

"Transmission system with improved reconstruction of missing parts"

The present invention is related to a transmission system comprising a first node with a source encoder for deriving an encoded signal from an input signal, the first node further comprises a transmitter for transmitting the encoded signal to a second node via a transmission medium, the second node comprising reconstruction means for deriving a reconstructed signal
5 from the encoded signal.

The present invention is also related to a node, reconstruction means, and a reconstruction method.

A transmission system according to the preamble is known from US Patent No. 4,907,277.

10 Such transmission systems are used in applications in which source signals have to be transmitted over a transmission medium with a limited transmission capacity or have to be stored on storage media with a limited storage capacity. Examples of such applications are the transmission of speech signals over the Internet, the transmission of speech signals from a mobile phone to a base station and vice versa and storage of speech signals on a CD-ROM, in a solid
15 state memory or on a hard disk drive.

In order to reduce the bit rate of the signal to be transmitted or stored, a source encoder is used which derives an encoded signal from the input signal. Such a source encoder can operate according to different operating principles. Examples of such operating principles are PCM, DPCM, RPE, CELP and Transform coding (sub-band coding, DCT).

20 In the case of unreliable transmission media, such as the mobile radio channel, it may occur that parts of the encoded signal are not received correctly by the second node. In order to maintain the quality of the decoded signal, the second node comprises an interpolator for completing the missing parts of the reconstructed signal. The above mention US patent discloses a way of obtaining a good quality of the completed missing parts by interpolation of surrounding
25 parts of said missing parts. A disadvantage of the transmission system according to said US patent is the increased decoding delay due to the interpolation process.

The object of the present invention is to provide a transmission system according to the preamble in which the average delay value is reduced.

In order to obtain said objective, the transmission system according to the invention is characterized in that the reconstruction means are arranged for providing the reconstructed signal immediately, if the quality of the received encoded signal meets some
5 reconstructed signal immediately, if the quality of the received encoded signal meets some quality criterion, and in that the reconstruction means are arranged for providing the reconstructed signal after a reconstruction delay, if the quality of the received encoded signal does not meet said quality criterion.

The present invention is based on the recognition that the possibility to reconstruct
10 the source signal under bad signal conditions improves if the reconstruction delay is increased under said bad signal conditions. Increasing the reconstruction delay allows the use of interpolation for completing missing parts of the decoded signal, or it allows requesting re-transmission of the missing parts of the encoded signal by the first node. It is observed that the reconstruction delay is only increased under bad signal conditions in order to make the delay of
15 the signal not larger than necessary under good signal conditions.

An embodiment of the invention is characterized in that the quality criterion is the completeness of the received encoded signal, and in that the reconstruction means comprise completion means for completing the reconstructed signal if the received signal is not complete. According to this embodiment the source signal is directly reconstructed if the received signal is
20 complete from a given instant in time. If parts of the decoded signal are missing, the reconstruction delay is increased, allowing interpolation or requesting re-transmission for completing the missing parts of the encoded signal. It is observed that interpolation not necessary has to be performed on the encoded signal, but that it is also possible to perform the interpolation on the decoded frames of the signal.

25 A further embodiment of the present invention is characterized in that the reconstruction means are arranged for increasing the reconstruction delay in dependence of the quality of the received encoded signal.

By increasing the reconstruction delay with decreasing quality of the received encoded signal, it becomes more easy to obtain a better reconstruction of the source signal. If e.g.
30 larger parts of the received encoded signal are missing, more additional time is required for the completion of them by interpolation or re-transmission by the first node.

A still further embodiment of the present invention is characterized in that the reconstruction means are arranged for reducing the reconstruction delay after detection of the absence of a reconstructed signal.

By reducing the reconstruction delay if the absence of a source signal is
5 determined, it is obtained that the reconstruction delay is not larger than absolutely necessary for obtaining a good reconstruction of the source signal.

