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(54) **METHOD AND SYSTEM FOR IMPROVED ACOUSTIC TRANSMISSION OF DATA**

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CPC ***H04B 11/00*** (2013.01)

(58) **Field of Classification Search**
CPC H04B 11/00; H04L 1/0071
USPC 375/275, 272, 303, 307, 334, 335, 260
See application file for complete search history.

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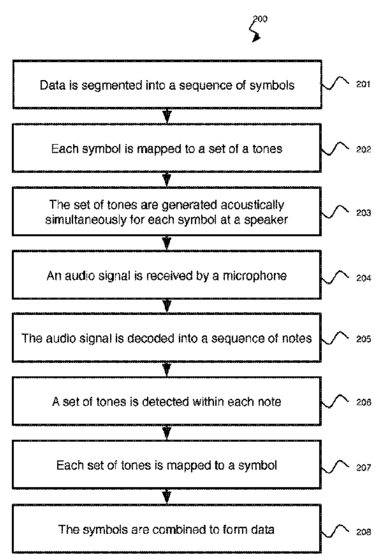
(57) **ABSTRACT**

The present invention relates to a method for communicating data acoustically. The method includes segmenting the data into a sequence of symbols; encoding each symbol of the sequence into a plurality of tones; and acoustically generating the plurality of tones simultaneously for each symbol in sequence. Each of the plurality of tones for each symbol in the sequence may be at a different frequency.

20 Claims, 2 Drawing Sheets



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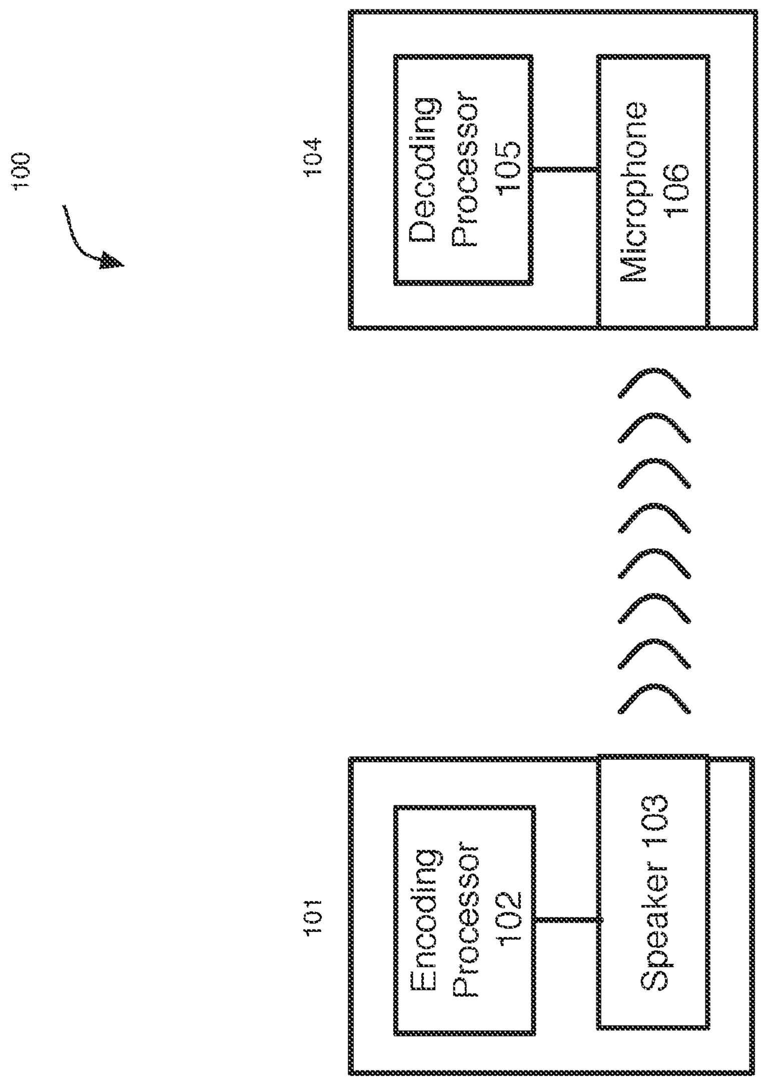
100
104
Decoding Processor 105
Microphone 106
101
Encoding Processor 102
Speaker 103

