot of phase shifted audio transmissions according to an exemplary embodiment of the present disclosure.

[0027] FIG. **4** illustrates a plot of a preamble according to an exemplary embodiment of the present disclosure.

[0028] FIG. **5** illustrates a plot of phase differences according to an exemplary embodiment of the present disclosure.

[0029] FIG. **6** illustrates a system according to an exemplary embodiment of the present disclosure.

[0030] FIG. **7** illustrates a method according to an exemplary embodiment of the present disclosure.

[0031] FIG. **8** illustrates a method according to exemplary embodiments of the present disclosure.

[0032] FIG. **9** illustrates a computing system according to an exemplary embodiment of the present disclosure.

DETAILED DESCRIPTION OF EXAMPLE EMBODIMENTS

[0033] Aspects of the present disclosure relate to phase shift correction of audio transmissions that are used to transmit data between computing devices.

[0034] Various techniques and systems exist to exchange data between computing devices without connecting to the same communication network. For example, the computing devices may transmit data via direct communication links between the devices. In particular, data may be transmitted

according to one or more direct wireless communication protocols, such as Bluetooth®, ZigBee®, Z-Wave®, Radio-Frequency Identification (RFID), Near Field Communication (NFC), and Wi-Fi® (e.g., direct Wi-Fi® links between computing devices). However, each of these protocols relies on data transmission using electromagnetic waves at various frequencies. Therefore, in certain instances (e.g., ZigBee®, Z-Wave®, RFID, and NFC), computing devices may typically require specialized hardware to transmit data according to these wireless communication protocols. In further instances (e.g., Bluetooth®, ZigBee®, Z-Wave®, and Wi-Fi®), computing devices may typically have to be communicatively paired in order to transmit data according to these wireless communication protocols. Such communicative pairing can be cumbersome and slow, reducing the likelihood that users associated with one or both of the computing devices will utilize the protocols to transmit data.

[0035] Therefore, there exists a need to wireless transmit data in a way that (i) does not require specialized hardware and (ii) does not require communicative pairing prior to data transmission. One solution to this problem is to transmit data using audio transmissions. For example, FIG. **1** illustrates a system **100** according to an exemplary embodiment of the present disclosure. The system **100** includes two computing devices **102**, **104** configured to transmit data **122**, **124** using audio transmissions **114**, **116**. In particular, each computing device **102**, **104** includes a transmitter **106**, **108** and a receiver **110**, **112**. The transmitters **106**, **108** may include any type of device capable of generating audio signals, such as speakers. In certain implementations, the transmitters **106**, **108** may be implemented as a speaker built into the computing device **102**, **104**. For example, one or both of the computing devices may be a smart phone, tablet computer, and/or laptop with a built-in speaker that performs the functions of the transmitter **106**, **108**. In other implementations, the transmitters **106**, **108** may be implemented as a speaker external to the computing device **102**, **104**. For example, the transmitters **106**, **108** may be implemented as one or more speakers externally connected to the computing device **102**, **104**.

[0036] The receivers **110**, **112** may include any type of device capable of receiving audio transmissions and converting the audio transmissions into signals (e.g., digital signals) capable of being processed by a processor of the computing device, such as microphones. In other implementations, the receivers **110**, **112** may be implemented as a microphone built into the computing device **102**, **104**. For example, one or both of the computing devices may be a smart phone, tablet computer, and/or laptop with a built-in microphone that performs the functions of the receivers **110**, **112**. In other implementations, the receivers **110**, **112** may be implemented as a microphone external to the computing device **102**, **104**. For example, the receivers **110**, **112** may be implemented as one or more microphones external to the computing device **102**, **104** that are communicatively coupled to the computing device **102**, **104**. In certain implementations, the transmitter **106**, **108** and receiver **110**, **112** may be implemented as a single device connected to the computing device. For example, the transmitter **106**, **108** and receiver **110**, **112** may be implemented as a single device containing both a speaker and a microphone that is communicatively coupled to the computing device **102**, **104**.

[0037] In certain implementations, one or both of the computing devices **102**, **104** may include multiple transmitters **106**, **108** and/or multiple receivers **110**, **112**. For example, the computing device **104** may include multiple transmitters **108** and multiple receivers **112** arranged in multiple locations so that the computing device **104** can communicate with the computing device **102** in multiple locations (e.g., when the computing device **102** is located near at least one of the multiple transmitters **108** and multiple receivers **112**). In additional or alternative implementations, one or both of the computing devices **102**, **104** may include multiple transmitters **106**, **108** and/or multiple receivers **110**, **112** in a single location. For example, the computing device **104** may include multiple transmitters **108** and multiple receivers **112** located at a single location. The multiple transmitters **108** and multiple receivers **112** may be arranged to improve coverage and/or signal quality in an area near the single location. For example, the multiple transmitters **108** and multiple receivers **112** may be arranged in an array or other configuration so that other computing devices **102** receive audio transmissions **114**, **116** of similar quality regardless of their location relative to the transmitters **108** and receivers **112** (e.g., regardless of the location of the computing devices **102** within a service area of the transmitters **108** and receivers **112**).

[0038] The computing devices **102**, **104** may generate audio transmissions **114**, **116** to transmit data **122**, **124** to one another. For example, the computing devices **102** may generate one or more audio transmissions **114** to transmit data **122** from the computing device **102** to the computing device **104**. As another example, the computing device **104** may generate one or more audio transmissions **116** to transmit data **124** from the computing device **104** to the computing device **102**. In particular, the computing devices **102**, **104** may create one or more packets **118**, **120** based on the data **122**, **124** (e.g., including a portion of the data **122**, **124**) for transmission using the audio transmissions **114**, **116**. To generate the audio transmission **114**, **116**, the computing devices **102**, **104** may modulate the packets **118**, **120** onto an audio carrier signal. The computing devices **102**, **104** may then transmit the audio transmission **114**, **116** via the transmitter **106**, **108**, which may then be received by the receiver **110**, **112** of the other computing devices **102**, **104**. In certain instances (e.g., where the data **122**, **124** exceeds a predetermined threshold for the size of a packet **118**, **120**), the data **122**, **124** may be divided into multiple packets **118**, **120** for transmission using separate audio transmissions **114**, **116**.

[0039] Accordingly, by generating and transmitting audio transmissions **114**, **116** in this way, the computing devices **102**, **104** may be able to transmit data **122**, **124** to one another without having to communicatively pair the computing devices **102**, **104**. Rather, a computing device **102**, **104** can listen for audio transmissions **114**, **116** received via the receivers **110**, **112** from another computing device **102**, **104** without having to communicatively pair with the other computing device **102**, **104**. Also, because these techniques can utilize conventional computer hardware like speakers and microphones, the computing devices **102**, **104** do not require specialized hardware to transmit the data **122**, **124**.

[0040] However, transmitting data by audio transmissions includes other limitations. In particular, audio transmissions are susceptible to types of interference and/or distortions that are either not present or less prevalent for data transmissions by electromagnetic signals. For instance, when transmitting data by electromagnetic signals, movements of

a computing device transmitting the electromagnetic signals may cause negligible changes to the electromagnetic signals when received by another computing device. However, when data is transmitted using sound waves (e.g., using audio transmissions), movements of one or both of a transmitting and a receiving computing device may degrade the received sound waves. In particular, movements of the transmitting and/or receiving computing device may cause phase shifts within audio transmission, which can interfere with the synchronization and subsequent processing of the audio transmission, including extraction of data from the audio transmission.