A still further embodiment of the invention is characterized in that the source signal comprises a speech signal, in that the second node comprises comfort noise introduction means for introducing comfort noise with a level that increases with decreasing quality of the
10 received encoded signal.

By introducing more comfort noise with decreasing quality of the received encoded signal, the degradation of the transmission quality results in an audible way similar as with an analog transmission system to which users are accustomed to.

A still further embodiment of the invention is characterized in that the
15 transmission system comprises a full duplex speech transmission system, and in that the second node comprises side tone introduction means for introducing a side tone with a level which decreases with the reconstruction delay.

A consequence of increasing the delay of the decoding is that the adverse effect of echoes is more pronounced. A source of echoes is the introduction of side tone, which is very common in
20 telephone systems. Side tone is introduced in order to provide the user some acoustical feedback of the transmitted audio signal. By reducing the level of the side tone signal the adverse effect of echoes is reduced.

The invention will now be explained with reference to the drawing figures. Herein shows:

25 Fig. 1, a first embodiment of the transmission system according to the invention in which interpolation is used for completing the received signal;

Fig. 2, a detailed drawing of the interpolator 14 according to Fig. 1;

Fig. 3, a detailed drawing of an arrangement performing the function of the interpolator 14 and the selector 18;

30 Fig. 4, a timing diagram for the reconstruction of a received signal in the transmission system according to Fig. 1;

Fig. 5, a detailed drawing of the error detector 16;

Fig. 6, a second embodiment of the invention in which requesting re-transmission is used for completing the received signal;

Fig. 7, a first possible timing diagram for the reconstruction of a received signal in the transmission system according to Fig. 6;

5 Fig. 8, a second possible timing diagram for the reconstruction of a received signal in the transmission system according to Fig. 6;

Fig. 9, an embodiment of the audio processing functions in a second node according to the invention.

In the transmission system according to Fig. 1 the signal to be transmitted by the
10 node 2 is applied to the input of a source encoder 8. The encoded signal at the output of the source encoder 8 is presented as frames which are transmitted by the transmitter 10 to the second node 6. The operation of the transmitter 10 includes channel coding and modulation.

In the second node 6, the signal from the transmission medium 4 is processed by the receiver 12. The operations of the receiver 12 include demodulation and channel decoding.
15 The reconstruction means according to the inventive concept comprise the arrangement 13 and the decoder 20. At the output of the receiver 12 the received encoded signal is present. This received encoded signal is applied to quality determining means 16 which determines the quality of the received encoded signal. The quality determining means 16 can e.g. comprise a decoder for a block code such as a Reed-Solomon code. In this case the quality criterion can be whether
20 or not the received encoded signal comprises incorrigible errors or not.

If the quality criterion is met (no incorrigible errors), the present frame of the received encoded signal is complete. If all previous frames also were complete, the received encoded signal is directly passed to a decoder 20 via the selector 18. The selector 18 receives an appropriate control signal from the quality determining means to pass the received decoded
25 signal directly to the decoder 20. At the output of the decoder 20, the reconstructed signal is available.

If the quality criterion is not met (incorrigible errors present), the selector 18 is instructed to present the previous frame again to the decoder 20. Furthermore the interpolator 14 is instructed to complete the missing frame from the frames surrounding the incorrectly received
30 frame.

After the interpolation has been performed, the interpolated frame is passed to the decoder. Due to the interpolation the decoding of the interpolated frame, and consequently the

provision of the reconstructed source signal will be delayed. It is observed that it is not possible to re-select the undelayed received encoded signal to be passed to the encoder, because this would result in a noticeable disturbance. Only in the case of a period of silence it is possible to change back to undelayed reconstruction. If such a period of silence is detected in the quality
 5 detection means 16, the selector 18 is instructed to pass again the output signal of the receiver 12 directly to the decoder 12.