Figure 1

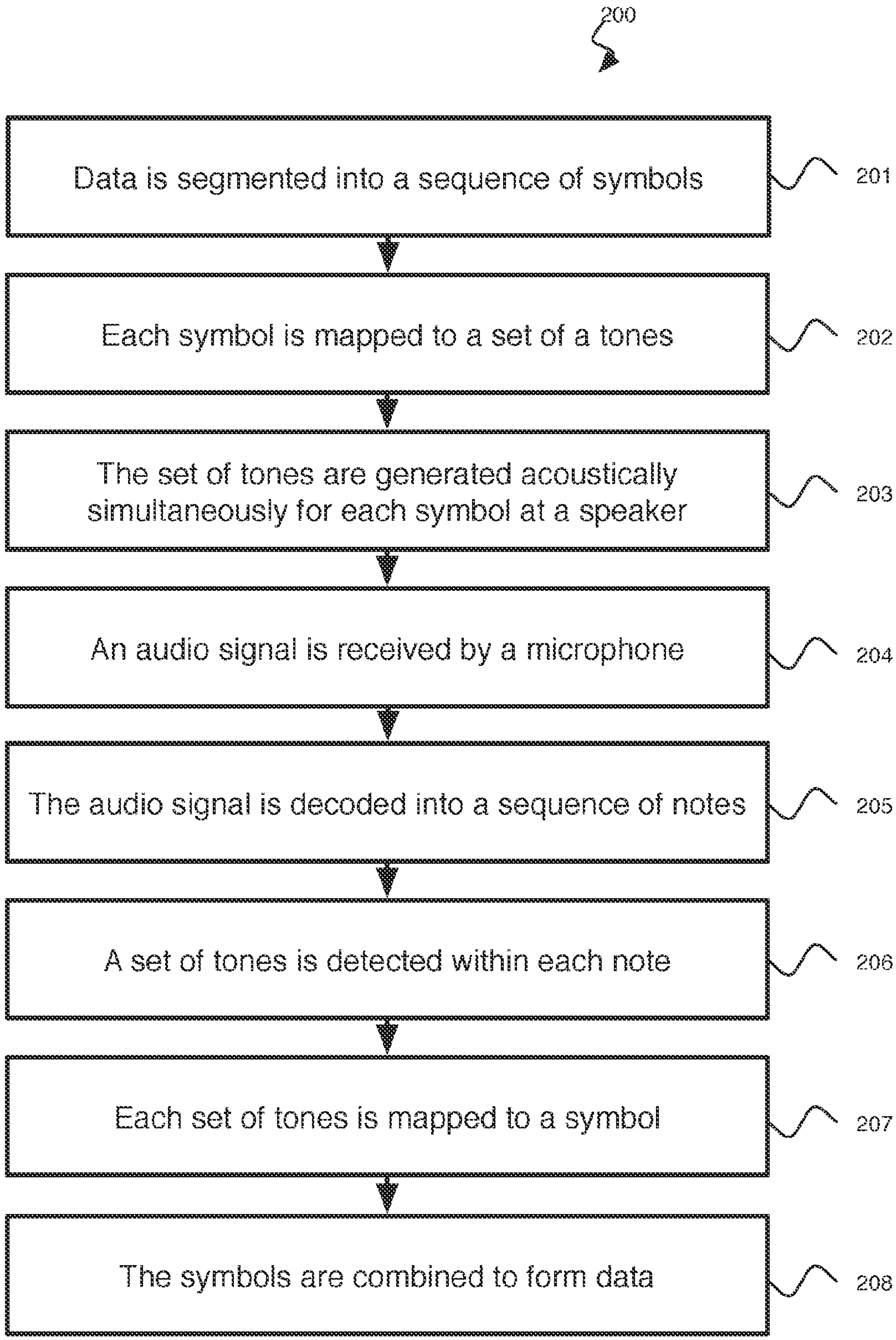
200
Data is segmented into a sequence of symbols
201
Each symbol is mapped to a set of a tones
202
The set of tones are generated acoustically simultaneously for each symbol at a speaker
203
An audio signal is received by a microphone
204
The audio signal is decoded into a sequence of notes
205
A set of tones is detected within each note
206
Each set of tones is mapped to a symbol
207
The symbols are combined to form data
208

Figure 2

METHOD AND SYSTEM FOR IMPROVED ACOUSTIC TRANSMISSION OF DATA

This application is a continuation of U.S. application Ser. No. 16/956,905, filed Jun. 22, 2020, which is the U.S. national phase of International Application No. PCT/GB2018/053733 filed 20 Dec. 2018, which designated the U.S. and claims priority to GB Patent Application No. 1721457.8 filed 20 Dec. 2017, the entire contents of each of which are hereby incorporated by reference.