[0041] Therefore, there exists a need to identify and correct phase shifting distortions for audio transmissions. One solution to this problem is to measure differences between a first portion of an audio transmission and a corresponding, predetermined audio sequence. For example, phase differences between the first portion of the audio transmission and the predetermined audio sequence may be measured to estimate a movement speed between a transmitter and a receiver of the audio transmission. A second portion of the audio transmission, such as a payload of the audio transmission, may be corrected based on the estimated movement speed between the transmitter and the receiver. In this way, the computing device that receives the audio transmission can properly account for phase shifts and/or time delays of received audio transmissions. Furthermore, because the correction is performed by the computing device receiving an audio transmission, these techniques can account for interference and disturbances that occur during or after transmission of the audio transmission without requiring special processing by the computing device that transmits the audio transmission.

[0042] FIG. **2** illustrates an audio transmission **200** according to an exemplary embodiment of the present disclosure. The audio transmission **200** may be used to transmit data from one computing device to another computing device. For example, referring to FIG. **1**, the audio transmission **200** may be an example implementation of the audio transmissions **114**, **116** generated by the computing devices **102**, **104**. The audio transmission **200** includes multiple symbols **1-24**, which may correspond to discrete time periods within the audio transmission **200**. For example, each symbol **1-24** may correspond to 2 ms of the audio transmission **200**. In other examples, the symbols **1-24** may correspond to other time periods within the audio transmission **200** (e.g., 1 ms, 10 ms, 20 ms, 40 ms). Each symbol **1-24** may include one or more frequencies used to encode information within the audio transmission **200**. For example, the one or more frequencies may be modulated onto an audio channel (e.g., one or more predetermined carrier signals including a predetermined baseband signal such as a pulse-shaped complex number and/or a predetermined carrier frequency) in order to encode information in the audio transmission **200**. In particular, information may be encoded by modulating or varying the phase of the audio channel for each symbol **1-24**.

[0043] In particular, certain symbols **1-24** may correspond to particular types of information within the audio transmission **200**. For example, the symbols **1-6** may correspond to a preamble **202** and symbols **7-24** may correspond to a payload **204**. The preamble **202** may contain predetermined symbols produced at predetermined points of time (e.g., according to a predetermined phase difference pattern and/or frequency pattern). The preamble **202** may be used to identify the audio transmission **200** to a computing device receiving the audio transmission **200**. For example, a receiver of the computing device receiving audio transmissions such as the audio transmission **200** may also receive other types of audio data (e.g., audio data from environmental noises and/or audio interference). The preamble **202** may therefore be configured to identify audio data corresponding to the audio transmission **200** when received by the receiver of the computing device. In particular, the computing device may be configured to analyze incoming audio data from the receiver and to disregard audio data that does not include the preamble **202**. Upon detecting the preamble **202**, the computing device may begin receiving and processing the audio transmission **200**. The preamble may also be used to align processing of the audio transmission **200** with the symbols **1-24** of the audio transmission **200**. In particular, by indicating the beginning of the audio transmission **200**, the preamble **202** may enable the computing device receiving the audio transmission **200** to properly align its processing of the audio transmission with the symbols **1-24**.

[0044] The payload **204** may include the data intended for transmission, along with other information enabling proper processing of the data intended for transmission. In particular, the packets **208** may contain data desired for transmission by the computing device generating the audio transmission **200**. For example, and referring to FIG. **1**, the packet **208** may correspond to the packets **118**, **120** which may contain all or part of the data **122**, **124**. The header **206** may include additional information for relevant processing of data contained within the packet **208**. For example, the header **206** may include routing information for a final destination of the data (e.g., a server external to the computing device receiving the audio transmission **200**). The header **206** may also indicate an originating source of the data (e.g., an identifier of the computing device transmitting the audio transmission **200** and/or a user associated with the computing device transmitting the audio transmission **200**).

[0045] The preamble **202** and the payload **204** may be modulated to form the audio transmission **200** using similar encoding strategies (e.g., similar encoding phases). Accordingly, the preamble **202** and the payload **204** may be susceptible to similar types of interference (e.g., similar types of frequency-dependent attenuation and/or similar types of frequency-dependent delays). Proper extraction of the payload **204** from the audio transmission **200** may rely on proper demodulation of the payload **204** from an audio carrier signal and proper recognition of phase differences for the symbols of the payload. Therefore, to accurately receive the payload **204**, the computing device receiving the audio transmission **200** must account for the interference.

[0046] Symbols **1-24** and their configuration depicted in FIG. **2** are merely exemplary. It should be understood that certain implementations of the audio transmission **200** may use more or fewer symbols, and that one or more of the preamble **202**, the payload **204**, the header **206**, and/or the packet **208** may use more or fewer symbols than those depicted and may be arranged in a different order or configuration within the audio transmission **200**.

[0047] FIG. **3** illustrates a plot **300** of phase shifted audio transmissions according to an exemplary embodiment of the present disclosure. The plot **300** includes signals **302**, **304**, which may correspond to two different signals. In particular, the signals **302**, **304** may correspond to symbols of an audio

transmission. For example, the signal **302** may represent an expected signal contained by a symbol of an audio transmission (e.g., the preamble or other training sequence of the audio transmission) and the signal **304** may represent a received signal contained by the symbol of the audio transmission (e.g., the signal as actually received by a receiving computing device).

[0048] As depicted, both signals **302**, **304** have the same frequency. However, the signal **304** occurs after signal **302** (i.e., the signal **304** is phase shifted relative to the signal **302**). In particular, the signal **304** is delayed by a phase shift **306** relative to the signal **302**. As explained above, the phase shift **306** may be caused by movement between a transmitter and a receiver of the audio transmission. In particular, if the transmitter is moving away from the receiver and/or if the receiver is moving away from the transmitter, a phase shift **306** resulting in a delay of the signal **304** may occur.

[0049] Other types of phase shifts may also occur. For example, in other instances, a phase shift may result in the signal **304** occurring before the signal **302**. For example, if the computing device transmitting the audio signal moves toward the computing device receiving the audio signal and/or the computing device receiving the audio signal moves toward the computing device transmitting the audio signal, a phase shift may result that causes the signal **304** to occur earlier than the signal **302**.

[0050] As explained above, phase shifts may be used to encode information in audio transmissions. Phase shifts may similarly be used in the symbols of the preamble of audio transmissions. For example, FIG. **3** illustrates a plot **400** of desired phase differences for a preamble according to an exemplary embodiment of the present disclosure. Referring to FIG. **2**, the preamble may correspond to a preamble **202** of an audio transmission **200** transmitted by a computing device. The plot **400** indicates the relative phase differences between signals received at multiple times within an audio transmission (e.g., within the preamble of a received audio transmission). The times T**1**-T**6** may correspond to symbols of a received audio transmission. For example, and referring again to FIG. **2**, the times T**1**-T**6** may correspond to the symbols **1**-**6** of the preamble **202**.

[0051] When an audio transmission is initially transmitted, each time T**1**-T**6** may correspond to a signal with a corresponding, predetermined phase difference (e.g., a phase difference caused by a phase shift relative to the first symbol of the preamble). The plot **400** indicates these phase differences at times T**1**-T**6** corresponding to the symbols **1**-**6**. In particular, the plot **400** indicates the phase differences (in radians) relative to the phase of the signal received at time T**1**. As depicted, the signals received at times T**1**-T**6** have phase differences that decrease. Namely, the phase differences decrease by 0.25 radians for each subsequent time T**1**-T**6** (e.g., for subsequent symbols) and decrease from a phase difference of 0 radians at time T**1** to a phase difference of −1.25 radians at time T**6**. These phase differences may be predetermined (e.g., predetermined to indicate the presence of an audio transmission.