In the interpolator 14, the output signal of the receiver 12 is applied to a cascade connection of a delay element 22 and a delay element 24. The delay value of these delay elements is equal to the duration of one frame. The interpolator 26 is arranged for calculating an
 10 interpolated frame from the frame at the input of the delay element 26 and the output of the delay element 24.

In case the signal to be transmitted is a speech signal, the encoded signal can be based on linear prediction. The frame comprises a representation of a plurality of prediction coefficients and a representation of an excitation signal. The reconstructed signal is obtained by
 15 applying the excitation signal to a synthesis filter, having parameters derived from the prediction coefficients. If the frame $i-1$ is incorrectly received, the prediction coefficients $\alpha_K[i-1]$ are calculated according to :

$$\alpha_K[i-1] = \frac{\alpha_K[i-2] + \alpha_K[i]}{2} \quad (A)$$

The prediction coefficients interpolated can e.g. be Log Area Ratios, Line Spectral Pairs and arcsine functions of reflection coefficients. These representations of prediction coefficients are
 20 well known to those skilled in the art.

Because the excitation signals can be very different from frame to frame an interpolated excitation signal can be very different from the original signal. Consequently the excitation signal is normally not interpolated but the value of the previous frame is used.

In the case a frame is incorrectly received, the selector 28 is instructed to pass the
 25 output of the interpolator 26 to the decoder 20. If a frame is correctly received, the over one frame period delayed received encoded signal which is available at the output of the delay element 22 is passed to the decoder 20.

Fig. 3 shows an arrangement which combines the function of the interpolator 14 and the selector 18. Furthermore the arrangement is able to provide completion of one or two
 30 missing frames by interpolation.

The input signal of the arrangement is applied to a cascade connection of a delay element 30, a delay element 32 and a delay element 34. The arrangement receives from the quality determining means 16 three control signals. A first control signal ERR indicates that the frame present on the input of the arrangement is in error. The second control signal DELAY indicates the present delay of the arrangement. The third signal INTERPOLATE # indicates the number of frames that has to be completed by interpolation.

In case all frames are correctly received, the value of the signal ERR is FALSE, the value of the signal DELAY is equal to 0 and the value of the signal INTERPOLATE # is also equal to 0. In this case the selector 40 is instructed to pass the input signal of delay element 30 directly to the decoder 20. This case is shown in the graphs 50 and 52 of Fig. 4 for the frames 1,2 and 3.

In the case a frame is received in error, the signal ERROR will become equal to 1. As long as the numbers of errors indicated by ERR is smaller or equal than the value of DELAY, the selector will pass the same output signal to the decoder 20. Because in this case the number of errors (1) is larger than the value of DELAY, the logic circuit 42 will instruct the selector 40 to present the previous frame i.e. frame 3 again at the output until an interpolated frame 3' is available. This is visible in graph 50 which shows that frame 3 is again supplied to the decoder.

At the reception of the first correct frame, it is known how many frames are missing, and consequently over how many frames the interpolation should be performed. This number of frames is signaled by the signal INTERPOLATE #. At the same instant, the value DELAY is set to the max function of the present value of DELAY and the number of missing frames. In the graph 30 only frame 4 is missing between frame 3 and 5. As soon as frame 5 is received correctly, the signals DELAY and INTERPOLATE # are set to 1. This causes the selector 36 to pass the output signal of the delay element 32 (i.e. frame 3) to a first input of the interpolator 38. At the second input of the interpolator 30 the input signal of delay element 30 (i.e. frame 5) is available.

As soon as the interpolation is completed, the output signal of the interpolator 38 is passed by the selector 40 to the decoder 20. This can be seen in graph 50 in which an interpolated frame 4' is passed after the second instance of frame 3.

The value 1 of the signal DELAY causes the selector 40 to pass the output of the delay element 30 to the input of the decoder 20, after the interpolated frame 4'. Because at that instant frame 5 is available at the output of delay element, frame 5 is passed to the decoder 20

subsequent to frame 4' as can be seen from graph 50. From graph 50 it can be seen that the delay is increased after the occurrence of a transmission error. If a next single error arises, no discontinuity will be present because now the interpolation result is present in time. Because the value of DELAY remains the same, the subsequent frames to be passed to the decoder 20 remain
 5 being taken from the output of the delay element 30.

