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Chen

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(54) **COMBINING TRANSPONDER BANDWIDTHS FOR SOURCE AND FORWARD ERROR CORRECTION ENCODING EFFICIENCY**

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This patent is subject to a terminal disclaimer.

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H04B 7/185 (2006.01)
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(52) **U.S. Cl.**
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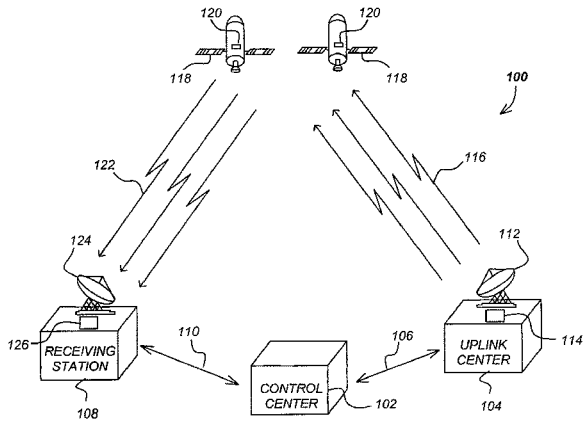
(57) **ABSTRACT**

An apparatus and method for combining transponder bandwidths comprises a wide-band virtual transponder for transmitting a single data stream. The wide-band virtual transponder is comprised of a plurality of narrow-band physical transponders. A plurality of elementary streams are statistically multiplexed to create the single data stream, wherein the single data stream is forward error correction encoded and demultiplexed into a plurality of transponder streams for transmission by the plurality of physical transponders. The physical transponders each use a different portion of a signal spectrum, wherein the different portion may be guard bands or a combination of legacy bands and guard bands. Upon receipt, the transponder streams are multiplexed to recover the single data stream, wherein the recovered single data stream is forward error correction decoded and statistically demultiplexed to recover the plurality of elementary streams.

25 Claims, 5 Drawing Sheets



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H04B 14/04	(2006.01)
H04K 1/10	(2006.01)
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See application file for complete search history.

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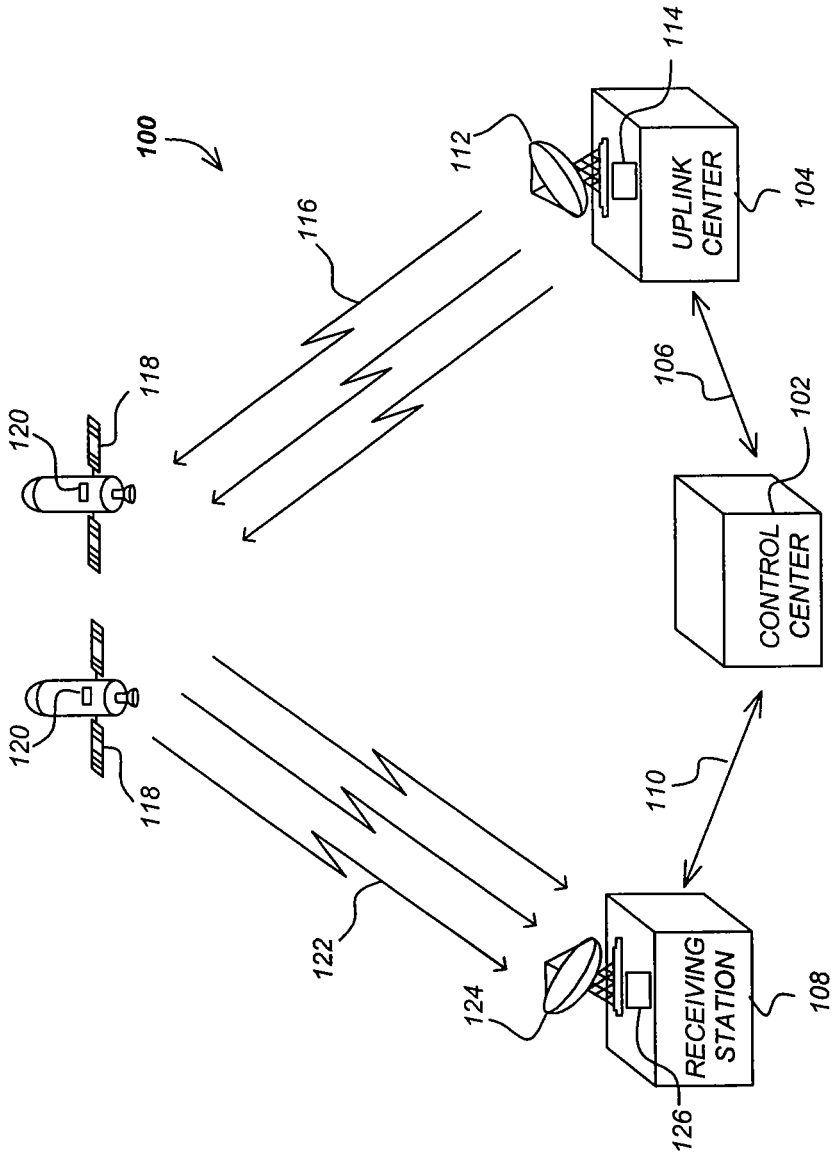
100
UPLINK CENTER
104
CONTROL CENTER
102
RECEIVING STATION
108
106
110
112
114
116
118
120
122
124
126