[0052] As depicted, the preamble includes six predetermined phase differences that decrease in frequency from time T**1** to time T**6**. However, other configurations may include additional or fewer predetermined signals with phase differences (e.g., additional or fewer symbols in the preamble). Further, the predetermined phase differences may follow alternative patterns. In particular, other implementations may include predetermined phase differences that increase in frequency over time, or that follow any other pattern or progression over time. Also, the depicted plot **400** may correspond to a portion of the audio transmission other than the preamble, such as a portion of the header of the audio transmission.

[0053] In still further embodiments, rather than containing symbols with known phase differences of the audio carrier signal, the preamble may include symbols containing corresponding, predetermined frequencies. For example, each time T**1**-T**6** may correspond to known frequencies for the corresponding symbols **1**-**6**. The frequencies for the symbols of the preamble may correspond to a known pattern of the preamble (e.g., descending frequencies, ascending frequencies, and/or another frequency patterns).

[0054] To account for movement of one or both of the receiving computing device and the transmitting computing device, computing devices receiving audio transmissions may estimate a movement speed between the transmitting and receiving computing devices. To do so, computing devices receiving audio transmissions may, determine a phase shift of one or more symbols of the audio transmission.

[0055] Phase shifts such as the phase shift **406** may occur for multiple symbols in an audio transmission. For example, FIG. **5** illustrates a plot **500** of phase differences according to an exemplary embodiment of the present disclosure. The plot **500** includes lines **502**, **504**, **506** that correspond to audio transmissions with different movement speeds. For example, the line **502** may correspond to an audio transmission where the transmitter is moving away from the receiver and/or where the receiver is moving away from the transmitter. The line **504** may correspond to an audio transmission with minimal movement of the transmitter and receiver. The line **506** may correspond to an audio transmission where the transmitter is moving toward the receiver and/or where the receiver is moving toward transmitter.

[0056] The plot **500** depicts changes in the phase differences for six symbols of the audio transmissions and different scenarios, each scenario corresponding to a line **502**, **504**, **506**. The six symbols may correspond to a preamble of the audio transmission, such as symbols **1**-**6** of the preamble **202**. The six symbols may also correspond to another portion of the audio transmission, such as a training sequence or other expected sequence within the audio transmission. The phase differences may be measured by comparing received signals for the symbols of the audio transmission to expected signals for the symbol of the audio transmission (e.g., to an expected phase of a signal of the symbol of the preamble **202**). For example, the phase differences for the lines **502**, **504**, **506** may be determined by comparing received audio transmissions to expected audio transmissions, similar to determining the phase shift **306** of the plot **300**. In particular, the phase differences for the lines **502**, **504**, **506** may be determined by comparing the phases of signals received for each symbol to expected phases for the symbol (e.g., expected phases and/or phase differences, such as the phase differences indicated in the plot **400**). The phase differences as depicted in the plot **500** are measured in radians, where 2π radians represents a complete cycle of the signal (e.g., a peak-to-peak cycle of the signal. The phase differences may additionally or alternatively be measured according to other units. For example, the phase differences may be measured as a time difference between the expected

signal (e.g., the signal **402**) and the received signal (e.g., **404**). Positive phase differences may indicate delays (e.g., where the received audio transmission occurs later than the expected audio transmission), while negative phase difference may indicate the received audio transmission occurs before the expected audio transmission.

[0057] As shown, when the transmitter or receiver moves, the phase shift may change between symbols of the auditory transmission. For example, the phase differences for the audio transmission corresponding to line **502** increase for subsequent symbols of the audio transmission. In particular, the phase differences for the line **502** increase from about zero radians for the first symbol to about one radian for the sixth symbol. As another example, the phase differences for the audio transmission corresponding to the line **506** decrease for subsequent symbols. In particular, the phase differences for the line **506** decrease from about zero radians for the first symbol to about negative one radians for the sixth symbol. By contrast, the line **504** does not indicate a significant change in phase difference for subsequent symbols.

[0058] Accordingly, changes in phase difference between symbols of an audio transmission may indicate movement of one or both of the transmitter and the receiver. For example, the line **502** indicates increasing phase differences and is associated with an audio transmission involving a transmitter moving away from a receiver and/or a receiver moving away from a transmitter of the audio transmission. Therefore, increases in phase differences may indicate such movements of the transmitter and/or receiver. As another example, the line **506** indicates decreasing phase differences and is associated with an audio transmission involving a transmitter moving toward a receiver and/or a receiver moving toward a transmitter of the audio transmission. Therefore, decreases in phase difference may indicate such movements of the transmitter and/or receiver. Further, no or minimal changes to the phase difference may indicate minimal movement between the transmitter and receiver of an audio transmission. For example, the line **504** indicates minimal changes in phase differences and corresponds to an audio transmission with minimal movement of the transmitter and/or receiver.

[0059] Additionally, the rate of change of phase differences between symbols of an audio transmission may also indicate a speed of movement. For example, larger changes of phase differences between symbols of an audio transmission may indicate faster movement. As a specific example, a line increasing from a phase difference of zero for the first symbol to a phase difference of 0.5 radians for the sixth symbol may correspond to a scenario with slower movement (e.g., slower movement of the transmitter and/or receiver of the audio transmission) than the audio transmission corresponding to the line **502**. As another example, a line decreasing from a phase difference of zero for the first symbol to a phase difference of −0.5 radians for the sixth symbol may correspond to a scenario with slower movement than the audio transmission corresponding to the line **506**.

[0060] The lines **502**, **504**, **506** may be determined based on determined differences for symbols from received audio transmissions. For example, differences **508**, **510**, **512**, **514**, **516**, **518**, **520**, **522**, **524** may be identified for the six symbols of received audio transmissions. Only a subset of the differences **508**, **510**, **512**, **514**, **516**, **518**, **520**, **522**, **524** include corresponding reference numbers, but it should be understood that measurements may be made for all six symbols of the received transmissions. The line **502**, **504**, **506** may then be identified based on the differences **508**, **510**, **512**, **514**, **516**, **518**, **520**, **522**, **524** for the received transmission. For example, the line **502**, **504**, **506** may be determined by finding a correlation (e.g., a line of best fit or other statistical correlation) for the differences **508**, **510**, **512**, **514**, **516**, **518**, **520**, **522**, **524**. The lines **502**, **504**, **506** may then be utilized to determine whether the transmitter and/or receiver of an audio transmission moved.

[0061] FIG. **6** illustrates a system **600** according to an exemplary embodiment of the present disclosure. The system **600** may be configured to detect and correct for interference of audio transmissions resulting from movement of the transmitter and/or receiver of the audio transmission. The system **600** includes a computing device **602** and an audio transmission **604**. The computing device **602** may receive the audio transmission **604**. For example, the computing device **602** may be an exemplary implementation of one or both of the computing devices **102**, **104** and may receive the audio transmission **604** via a receiver **110**, **112**. The audio transmission **604** may be generated to contain data, e.g., data encoded into one or more symbols of at least a portion of the audio transmission **604**. For example, the data may be contained in a packet included with the audio transmission **604**.