If two frames are missing from the input signal, as is shown in graph 52 where the frames 8 and 9 are missing, an interpolation over two frames has to be performed. At the detection of the erroneously received frame 8, the signal ERR will be set to 1. Because the number of errors and the value of DELAY are equal to 1, the selector 40 is instructed to maintain
 10 passing the output signal of delay element 30 (i.e. frame 7) to the decoder 20. When the next frame 9 also turns out to be erroneous, the value of ERR is increased to two. Because the number of errors ERR is now larger than the value of DELAY, the selector 40 is instructed to pass the previous frame (i.e. frame 7) again to the decoder 20.

Directly after frame 10 is correctly received, the quality determining means 16
 15 submit a signal INTERPOLATE # with a value of two. The selector 36 is instructed thereby to pass the output of the delay element 34 instead of the output of the delay element 32 to the first input of the interpolator 38. The interpolator 38 now calculates the LPC parameters of the missing frames according to:

$$\alpha_K[i-1] = \frac{\alpha_K[i-3]}{3} + \frac{2 \cdot \alpha_K[i]}{3} \quad (B)$$

$$\alpha_K[i-2] = \frac{2 \cdot \alpha_K[i-3]}{3} + \frac{\alpha_K[i]}{3} \quad (C)$$

As soon as the interpolated frames 8' and 9' are determined, they are subsequently passed to the
 20 decoder 20 as is shown in graph 50. Due to the value of INTERPOLATE # =2, the value delay is also set to 2, which instructs the selector 40 to pass the output signal of the delay element 32 to the decoder 20. After the interpolated frames are passed to the decoder 20, frame 10 is present at the output of the delay element 32. Consequently, frame 10 is passed to the decoder 20 directly after frame 9'.

25 In graph 52 it is shown that frame 13 is missing too. As long the number of errors indicated by the signal ERR is smaller than the delay value, the selector 40 keeps passing the output signal of the delay element 32 to the decoder 20. Only if an interpolated frame (i.e. frame 13) is calculated after the value of INTERPOLATE # is received from the quality detection means, the selector 40 passes the interpolated frame instead of the output signal of the delay

element 32 to the decoder 20. Because the number of errors (ERR) do not exceed the value of DELAY, no discontinuities do occur.

If a prolonged period of absence of a source signal is detected, the delay value is reset to 0, in order to make the delay not larger than necessary. This can be seen from graph 50 and 52 in which the value of DELAY is reduced to 0 after three frames without source signal have been received.

In the quality determining means 16 according to Fig. 5, the output signal of the channel decoder is applied to an error detector 66 and to a silence detector 60. If the receiver comprises a channel decoder which already has an output indicating the presence of incorrigible errors, the error detector comprises a simple buffer which holds the error signal until the next frame is presented at the output of the receiver. Otherwise the error detector 60 determines whether the received frame comprises incorrigible errors.

The error detector 66 presents for each incorrigible frame a count signal to an error counter 64 in order to increment the count value. The count value is passed to the maximum value determiner 62 and to an output terminal representing the signal ERR. This maximum value determiner 62 takes over the count value only if it is larger than its present output value. The output signal of the maximum value determiner 62 represents the delay value as discussed with reference to Fig. 3.

The error detector 66 presents a signal indicating the reception of a first correct frame after one or more incorrigible frames. This signal is used to reset the error counter, and for causing the buffer 16 to present its content as output signal INTERPOLATE # in order to start an interpolation to complete the incorrigible frames.

The silence detector determines the presence of a predetermined number of frames carrying a very small or zero signal. If this number is reached, the silence detector resets the value of DELAY at the output of the maximum value determiner 62 to 0, in order to set the delay value in the interpolator 14 (or the arrangement 14 + 18) to zero.