FIELD OF INVENTION

The present invention is in the field of data communication. More particularly, but not exclusively, the present invention relates to a method and system for acoustic transmission of data.

BACKGROUND

There are a number of solutions to communicating data wirelessly over a short range to and from devices using radio frequencies. The most typical of these is WiFi. Other examples include Bluetooth and Zigbee.

An alternative solution for a short range data communication uses a "transmitting" speaker and "receiving" microphone to send encoded data acoustically over-the-air.

Such an alternative may provide various advantages over radio frequency-based systems. For example, speakers and microphones are cheaper and more prevalent within consumer electronic devices, and acoustic transmission is limited to "hearing" distance.

There exist several over-the-air acoustic communications systems. A popular scheme amongst over-the-air acoustic communications systems is to use Frequency Shift Keying as the modulation scheme, in which digital information is transmitted by modulating the frequency of a carrier signal to convey 2 or more integer levels (M-ary fixed keying, where M is the distinct number of levels).

One such acoustic communication system is described in US Patent Publication No. US2012/084131A1, DATA COMMUNICATION SYSTEM. This system, invented by Patrick Bergel and Anthony Steed, involves the transmission of data using an audio signal transmitted from a speaker and received by a microphone where the data, such as a shortcode, is encoded into a sequence of tones within the audio signal.

Acoustic communication systems using Frequency Shift Keying such as the above system can have a good level of robustness but are limited in terms of their throughput. The data rate is linearly proportional to the number of tones available (the alphabet size), divided by the duration of each tone. This is robust and simple in complexity, but is spectrally inefficient.

Radio frequency data communication systems may use phase- and amplitude-shift keying to ensure high throughput. However, both these systems are not viable for over-the-air data transmission in most situations, as reflections and amplitude changes in real-world acoustic environments renders them extremely susceptible to noise.

There is a desire for a system which provides improved throughput in acoustic data communication systems.

It is an object of the present invention to provide a method and system for improved acoustic data transmission which overcomes the disadvantages of the prior art, or at least provides a useful alternative.

SUMMARY OF INVENTION

According to a first aspect of the invention there is provided a method for communicating data acoustically, including:

a) Segmenting the data into a sequence of symbols;

b) Encoding each symbol of the sequence into a plurality of tones; and

c) Acoustically generating the plurality of tones simultaneously for each symbol in sequence;

wherein each of the plurality of tones for each symbol in the sequence are at a different frequency.

Other aspects of the invention are described within the claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Embodiments of the invention will now be described, by way of example only, with reference to the accompanying drawings in which:

FIG. **1**: shows block diagram illustrating a data communication system in accordance with an embodiment of the invention; and

FIG. **2**: shows a flow diagram illustrating a data communication method in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

The present invention provides an improved method and system for acoustically communicating data.

The inventors have discovered that throughput can be increased significantly in a tone-based acoustic communication system by segmenting the data into symbols and transmitting K tones simultaneously for each symbol where the tones are selected from an alphabet of size M. In this way, a single note comprising multiple tones can encode symbols of size $\log_2$ (M choose K) bits compared to a single tone note which encodes a symbol into only $\log_2$ (M) bits. The inventors have discovered that this method of increasing data density is significantly less susceptible to noise in typical acoustic environments compared to PSK and ASK at a given number of bits per symbol.

In FIG. **1**, an acoustic data communication system **100** in accordance with an embodiment of the invention is shown.

The system **100** may include a transmitting apparatus **101** comprising an encoding processor **102** and a speaker **103**.

The encoding processor **102** may be configured for segmenting data into a sequence of symbols and for encoding each symbol of the sequence into a plurality of tones. Each symbol may be encoded such that each of the plurality of tones are different. Each symbol may be encoded into K tones. The data may be segmented into symbols corresponding to B bits of the data. B may be log 2 (M choose K) where M is the size of the alphabet for the tones. The alphabet of tones may be spread evenly over a frequency spectrum or may be spread in ways to improve transmission.