[0062] However, during transmission of the audio transmission **604**, the transmitter and/or receiver of the audio transmission **604** may move relative to one another. In particular, the transmitter and/or receiver may move along an axis that connects the transmitter and receiver (e.g., may experience movement along a "line of sight" between the transmitter and the receiver). This type of movement may cause interference with the audio transmission **604**, which may result in, e.g., phase shifts for symbols of the audio transmission. These phase shifts may result in inaccuracies during subsequent processing of the audio transmission **604** (e.g., subsequent demodulation and/or extraction of data stored within the audio transmission **604**). Therefore, to maximize the accuracy of such subsequent processing, it may be necessary to detect and correct for movement of the transmitter and/or receiver of the audio transmission.

[0063] To detect movement of transmitter and/or receiver, the computing device **602** may identify a first portion **606** of the audio transmission **604**. The first portion **606** may be identified as a part of the audio transmission **604** that corresponds to an expected sequence **610**. The expected sequence **610** may contain one or more symbols that occur at known times and contain signals having a known frequency and/or phase. In particular, the expected sequence **610** may contain signals that the first portion **606** was generated to include (e.g., before transmission and reception of the audio transmission **604**). In certain implementations, the first portion **606** may correspond to the preamble of the audio transmission **604** and the expected sequence **610** may contain the preamble as generated prior to transmission of the audio transmission. In additional or alternative implementations, the first portion **606** may correspond to other parts of the audio transmission **604**. For example, the audio transmission **604** may include one or more training sequences in addition or alternatively to the preamble. The training sequences may include symbols containing known

frequencies at known phases. The training sequences may therefore be identified as the first portion **606** of the audio transmission **604**.

[0064] The computing device **602** may also identify one or more phase differences **612** between the first portion **606** and the expected sequence **610**. The computing device **602** may identify the phase differences **612** on a per-symbol basis. For example, the computing device **602** may identify corresponding symbols of the first portion **606** and the expected sequence **610** and may identify the one or more phase differences **612** between the corresponding symbols. The phase differences **612** may be determined by comparing the signals of the corresponding symbols and determining an amount by which the phase of the symbol from the first portion **606** differs from the phase of the symbol from the expected sequence **610**.

[0065] The computing device **602** may also determine a movement speed **614** between the transmitter and the receiver of the audio transmission **604**. For example, the movement speed **614** may indicate whether the transmitter and/or receiver are moving closer together or whether the transmitter and/or receiver are moving farther apart. In particular, the movement speed **614** may indicate whether the transmitter and/or receiver are moving closer together or farther apart along an axis connecting the transmitter and the receiver. The movement speed **614** may also indicate an estimate of the magnitude of movement speed **614** (e.g., how fast the transmitter and/or receiver are moving relative to one another) between the transmitter and the receiver of the audio transmission **604**. To determine the movement speed **614**, the computing device **602** may analyze how the phase differences change between corresponding symbols of the first portion **606** and the expected sequence **610**. For example, the computing device **602** may determine that the transmitter and receiver are moving farther apart if the phase differences **612** between the first portion **606** and the expected sequence **610** increase for subsequent symbols. As another example, the computing device **602** may determine that the transmitter and receiver are moving closer together if the phase differences **612** between the first portion **606** and the expected sequence **610** decrease for subsequent symbols. The computing device **602** may further determine the magnitude of the movement speed **614** based on the rate of change of the phase differences **612**. In particular, as further explained above, if the phase differences **612** increase or decrease at a greater rate between the corresponding symbols of the first portion **606** and the expected sequence **610**, the computing device **602** may determine that the movement speed **614** is larger (e.g., that the transmitter and/or receiver are moving faster relative to one another).

[0066] The computing device **602** may also correct phase shifts within the audio transmission **604**. For example, the computing device **602** may identify a second portion **608** of the audio transmission **604** and may correct phase difference of symbols within the second portion **608**. The second portion **608** may include one or more portions of the audio transmission **604** not included in the first portion **606**. For example, the second portion **608** may include all or part of the payload of the audio transmission **604**. As another example, the second portion **608** may be selected to include at least a portion of data included within the audio transmission. In certain implementations, the second portion **608** may include all of the audio transmission **604** (e.g., to correct phase shifts for the entire audio transmission **604**).

[0067] The computing device **602** may calculate phase corrections **616** for the second portion **608**. The phase corrections **616** may be calculated to offset phase shifts within the second portion **608** caused by movement of the transmitter and/or receiver of the audio transmission **604**. The phase corrections **616** may therefore be calculated according to the movement speed **614**. As illustrated in FIG. **5**, when the transmitter and/or receiver move further from one another, the phase differences **612** increase for subsequent symbols within audio transmissions. When the transmitter and/or receiver are moving closer to one another, the phase differences decrease for subsequent symbols within audio transmissions. Therefore, depending on the type of movement speed **614**, the computing device **602** may calculate the phase corrections **616** to increase or decrease for subsequent symbols within the second portion **608**. In particular, if the movement speed **614** indicates that the transmitter and/or receiver are moving further apart, the phase corrections **616** may be calculated to increase across the symbols of the second portion **608**. Also, if the movement speed **614** indicates that the transmitter and/or receiver are moving closer together, the phase corrections **616** may be calculated to decrease across the symbols of the second portion **608**.

[0068] The computing device **602** may then apply the phase corrections **616** to the second portion **608** to generate the corrected second portion **618**. The corrected second portion **618** may represent a version of the second portion **608** of the audio transmission **604** that is corrected to remove phase shifts caused by movement of the transmitter and/or receiver of the audio transmission **604**. Because the phase shifts are removed in the corrected second portion **618**, the corrected second portion **618** may represent a more accurate version of the second portion **608** and may therefore be utilized for subsequent processing (e.g., processing to extract stored data and/or packets from the audio transmission **604**). To generate the corrected second portion **618**, the computing device **602** may apply the phase corrections **616** to the symbols of the second portion **608**. In applying the phase corrections **616**, the computing device **602** may offset or otherwise adjust timing information of the signals contained by the symbols of the second portion **608**. For example, the computing device **602** may identify a corresponding phase correction from the phase corrections **616** for a symbol of the second portion **608** and may apply the corresponding phase correction to the symbol by adjusting the timing information of the signal according to the corresponding phase correction. This procedure may be repeated for all or part of the symbols within the second portion **608** to generate the corrected second portion.

[0069] The computing device **602** may be implemented by a computing system. For example, although not depicted, the computing device **602** may contain a processor and a memory that implement at least one operational feature of the computing device **602**. For example, the memory may contain instructions which, when executed by the processor, cause the processor to implement at least one operational feature of the computing device **602**.

[0070] FIG. **7** illustrates a method **700** according to an exemplary embodiment of the present disclosure. The method **700** may be performed to determine a movement speed of a transmitter and/or receiver of an audio transmission and to correct interference for at least a portion of the audio transmission caused by the movement of the trans-

mitter and/or receiver. The method **700** may be implemented on a computer system, such as the system **600**. For example, the method **700** may be implemented by the computing device **602**. The method **700** may also be implemented by a set of instructions stored on a computer readable medium that, when executed by a processor, cause the computer system to perform the method. For example, all or part of the method **700** may be implemented by a CPU and a memory of the computing device **602**. Although the examples below are described with reference to the flowchart illustrated in FIG. **7**, many other methods of performing the acts associated with FIG. **7** may be used. For example, the order of some of the blocks may be changed, certain blocks may be combined with other blocks, one or more of the blocks may be repeated, and some of the blocks described may be optional.