In the embodiment of the invention according to Fig. 6, the source signal to be transmitted is applied to an encoder 8 to obtain an encoded signal. The output of the encoder 8 is connected to an input of a buffer 72. The output signal (frames) of the buffer 72 is offered to a transmitter 10 for transmission to the second node 4. The buffer 72 is arranged for temporary storing the frames offered to the transmitter 10, to have them still available in case a re-transmission is requested by the second node 4.

In the second node 4, the signal from the first node 2 is obtained from the transmission medium by a receiver 12. The output of the receiver 12 is connected to a first input of a selector 74, an input of a buffer memory 7, and to an input of an error detector 76. The error detector 76 determines whether the frames transmitted by the first node 2 are correctly received by the second node 4. In the case the frames are received correctly, the error detector 76 instructs the selector 74 to pass the output signal of the receiver 12 directly to the decoder 20. This is also shown in Fig. 7.

Graph 79 shows the sequence of frames generated by the encoder 8. Graph 80 shows the sequence of frames at the output of the receiver 12 and graph 81 shows the sequence of frames passed to the decoder 20. From Fig. 7 it is clear that the frames 1,2 and 3 are correctly received by the receiver 12 and that they are passed directly to the decoder 20. In the case the error detector 76 detects a transmission error, the selector 74 is instructed to pass the previous frame to the decoder 20. The error detector 76 transmits via a transmitter 78 a request for re-transmission of the erroneously received frame. The buffer 7 is present to store frames subsequent to the erroneously received frame received before the re-transmitted frame is received. This is required in to be able to pass the frames in the correct order to the decoder 20.

In graph 80 it can be seen that frame 4 is received in error. The error detector 76 will request re-transmission of frame 4. The transmitter takes frame 4 from its buffer 72 and retransmits it to node 2. With respect to Fig. 7 it is assumed that the first node re-transmits frame 4 before it transmits frame 5. This can be achieved by using a positive acknowledge procedure, in which the reception of each frame is confirmed by the second node. In the same way is dealt with the erroneous reception of the frames 8,9 and 12.

Fig. 8 shows the situation in case negative acknowledgment is used, in which only the reception of erroneously received frames is communicated to the first node. From graph 86 it can be seen that frame 5 is received before re-transmitted frame 4. To maintain the correct order of the frames, the frame 5 is temporarily stored in the buffer memory 7 until the re-transmitted frame 4 is received. After the re-transmitted frame 4 is passed to the decoder 20, the selector 74 passes the delayed frame 5 to the decoder 20. The selector 74 keeps passing the delayed frames to the decoder 20, in order to prevent discontinuities until the next error occurs. If two frames are missing such as is indicated with respect to the frames 7 and 8 in graph 86 a re-transmission can already take place before any subsequent frame is transmitted to the second node 4.

Consequently, no buffering is required in said second node and the received frames are directly

passed to the decoder 50. During the occurrence of the errors, the same frame 7 is repeatedly passed to the decoder 20. However now a delay is introduced in the first node as can be seen from graphs 85 and 86.

After the occurrence of a silence period, the delay values in the first node and the second node are reset to 0, as can be seen from the graphs 85, 86 and 87.

In the second node according to Fig. 9, the audio processing according to the invention is shown. The signal from the first node is received by the receiver 90 and is passed to a control device 92 which performs the function of error detector and interpolator as explained with reference to the previous drawings. A first output of the control device carrying the received frame is passed to a decoder 94. The output signal of the decoder 94 is connected to a first input of an adder 97. The output of the adder 97 is coupled to a loudspeaker 102 via an amplifier 98.

The second node further comprises a microphone 104 which is coupled to an encoder 110 via an amplifier 106. The output of the encoder 110 is connected to an input of a transmitter 112 for transmitting the encoded signal to the first node.