The processor **102** and/or speaker **103** may be configured for acoustically transmitting the plurality of tones simultaneously for each symbol in sequence. For example, the processor **102** may be configured for summing the plurality of tones into a single note or chord for generation at the speaker **103**. Alternatively, the speaker **103** may include a plurality of cones and each cone may generate a tone.

The system **100** may include a receiving apparatus **104** comprising a decoding processor **105** and a microphone **106**.

The microphone **106** may be configured for receiving an audio signal which originates at the speaker **103**.

The decoding processor **105** may be configured for decoding the audio signal into a sequence of notes (or chords), for identifying a plurality of tones within each note, for decoding the plurality of tones for each note into a symbol to form a sequence of symbols, and for reconstituting data from the sequence of symbols.

It will also be appreciated by those skilled in the art that the above embodiments of the invention may be deployed on different apparatuses and in differing architectures. For example, the encoding processor **102** and speaker **103** may exist within different devices and the audio signal to be generated may be transmitted from the encoding processor **102** (e.g. the processor **102** may be located at a server) to the speaker **103** (e.g. via a network, or via a broadcast system) for acoustic generation (for example, the speaker **103** may be within a television or other audio or audio/visual device). Furthermore, the microphone **106** and decoding processor **105** may exist within different devices. For example, the microphone **106** may transmit the audio signal, or a representation thereof, to a decoding processor **105** in the cloud.

The functionality of the apparatuses **101** and **104** and/or processors **102** and **105** may be implemented, at least in part, by computer software stored on an intangible computer-readable medium.

Referring to FIG. **2**, a method **200** for communicating data acoustically will be described.

The data may be comprised of a payload and error correction. In some embodiment, the data may include a header. The header may include a length related to the transmission (e.g. for the entire data or the payload). The length may be the number of symbols transmitted.

In step **201**, the data is segmented into a sequence of symbols (e.g. at transmitting apparatus **101** by encoding processor **102**). The data may be segmented by first treating the data as a stream of bits. The segment size (B) in bits may be determined by:

$$B=\log_2(M \text{ choose } K)$$

M is the size of the alphabet of the tones at different frequencies spanning an audio spectrum and K is the number of tones per note or chord.

The audio spectrum may be wholly or, at least partially, audible to human beings (e.g. within 20 Hz to 20 kHz), and/or may be wholly, or at least partially, ultrasonic (e.g. above 20 kHz). In one embodiment, the audio spectrum is near-ultrasonic (18 kHz to 20 kHz).

In step **202**, each symbol in the sequence may be mapped to a set of tones (e.g. at transmitting apparatus **101** by encoding processor **102**) Each set may comprise K tones. The tones may be selected from the alphabet of M tones. Preferably each tone within a set is a different tone selected from the alphabet. The symbol may be mapped to the set of tones via bijective mapping. In one embodiment, a hash-table from symbol to tone set may be used to encode the symbol (a second hash-table may map the set of tones to symbol to decode a detected set of tones). One disadvantage of using hashtables is that because the hash-table must cover all possible selections of tones for the set, as M and/or K increases, the memory requirements may become prohibitively large. Therefore, it may be desirable if a more efficient bijective mapping schema could be used. One embodiment, which addresses this desire, uses a combinatorial number system (combinadics) method to map symbols to tone sets and detected tone sets to symbols.

In the combinadics method, each symbol (as an integer) can be translated into a K-value combinatorial representation (e.g. a set of K tones selected from the alphabet of M tones). Furthermore, each set of K tones can be translated back into a symbol (as an integer).

In step **203**, the set of tones may be generated acoustically simultaneously for each symbol in the sequence (e.g. at the transmitting apparatus **101**). This may be performed by summing all the tones in the set into an audio signal and transmitting the audio signal via a speaker **103**. The audio signal may include a preamble. The preamble may assist in triggering listening or decoding at a receiving apparatus (e.g. **104**). The preamble may be comprised of a sequence of single or summed tones.

In step **204**, the audio signal may be received by a microphone (e.g. **106** at receiving apparatus **104**).

In step **205**, the audio signal may be decoded (e.g. via decoding processor **105**) into a sequence of notes. Decoding of the audio signal may be triggered by detection first of a preamble.

Each note may comprise a set of tones and the set of tones may be detected within each node (e.g. by decoding processor) in step **206**. The tones may be detected by computing a series of FFT frames for the audio signal corresponding to a note length and detecting the K most significant peaks in the series of FFT frames. In other embodiments, other methods may be used to detect prominent tones.