[0071] The method **700** may begin with receiving an audio transmission (block **702**). For example the computing device **602** may receive an audio transmission **604** containing data. The audio transmission **604** may include multiple symbols which contain symbols encoding or otherwise containing data and/or other information for transmission by the audio transmission **604**. A first portion of the audio transmission may be identified containing a first subset of symbols (block **704**). For example, the computing device **602** may identify a first portion **606** of the audio transmission **604**. The first portion **606** may contain a first subset of the symbols of the audio transmission **604**. For example, the first subset of the symbols contained by the first portion **606** may correspond to a known set of symbols. In particular, the first portion **606** may have initially been generated (e.g., before transmission) to be identical to or to resemble an expected sequence **610** containing expected symbols that are known prior to receiving the audio transmission **604**. For example, the expected sequence **610** may be the same for each received audio transmission **604** and/or may change according to a known pattern for each received audio transmission **604**. Accordingly, the computing device **602** may store a copy of the expected sequence **610** corresponding to the first portion **606**.

[0072] The first subset of the symbols may be compared to the expected symbols of the expected audio sequence (block **706**). For example, the computing device **602** may compare the first subset of symbols from the first portion **606** to the expected symbols of the expected sequence **610**. In comparing the first subset of symbols to the expected symbols, the computing device **602** may identify one or more differences between the first subset of symbols and the expected symbols. In particular, the computing device **602** may compare symbols from the first subset of symbols to corresponding symbols from the expected symbols and may identify one or more differences between the symbols of the received audio transmission and the corresponding symbols from the expected symbols. In certain implementations, the differences may include phase differences between the first subset of symbols and the expected symbols. Further details regarding comparisons between the first subset of symbols and the expected symbols are discussed below in connection with the method **800** and FIG. **8**.

[0073] A movement speed between the transmitter and receiver of the audio transmission may then be identified based on the differences between the first subset of symbols and the expected symbols (block **708**). As explained above, the differences between the first subset of symbols and the expected symbols may include phase differences between the first subset of symbols and the expected symbols and may therefore indicate phase shifts during transmission of the audio transmission **604**. As explained above, the phase shifts may be caused by movement between the transmitter and receiver (e.g., the transmitter and/or receiver moving further away from or closer to one another). In particular, such phase shifts may be caused by movement of the transmitter and/or receiver along an axis connecting the transmitter and receiver (e.g., "line of sight" movement of the transmitter and/or receiver).

[0074] Changes in the phase differences for subsequent symbols of the first subset of symbols and the expected symbols may therefore indicate movement of the transmitter and/or receiver. Therefore, the computing device **602** may analyze changes in the phase differences for subsequent symbols to determine the movement speed. In particular, the computing device **602** may identify a correlation for the phase differences, such as the lines **502**, **504**, **506**, and may identify phase drifts between the symbols as changes to the phase differences between the symbols. The computing device may then use the rate of change (e.g., the slope) of the correlation to determine the movement speed **614** of the transmitter and/or receiver. In particular, if $\Delta\theta$ represents the phase drift per symbol, the velocity may be determined as

$$v = \frac{\Delta\theta}{2\pi}\lambda/T_{symbol},$$

where λ represents the wavelength of the carrier signal of the audio transmission **604** and T_{symbol} represents the duration of each symbol. For example, as depicted, the phase drift $\Delta\theta$ for line **502** is about 0.15 radians/symbol. The duration of each symbol T_{symbol} may be 2 ms and, assuming a 18.6 kHz carrier frequency, the carrier signal wavelength is about 0.7 inches. In such a scenario, the velocity may be determined as

$$v = \frac{0.15}{2\pi}0.7 \text{ in}/2 \text{ ms} \cong 11.1 \text{ in}/sec.$$

As explained further above, a positive movement speed **614** may indicate that the transmitter and/or receiver of the audio transmission **604** are moving further from one another and a negative movement speed **614** may indicate that the transmitter and/or receiver of the audio transmission **604** are moving closer to one another.

[0075] A second portion of the audio transmission may then be identified (block **710**). For example, the computing device **602** may identify a second portion **608** of the audio transmission **604**. The second portion **608** of the audio transmission may include a second subset of symbols of the audio transmission **604**. The second subset of symbols may differ at least in part from the first subset of symbols. As explained further above, the second portion **608** may correspond to a portion of the audio transmission **604** containing data for transmission. For example, the second portion **608** may contain a packet of data for transmission by the audio transmission **604**. Other implementations for selecting the second portion **608** are discussed above.

[0076] The second subset of symbols may be corrected based on the movement speed between the transmitter and

receiver (block **712**). For example, the computing device **602** may correct the second subset of symbols based on the movement speed **614**. In particular, the computing device **602** may correct the second subset of symbols by determining the different phase shifts for each symbol caused by the movement speed **614** of the transmitter and/or receiver (e.g., the changed phase shift for the second subset of symbols). For example, the computing device **602** may determine phase corrections **616** for the second subset of symbols. The phase corrections **616** may be determined based on the phase drift $\Delta\theta$ of the phase differences **612**.

[0077] For example, to determine the phase corrections **616**, the computing device **602** may project the phase differences **612** of the first subset of symbols for other symbols within the audio transmission **604** (e.g., earlier and/or later symbols within the audio transmission **604**). For example, where the first portion **606** is the preamble of the audio transmission **604** (e.g., symbols **1-6** of the audio transmission), the second portion may include the payload of the audio transmission **604** (e.g., symbols **7-24** of the audio transmission). To determine the phase corrections **616**, the computing device **602** may project the phase differences **612** of the first subset of symbols **1-6** to the second subset of symbols **7-24**. In certain implementations, the projection may be based on the correlation of the differences between the first subset of symbols and the expected symbols (e.g., the phase drift). For example, the computing device **602** may determine a phase difference, indicated by the correlation phase drift with for the first symbol (e.g., the symbol **7**). The phase correction **216** may then be identified to undo the phase difference. For example, the phase correction **216** may be identified as the opposite of the identified phase shift. As a specific example, if the phase difference of the symbol **7** is 1.2 radians, the phase correction **216** of the symbol may be −1.2 radians. The phase corrections **616** for subsequent symbols (e.g., symbols **8-24**) may be determined based on the phase correction **616** for the first symbol and the phase drift $\Delta\theta$ between consecutive symbols (e.g., so that the phase corrections **616** change linearly for consecutive symbols). For example, the phase correction **216** for symbol **8** may be determined by subtracting the phase drift per symbol **40** from the phase correction **216** for symbol **7** and the phase correction for symbol **9** may be determined by subtracting the phase drift per symbol $\Delta\theta$ from the phase correction **216** for symbol **8**. In certain implementations, the phase corrections **216** may be identified by first identifying phase differences for the second subset of symbols and then determining the phase corrections **216** to be the opposite of the phase shifts. In still further embodiments, phase corrections **216** may not be identified. Instead, phase differences may be identified for the second subset of symbols and the second subset of symbols may be corrected according to the identified phase differences.

[0078] Once the phase corrections **216** are determined, the second subset of symbols may be corrected by applying the phase corrections **216** to the second subset of symbols. For example, the computing device **602** may identify the phase corrections **216** corresponding to the second subset of symbols and may adjust the phase of the signals included in the symbols according to the corresponding phase correction **216**. For example, the computing device **602** may adjust timing information for the signals to shift the phase of the signals as indicated by the corresponding phase correction **216**. The corrected second subset of symbols may then be stored in a corrected second portion **618**, which may be utilized for subsequent processing of all or part of the audio transmission **604**. For example, the corrected second portion **618** may be used in subsequent processing to extract packets and/or data transmitted by the audio transmission **604**.