According to one aspect of the present invention, a level of comfort noise is introduced which is dependent on the amount of delay. Thereto, the delay value DELAY is passed by the control device 92 to a comfort noise generator 96. The comfort noise generator 96 introduces a comfort noise signal into the loudspeaker 102 by supplying a noise signal with a level which increases with the delay value to the adder 97.

According to a further aspect of the invention, an amount of side tone is introduced which decreases with an increasing delay value. Side tone is introduced in order to give the user the possibility to hear his/her own voice in the loudspeaker giving the indication that the system is operative. However side tone may be a cause of echoes which can become annoying in the case of a large transmission delay. By reducing the side tone level with increasing delay, it is prevented that due to the increased decoding delay annoying echoes occur. The introduction of a variable level side tone is done by the amplifier 100 which is controlled by the delay value from the control device 92.

Claims



1. Transmission system comprising a first node with a source encoder for deriving an encoded signal from an input signal, the first node further comprises a transmitter for transmitting the encoded signal to a second node via a transmission medium, the second node comprising reconstruction means for deriving a reconstructed signal from the encoded signal,
5 characterized in that the reconstruction means are arranged for providing the reconstructed signal immediately, if the quality of the received encoded signal meets some quality criterion, and in that the reconstruction means are arranged for providing the reconstructed signal after a reconstruction delay, if the quality of the received encoded signal does not meet said quality criterion.
- 10 2. Transmission system according to claim 1, characterized in that the quality criterion is the completeness of the received encoded signal, and in that the reconstruction means comprise completion means for completing the reconstructed signal if the received signal is not complete.
3. Transmission system according to claim 1, characterized in that the reconstruction
15 means are arranged for increasing the reconstruction delay in dependence of the quality of the received encoded signal.
4. Transmission system according to claim 1,2 or 3, characterized in that the reconstruction means are arranged for reducing the reconstruction delay after detection of the absence of a reconstructed signal.
- 20 5. Transmission system according to one of the claims 1, 2, 3 or 4, characterized in that the source signal comprises a speech signal, in that the second node comprises comfort noise introduction means for introducing comfort noise with a level that increases with decreasing quality of the received encoded signal.
6. Transmission system according one of the claims 1, 2, 3, 4 or 5, characterized in
25 that the transmission system comprises a full duplex speech transmission system, and in that the second node comprises side tone introduction means for introducing a side tone with a level which decreases with the reconstruction delay.

7. Transmission system according to claim 2 characterized in that the completion means are arranged for requesting re-transmission of the missing parts of the encoded signal by the first node.

8. Transmission system according to claim 2, characterized in that the completion
5 means are arranged for deriving the missing parts of the encoded or reconstructed signal by interpolation of surrounding parts of the encoded or reconstructed signal.

9. Node for use in a transmission system, comprising reconstruction means for deriving a reconstructed signal from an encoded signal, characterized in that the reconstruction means are arranged for providing the reconstructed signal immediately, if the quality of the
10 received encoded signal meets some quality criterion, and in that the reconstruction means are arranged for providing the reconstructed signal after a reconstruction delay, if the quality of the received encoded signal does not meet said quality criterion.

10. Reconstruction means, comprising a decoder for deriving a reconstructed signal from an encoded signal, characterized in that the reconstruction means are arranged for providing
15 the reconstructed signal immediately, if the quality of the received encoded signal meets some quality criterion, and in that the reconstruction means are arranged for providing the reconstructed signal after a reconstruction delay, if the quality of the received encoded signal does not meet said quality criterion.

11. Method for decoding an encoded signal, comprising deriving a reconstructed
20 signal from an encoded signal, characterized in that the method comprises decoding the encoded signal immediately after reception if the quality of the received encoded signal meets some quality criterion, and in that the method comprises providing the reconstructed signal immediately, if the quality of the received encoded signal meets some quality criterion, and providing the reconstructed signal after a reconstruction delay, if the quality of the received
25 encoded signal does not meet said quality criterion.