The set of detected tones can then be mapped to a symbol (e.g. via a hash-table or via the combinadics method described above) in step **207**.

In step **208**, the symbols can be combined to form data. For example, the symbols may be a stream of bits that is segmented into bytes to reflect the original data transmitted.

At one or more of the steps **205** to **208**, error correction may be applied to correct errors created during acoustic transmission from the speaker (e.g. **103**) to the microphone (e.g. **106**). For example, forward error correction (such as Reed-Solomon) may form a part of the data and may be used to correct errors in the data.

Embodiments of the present invention will be further described below:

Symbols, Lexical Mappings and the Combinatorial Number System (Combinadics)

In monophonic M-ary FSK, each symbol can represent M different values, so can store at most $\log_2 M$ bits of data. Within multi-tone FSK, with a chord size of K and an alphabet size of M, the number of combinatoric selections is M choose K:

$$M!/(K!(M-K)!)$$

Thus, for an 6-bit (64-level) alphabet and a chord size K of 4, the total number of combinations is calculated as follows:

$$64!/(4!60!)=635{,}376$$

Each symbol should be expressible in binary. The $\log_2$ of this value is taken to deduce the number of combinations that can be expressed, which is in this case 2^{19}. The spectral efficiency is thus improved from 6-bit per symbol to 19-bit per symbol.

Combinadics

To translate between K-note chords and symbols within the potential range, a bijective mapping must be created between the two, allowing a lexographic index A to be derived from a combination $\{X_1, X_2, \ldots X_K\}$ and vice-versa.

A naive approach to mapping would work by:

generating all possible combinations, and

storing a pair of hashtables from $A \leftrightarrow \{X_1, X_2, \ldots X_K\}$

Example for M=4, K=3

0 – {0, 1, 2}

1 – {0, 1, 3}

2 – {0, 1, 4}

3 – {0, 2, 3}

4 – {0, 2, 4}

5 – {0, 3, 4}

6 – {1, 2, 3}

7 – {1, 2, 4}

8 – {1, 3, 4}

9 – {2, 3, 4}

As the combinatoric possibilities increase, such as in the above example, the memory requirements become prohibitively large. Thus, an approach is needed that is efficient in memory and CPU.

Mapping from Data to Combinadics to Multi-Lone FSK

To therefore take a stream of bytes and map it to a multi-tone FSK signal, the process is as follows:

- segment the stream of bytes into B-bit symbols, where 2^B is the maximum number of binary values expressible within the current combinatoric space (e.g. M choose K)
- translate each symbol into its K-value combinatorial representation
- synthesize the chord by summing the K tones contained within the combination

In one embodiment, a transmission "frame" or packet may be ordered as follows:

1. Preamble/wakeup symbols (F)
2. Payload symbols (P)
3. Forward error-correction symbols (E)

FF PPPPPPPP EEEEEEEE

At decoding, a receiving may:

- decode each of the constituent tones using an FFT
- segment the input into notes, each containing a number of FFT frames equal to the entire expected duration of the note
- use a statistical process to derive what seem to be the K most prominent tones within each note
- translate the K tones into a numerical symbol using the combinatorial number system process described above
- concatenate the symbols to the entire length of the payload (and FEC segment)
- re-segment into bytes
- and finally, apply the FEC algorithm to correct any mis-heard tones

In another embodiment, the FEC algorithm may be applied before re-segmentation into bytes.

A potential advantage of some embodiments of the present invention is that data throughput for acoustic data communication systems can be significantly increased (bringing throughput closer to the Shannon limit for the channel) in typical acoustic environments by improved spectral efficiency. Greater efficiency results in faster transmission of smaller payloads, and enables transmission of larger payloads which previously may have been prohibitively slow for many applications.

While the present invention has been illustrated by the description of the embodiments thereof, and while the embodiments have been described in considerable detail, it is not the intention of the applicant to restrict or in any way limit the scope of the appended claims to such detail. Additional advantages and modifications will readily appear to those skilled in the art. Therefore, the invention in its broader aspects is not limited to the specific details, representative apparatus and method, and illustrative examples shown and described. Accordingly, departures may be made from such details without departure from the spirit or scope of applicant's general inventive concept.