[0079] In describing the method **700** above, examples were given that involved processing an entire audio transmission during a single execution of the method **700**. However, in practice, at least portions the method **700** may be repeated separately for different parts of an audio transmission. For example, in addition or alternative to the preamble, the audio transmission may include one or more training sequences including expected symbols containing expected frequencies and expected phases. The method **700** may be repeated for each of the training sequences. For example, in addition to a preamble at symbols **1-6**, an audio transmission may include a training sequence halfway through the training sequence at symbols **13-18**. Blocks **704-712** may then be repeated twice to fully process the audio transmission **604**: (i) once with symbols **1-6** being identified as the first portion and symbols **7-12** identified as the second portion and (ii) once with symbols **13-18** identified as the first portion and symbols **19-24** identified as the second portion. Repetition of the blocks **704-712** may occur in sequence (e.g., the computing device **602** may perform iteration (i) and may then perform iteration (ii)) or in parallel (e.g., the computing device **602** may perform iterations (i) and (ii) at least in part at the same time).

[0080] Furthermore, in addition to the method **700**, the computing device **602** may implement additional error correction and/or detection systems for different types of interference that may impact the audio transmission **604**. For example, the computing device **602** may also include error correction and/or detection systems configured to address other types of movement of the receiver and/or transmitter (e.g., movements of the transmitter and/or receiver that occur orthogonal to an axis connecting the transmitter and receiver). To properly balance between the various error correction and/or detection systems, certain blocks of the method **700** may be optional. For example, in certain implementations the computing device **602** may not perform blocks **710-712** if the movement speed **614** does not exceed a predetermined threshold. In such implementations, when the movement speed **614** is below the predetermined threshold, movement of the transmitter and/or receiver may not introduce sufficient interference to justify the computational and/or processing delays of correcting the second subset of symbols. For example, the predetermined threshold may be set so that movement speeds at or above 1 inch per second are corrected according to the blocks **710-712**.

[0081] FIG. **8** illustrates a method **800** according to exemplary embodiments of the present disclosure. The methods **800** may be implemented on a computer system, such as the system **600**. For example, the methods **800** may be implemented by the computing device **602**. The methods **800** may also be implemented by a set of instructions stored on a computer readable medium that, when executed by a processor, cause the computer system to perform the method. For example, all or part of the methods **800** may be implemented by a CPU and a memory of the computing device **602**. Although the examples below are described with reference to the flowchart illustrated in FIG. **8**, many other methods of performing the acts associated with FIG. **8** may be used. For example, the order of some of the blocks may

be changed, certain blocks may be combined with other blocks, one or more of the blocks may be repeated, and some of the blocks described may be optional.

[0082] The method **800** may be performed to compare a first subset of symbols from an audio transmission to expected symbols from an expected sequence. For example, the method **800** may be performed to at least partially implement block **706** of the method **700**. The method **800** may begin with identifying a phase difference of a signal contained by a symbol (block **802**). For example, the computing device **602** may identify a phase difference of a signal contained by a symbol of the first portion **606** of the audio transmission **604**. As explained previously, each symbol may contain a signal with a phase-shifted carrier frequency. The phase shift may be identified by comparing the phase of the signal to the phase of a first symbol of the first portion **606** of the audio transmission **604** (e.g., the first symbol of the preamble).

[0083] A corresponding expected symbol may then be identified (block **804**). The corresponding expected symbol may be identified from an expected sequence **610** corresponding to the first portion **606**. The expected sequence **610** may include expected symbols containing identical or similar phase differences to the phase differences contained by the first portion **606** (e.g., prior to transmission of the audio transmission **604**). For example, the expected sequence **610** may be a copy of the first portion **606** as initially generated prior to transmission of the audio transmitter. The corresponding expected symbol may therefore be identified as they symbol from the expected symbols with a same or similar phase shift as of the symbol identified in block **702**. The same or similar phase shift may be identified as any phase shift that differs from the phase shift of the symbol by less than a predetermined threshold (e.g., 0.1 radians, 0.5 radians, 10% of the phase shift of the symbol, 20% of the phase shift of the symbol, 50% of the phase shift of the symbol) The corresponding expected symbol may additionally or alternatively be identified as the symbol from the expected symbols in the same symbol position as the symbol identified in block **702**. For example, the second symbol of the expected symbols may be identified as the corresponding symbol for the second symbol of the first portion **606**.

[0084] A phase difference may then be calculated between the symbol and the corresponding expected symbol (block **806**). For example, the computing device **602** may calculate the phase difference between the symbol and the corresponding expected symbol. The phase difference may be calculated, as depicted in FIG. **4**, as the difference in time or radians between the signal of the symbol and the signal of the corresponding expected symbol (e.g., the difference in time or radians between occurrences of one or more corresponding features of the signals, such as peaks of the signals).

[0085] The method **800** may be repeated to process multiple symbols from the first subset of symbols. For example, the method **800** may be performed to process each of the first subset of symbols.

[0086] FIG. **9** illustrates an example computer system **900** that may be utilized to implement one or more of the devices and/or components of FIG. **1**, such as the computing devices **102**, **104**, **602**. In particular embodiments, one or more computer systems **900** perform one or more steps of one or more methods described or illustrated herein. In particular embodiments, one or more computer systems **900** provide the functionalities described or illustrated herein. In particular embodiments, software running on one or more computer systems **900** performs one or more steps of one or more methods described or illustrated herein or provides the functionalities described or illustrated herein. Particular embodiments include one or more portions of one or more computer systems **900**. Herein, a reference to a computer system may encompass a computing device, and vice versa, where appropriate. Moreover, a reference to a computer system may encompass one or more computer systems, where appropriate.

[0087] This disclosure contemplates any suitable number of computer systems **900**. This disclosure contemplates the computer system **900** taking any suitable physical form. As example and not by way of limitation, the computer system **900** may be an embedded computer system, a system-on-chip (SOC), a single-board computer system (SBC) (such as, for example, a computer-on-module (COM) or system-on-module (SOM)), a desktop computer system, a laptop or notebook computer system, an interactive kiosk, a mainframe, a mesh of computer systems, a mobile telephone, a personal digital assistant (PDA), a server, a tablet computer system, an augmented/virtual reality device, or a combination of two or more of these. Where appropriate, the computer system **900** may include one or more computer systems **900**; be unitary or distributed; span multiple locations; span multiple machines; span multiple data centers; or reside in a cloud, which may include one or more cloud components in one or more networks. Where appropriate, one or more computer systems **900** may perform without substantial spatial or temporal limitation one or more steps of one or more methods described or illustrated herein. As an example and not by way of limitation, one or more computer systems **900** may perform in real time or in batch mode one or more steps of one or more methods described or illustrated herein. One or more computer systems **900** may perform at different times or at different locations one or more steps of one or more methods described or illustrated herein, where appropriate.

[0088] In particular embodiments, computer system **900** includes a processor **906**, memory **904**, storage **908**, an input/output (I/O) interface **910**, and a communication interface **912**. Although this disclosure describes and illustrates a particular computer system having a particular number of particular components in a particular arrangement, this disclosure contemplates any suitable computer system having any suitable number of any suitable components in any suitable arrangement.

[0089] In particular embodiments, the processor **906** includes hardware for executing instructions, such as those making up a computer program. As an example and not by way of limitation, to execute instructions, the processor **906** may retrieve (or fetch) the instructions from an internal register, an internal cache, memory **904**, or storage **908**; decode and execute the instructions; and then write one or more results to an internal register, internal cache, memory **904**, or storage **908**. In particular embodiments, the processor **906** may include one or more internal caches for data, instructions, or addresses. This disclosure contemplates the processor **906** including any suitable number of any suitable internal caches, where appropriate. As an example and not by way of limitation, the processor **906** may include one or more instruction caches, one or more data caches, and one or more translation lookaside buffers (TLBs). Instructions in

the instruction caches may be copies of instructions in memory **904** or storage **908**, and the instruction caches may speed up retrieval of those instructions by the processor **906**. Data in the data caches may be copies of data in memory **904** or storage **908** that are to be operated on by computer instructions; the results of previous instructions executed by the processor **906** that are accessible to subsequent instructions or for writing to memory **904** or storage **908**; or any other suitable data. The data caches may speed up read or write operations by the processor **906**. The TLBs may speed up virtual-address translation for the processor **906**. In particular embodiments, processor **906** may include one or more internal registers for data, instructions, or addresses. This disclosure contemplates the processor **906** including any suitable number of any suitable internal registers, where appropriate. Where appropriate, the processor **906** may include one or more arithmetic logic units (ALUs), be a multi-core processor, or include one or more processors **906**. Although this disclosure describes and illustrates a particular processor, this disclosure contemplates any suitable processor.

[0090] In particular embodiments, the memory **904** includes main memory for storing instructions for the processor **906** to execute or data for processor **906** to operate on. As an example, and not by way of limitation, computer system **900** may load instructions from storage **908** or another source (such as another computer system **900**) to the memory **904**. The processor **906** may then load the instructions from the memory **904** to an internal register or internal cache. To execute the instructions, the processor **906** may retrieve the instructions from the internal register or internal cache and decode them. During or after execution of the instructions, the processor **906** may write one or more results (which may be intermediate or final results) to the internal register or internal cache. The processor **906** may then write one or more of those results to the memory **904**. In particular embodiments, the processor **906** executes only instructions in one or more internal registers or internal caches or in memory **904** (as opposed to storage **908** or elsewhere) and operates only on data in one or more internal registers or internal caches or in memory **904** (as opposed to storage **908** or elsewhere). One or more memory buses (which may each include an address bus and a data bus) may couple the processor **906** to the memory **904**. The bus may include one or more memory buses, as described in further detail below. In particular embodiments, one or more memory management units (MMUs) reside between the processor **906** and memory **904** and facilitate accesses to the memory **904** requested by the processor **906**. In particular embodiments, the memory **904** includes random access memory (RAM). This RAM may be volatile memory, where appropriate. Where appropriate, this RAM may be dynamic RAM (DRAM) or static RAM (SRAM). Moreover, where appropriate, this RAM may be single-ported or multi-ported RAM. This disclosure contemplates any suitable RAM. Memory **904** may include one or more memories **904**, where appropriate. Although this disclosure describes and illustrates particular memory implementations, this disclosure contemplates any suitable memory implementation.

[0091] In particular embodiments, the storage **908** includes mass storage for data or instructions. As an example and not by way of limitation, the storage **908** may include a hard disk drive (HDD), a floppy disk drive, flash memory, an optical disc, a magneto-optical disc, magnetic tape, or a Universal Serial Bus (USB) drive or a combination of two or more of these. The storage **908** may include removable or non-removable (or fixed) media, where appropriate. The storage **908** may be internal or external to computer system **900**, where appropriate. In particular embodiments, the storage **908** is non-volatile, solid-state memory. In particular embodiments, the storage **908** includes read-only memory (ROM). Where appropriate, this ROM may be mask-programmed ROM, programmable ROM (PROM), erasable PROM (EPROM), electrically erasable PROM (EEPROM), electrically alterable ROM (EAROM), or flash memory or a combination of two or more of these. This disclosure contemplates mass storage **908** taking any suitable physical form. The storage **908** may include one or more storage control units facilitating communication between processor **906** and storage **908**, where appropriate. Where appropriate, the storage **908** may include one or more storages **908**. Although this disclosure describes and illustrates particular storage, this disclosure contemplates any suitable storage.

[0092] In particular embodiments, the I/O Interface **910** includes hardware, software, or both, providing one or more interfaces for communication between computer system **900** and one or more I/O devices. The computer system **900** may include one or more of these I/O devices, where appropriate. One or more of these I/O devices may enable communication between a person (i.e., a user) and computer system **900**. As an example and not by way of limitation, an I/O device may include a keyboard, keypad, microphone, monitor, screen, display panel, mouse, printer, scanner, speaker, still camera, stylus, tablet, touch screen, trackball, video camera, another suitable I/O device or a combination of two or more of these. An I/O device may include one or more sensors. Where appropriate, the I/O Interface **910** may include one or more device or software drivers enabling processor **906** to drive one or more of these I/O devices. The I/O interface **910** may include one or more I/O interfaces **910**, where appropriate. Although this disclosure describes and illustrates a particular I/O interface, this disclosure contemplates any suitable I/O interface or combination of I/O interfaces.

[0093] In particular embodiments, communication interface **912** includes hardware, software, or both providing one or more interfaces for communication (such as, for example, packet-based communication) between computer system **900** and one or more other computer systems **900** or one or more networks **914**. As an example and not by way of limitation, communication interface **912** may include a network interface controller (NIC) or network adapter for communicating with an Ethernet or any other wire-based network or a wireless NIC (WNIC) or wireless adapter for communicating with a wireless network, such as a Wi-Fi network. This disclosure contemplates any suitable network **914** and any suitable communication interface **912** for the network **914**. As an example and not by way of limitation, the network **914** may include one or more of an ad hoc network, a personal area network (PAN), a local area network (LAN), a wide area network (WAN), a metropolitan area network (MAN), or one or more portions of the Internet or a combination of two or more of these. One or more portions of one or more of these networks may be wired or wireless. As an example, computer system **900** may communicate with a wireless PAN (WPAN) (such as, for example, a Bluetooth® WPAN), a WI-FI network, a WI-MAX network, a cellular telephone network (such as, for example, a Global System for Mobile Communications (GSM) network), or any other suitable wireless network or a combination of two or more of these. Computer system **900** may include any suitable communication interface **912** for any of these networks, where appropriate. Communication interface **912** may include one or more communication

interfaces **912**, where appropriate. Although this disclosure describes and illustrates a particular communication interface implementations, this disclosure contemplates any suitable communication interface implementation.

[0094] The computer system **902** may also include a bus. The bus may include hardware, software, or both and may communicatively couple the components of the computer system **900** to each other. As an example and not by way of limitation, the bus may include an Accelerated Graphics Port (AGP) or any other graphics bus, an Enhanced Industry Standard Architecture (EISA) bus, a front-side bus (FSB), a HYPERTRANSPORT (HT) interconnect, an Industry Standard Architecture (ISA) bus, an INFINIBAND interconnect, a low-pin-count (LPC) bus, a memory bus, a Micro Channel Architecture (MCA) bus, a Peripheral Component Interconnect (PCI) bus, a PCI-Express (PCIe) bus, a serial advanced technology attachment (SATA) bus, a Video Electronics Standards Association local bus (VLB), or another suitable bus or a combination of two or more of these buses. The bus may include one or more buses, where appropriate. Although this disclosure describes and illustrates a particular bus, this disclosure contemplates any suitable bus or interconnect.