The invention claimed is:

1. A device, comprising:

one or more processors; and

a non-transitory computer-readable medium storing instructions that, when executed by the one or more processors, cause the device to:

segment data into a sequence of symbols, each of the symbols having a preset number of bits;

determine for each symbol of the sequence of symbols three or more tones based on a mapping between symbols and sets of tones selected from tones spread evenly over a frequency spectrum, wherein the mapping includes a mapping between the symbols and a multi-tone Frequency Shift Keying (FSK) signal including three or more tones; and

generate an audio signal based on the determined tones for each symbol of the sequence of symbols.

2. The device of claim **1**, wherein each of the three or more tones for each symbol in the sequence of symbols is at a different frequency.

3. The device of claim **1**, wherein the mapping comprises a bijective mapping.

4. The device of claim **1**, further comprising:

a speaker,

wherein the non-transitory computer-readable medium storing instructions that, when executed by the one or more processors, further cause the device to:

transmit, via the speaker, the generated audio signal.

5. The device of claim **4**, wherein transmit, via the speaker, the generated audio signal comprises:

for each symbol in the sequence of symbols, cause, via the speaker, simultaneous playback of the three or more tones determined for the respective symbol.

6. The device of claim **1**, wherein generate an audio signal based on the three or more tones comprises:

generate a packet for a first set of symbols of the sequence of symbols, wherein the packet comprises a payload comprising the determined three or more tones.

7. The device of claim **6**, wherein the non-transitory computer-readable medium storing instructions that, when executed by the one or more processors, further cause the device to:

transmit, to a speaker, the packet for the first set of symbols of the sequence of symbols.

8. A non-transitory, computer-readable medium storing instructions that, when executed by one or more processors, cause a device to:

segment data into a sequence of symbols, each of the symbols having a preset number of bits;

determine for each symbol of the sequence of symbols three or more tones based on a mapping between symbols and sets of tones selected from tones spread evenly over a frequency spectrum, wherein the mapping includes a mapping between the symbols and a multi-tone Frequency Shift Keying (FSK) signal including three or more tones; and

generate an audio signal based on the determined tones for each symbol of the sequence of symbols.

9. The non-transitory, computer-readable medium of claim 8, wherein each of the three or more tones for each symbol in the sequence of symbols is at a different frequency.

10. The non-transitory, computer-readable medium of claim 8, wherein the mapping comprises a bijective mapping.

11. The non-transitory, computer-readable medium of claim 8, further comprising instructions, that when executed by the one or more processors, cause the device to:

transmit, via a speaker, the generated audio signal.

12. The non-transitory, computer-readable medium of claim 11, wherein transmit, via the speaker, the generated audio signal comprises:

for each symbol in the sequence of symbols, cause, via the speaker, simultaneous playback of the three or more tones determined for the respective symbol.

13. The non-transitory, computer-readable medium of claim 8, wherein generate an audio signal based on the three or more tones comprises:

generate a packet for a first set of symbols of the sequence of symbols, wherein the packet comprises a payload comprising the determined three or more tones.

14. The non-transitory, computer-readable medium of claim 13, further comprising instructions that, when executed by the one or more processors, further cause the device to:

transmit, to a speaker, the packet for the first set of symbols of the sequence of symbols.

15. A method, comprising:

segmenting data into a sequence of symbols, each of the symbols having a preset number of bits;

determining for each symbol of the sequence of symbols three or more tones based on a mapping between symbols and sets of tones selected from tones spread evenly over a frequency spectrum, wherein the mapping includes a mapping between the symbols and a multi-tone Frequency Shift Keying (FSK) signal including three or more tones; and

generating an audio signal based on the determined tones for each symbol of the sequence of symbols.

16. The method of claim 15, wherein each of the three or more tones for each symbol in the sequence of symbols is at a different frequency.

17. The method of claim 15, wherein the mapping comprises a bijective mapping.

18. The method of claim 15, further comprising:

causing, via a speaker, simultaneous playback of the three or more tones determined for the respective symbol for each symbol in the sequence of symbols.

19. The method of claim 15, wherein generating an audio signal based on the three or more tones comprises:

generating a packet for a first set of symbols of the sequence of symbols, wherein the packet comprises a payload comprising the determined three or more tones.

20. The method of claim 19, further comprising:

transmitting, to a speaker, the packet for the first set of symbols of the sequence of symbols.

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