[0095] Herein, a computer-readable non-transitory storage medium or media may include one or more semiconductor-based or other types of integrated circuits (ICs) (e.g., field-programmable gate arrays (FPGAs) or application-specific ICs (ASICs)), hard disk drives (HDDs), hybrid hard drives (HHDs), optical discs, optical disc drives (ODDs), magneto-optical discs, magneto-optical drives, floppy diskettes, floppy disk drives (FDDs), magnetic tapes, solid-state drives (SSDs), RAM-drives, SECURE DIGITAL cards or drives, any other suitable computer-readable non-transitory storage media, or any suitable combination of two or more of these, where appropriate. A computer-readable non-transitory storage medium may be volatile, non-volatile, or a combination of volatile and non-volatile, where appropriate.

[0096] Herein, "or" is inclusive and not exclusive, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A or B" means "A, B, or both," unless expressly indicated otherwise or indicated otherwise by context. Moreover, "and" is both joint and several, unless expressly indicated otherwise or indicated otherwise by context. Therefore, herein, "A and B" means "A and B, jointly or severally," unless expressly indicated otherwise or indicated otherwise by context.

[0097] The scope of this disclosure encompasses all changes, substitutions, variations, alterations, and modifications to the example embodiments described or illustrated herein that a person having ordinary skill in the art would comprehend. The scope of this disclosure is not limited to the example embodiments described or illustrated herein. Moreover, although this disclosure describes and illustrates respective embodiments herein as including particular components, elements, features, functions, operations, or steps, any of these embodiments may include any combination or permutation of any of the components, elements, features, functions, operations, or steps described or illustrated anywhere herein that a person having ordinary skill in the art would comprehend. Furthermore, reference in the appended claims to an apparatus or system or a component of an apparatus or system being adapted to, arranged to, capable of, configured to, enabled to, operable to, or operative to perform a particular function encompasses that apparatus, system, component, whether or not it or that particular function is activated, turned on, or unlocked, as long as that apparatus, system, or component is so adapted, arranged, capable, configured, enabled, operable, or operative. Additionally, although this disclosure describes or illustrates particular embodiments as providing particular advantages, particular embodiments may provide none, some, or all of these advantages.

1-20. (canceled)

21. A method comprising:

receiving an audio transmission, at least a portion of the audio transmission corresponding to data modulated onto a carrier signal for transmission by the audio transmission;

identifying a first portion of the audio transmission, the first portion of the audio transmission corresponding to an expected sequence;

comparing the first portion to the expected sequence to identify one or more differences between the first portion and the expected sequence; and

adjusting a second portion of the audio transmission different from the first portion of the audio transmission based on one or more differences between the first portion and the expected sequence.

22. The method of claim **21**, wherein the adjusting the second portion of the audio transmission comprises:

determining, based on the one or more differences between the first portion and the expected sequence, a movement speed between a transmitter of the audio transmission and a receiver of the audio transmission; and

adjusting the second portion of the audio transmission based on the movement speed.

23. The method of claim **22**, wherein determining the movement speed comprises:

determining a correlation between the differences; and

determining the movement speed based on the correlation.

24. The method of claim **22**, wherein the movement speed is determined to represent movement of at least one of the transmitter and the receiver along an axis extending between the transmitter and the receiver.

25. The method of claim **21**, wherein the first portion of the audio transmission includes a first subset of symbols and the expected sequence includes expected symbols, and wherein the comparing the first portion to the expected sequence includes comparing the first subset of symbols to the expected symbols to identify one or more differences between the first subset of symbols and the expected symbols.

26. The method of claim **25**, wherein the expected symbols contain expected frequencies, and wherein comparing the first subset of symbols to the expected symbols to identify one or more differences between the first subset of symbols and the expected symbols comprises, for each symbol of the first subset of symbols:

identifying a first frequency contained by the symbol;

identifying a corresponding expected symbol from among the expected symbols that contains an expected frequency with the same or similar frequency as the first frequency; and

calculating a phase difference between the symbol and the corresponding expected symbol.

27. The method of claim **21**, wherein the one or more differences between the first portion and the expected sequence includes a phase difference between the first portion and the expected sequence.

28. The method of claim **27**, wherein adjusting the second portion of the audio transmission comprises:

calculating, based on the phase difference between the first portion and the expected sequence, one or more phase corrections for the second portion; and

adjusting a phase of the second portion according to the phase correction.

29. The method of claim **21**, wherein a transmitter of the audio transmission initially generates the first portion of the audio transmission to be identical to the expected sequence.

30. The method of claim **29**, wherein the first portion of the audio transmission is a preamble of the audio transmission indicating a beginning of the audio transmission.

31. The method of claim **29**, wherein the first portion of the audio transmission is a training sequence of the audio transmission different from a preamble of the audio transmission indicating a beginning of the audio transmission.

32. A system comprising:

a processor; and

a memory storing instructions which, when executed by the processor, cause the processor to:

receive an audio transmission, at least a portion of the audio transmission corresponding to data modulated onto a carrier signal for transmission by the audio transmission;

identify a first portion of the audio transmission, the first portion of the audio transmission corresponding to an expected sequence;

compare the first portion to the expected sequence to identify one or more differences between the first portion and the expected sequence; and

adjust a second portion of the audio transmission different from the first portion of the audio transmission based on one or more differences between the first portion and the expected sequence.

33. The system of claim **32**, wherein the memory stores further instructions which, when executed by the processor while adjusting the second portion of the audio transmission, cause the processor to:

determine, based on the one or more differences between the first portion and the expected sequence, a movement speed between a transmitter of the audio transmission and a receiver of the audio transmission; and

adjust the second portion of the audio transmission based on the movement speed.

34. The system of claim **33**, wherein the memory stores further instructions which, when executed by the processor while determining the movement speed, cause the processor to:

determine a correlation between the differences; and

determine the movement speed based on the correlation.

35. The system of claim **33**, wherein the movement speed is determined to represent movement of at least one of the transmitter and the receiver along an axis extending between the transmitter and the receiver.

36. The system of claim **32**, wherein the first portion of the audio transmission includes a first subset of symbols and the expected sequence includes expected symbols, and wherein the comparing the first portion to the expected sequence includes comparing the first subset of symbols to the expected symbols to identify one or more differences between the first subset of symbols and the expected symbols.

37. The system of claim **36**, wherein the expected symbols contain expected frequencies, and wherein the memory stores further instructions which, when executed by the processor while comparing the first subset of the symbols to the expected symbols to identify one or more differences between the first subset of the symbols and the expected symbols cause the processor to, for each symbol of the first subset of the symbols:

identify a first frequency contained by the symbol;

identify a corresponding expected symbol from among the expected symbols that contains an expected frequency with the same or similar frequency as the first frequency; and

calculate a phase difference between the symbol and the corresponding expected symbol.

38. The system of claim **32**, wherein the memory stores further instructions which, when executed by the processor while identifying the one or more differences between the first portion and the expected sequence, cause the processor to identify a phase difference between the first portion and the expected sequence.

39. The system of claim **38**, wherein the memory stores further instructions which, when executed by the processor while adjusting the second portion, cause the processor to:

calculate, based on the phase difference between the first portion and the expected sequence, one or more phase corrections for the second portion; and

correct a phase of the second portion according to the phase correction.

40. A non-transitory, computer-readable medium storing instructions which, when executed by a processor, cause the processor to:

receive an audio transmission, at least a portion of the audio transmission corresponding to data modulated onto a carrier signal for transmission by the audio transmission;

identify a first portion of the audio transmission, the first portion of the audio transmission corresponding to an expected sequence;

compare the first portion to the expected sequence to identify one or more differences between the first portion and the expected sequence; and

adjust a second portion of the audio transmission different from the first portion of the audio transmission based on one or more differences between the first portion and the expected sequence.

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