FIG. 1

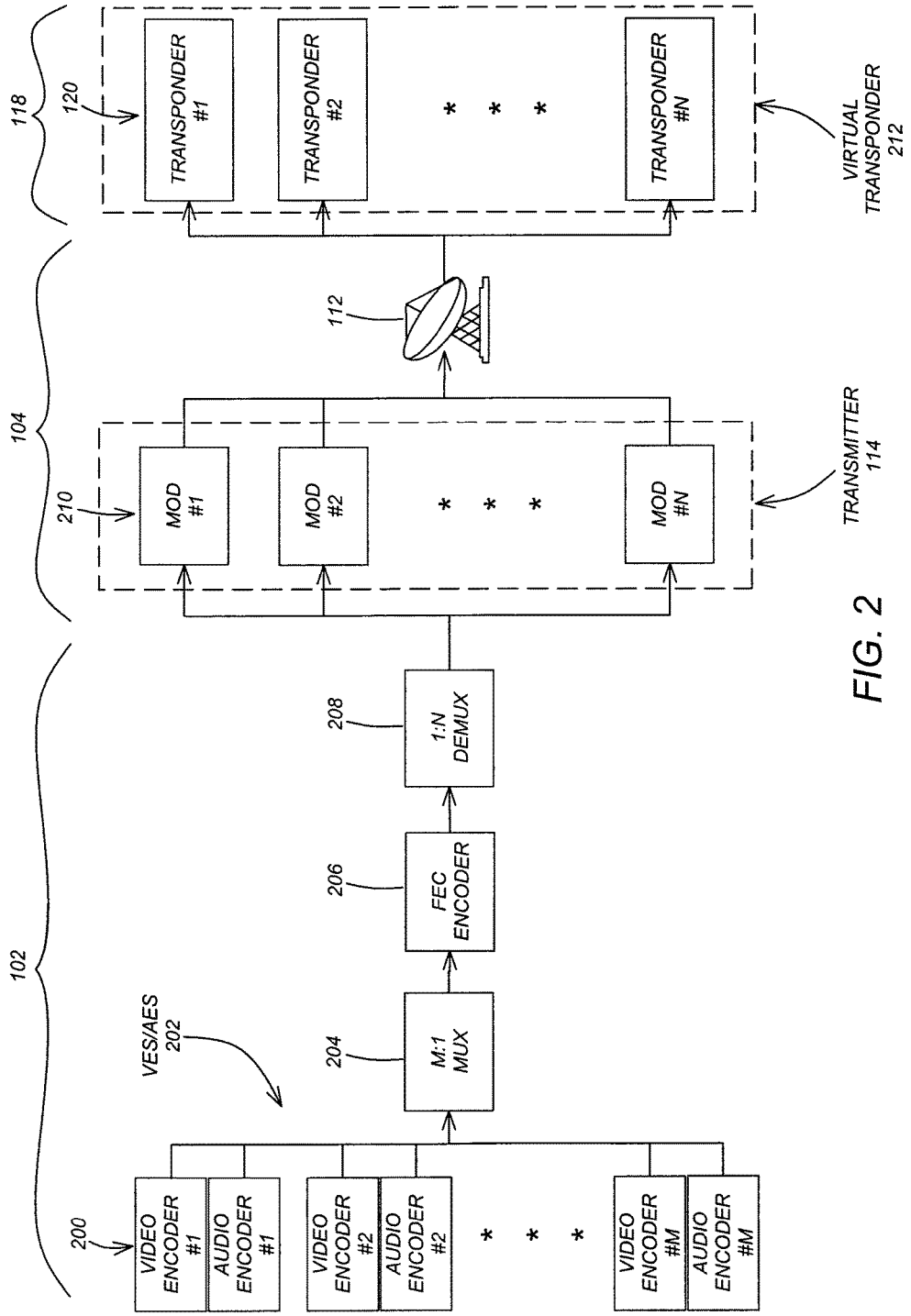
118
120
TRANSPONDER #1
TRANSPONDER #2
TRANSPONDER #N
VIRTUAL TRANSPONDER 212
104
112
210
MOD #1
MOD #2
MOD #N
TRANSMITTER 114
102
208
1:N DEMUX
206
FEC ENCODER
VES/AES 202
204
M:1 MUX
200
VIDEO ENCODER #1
AUDIO ENCODER #1
VIDEO ENCODER #2
AUDIO ENCODER #2
VIDEO ENCODER #M
AUDIO ENCODER #M

FIG. 2

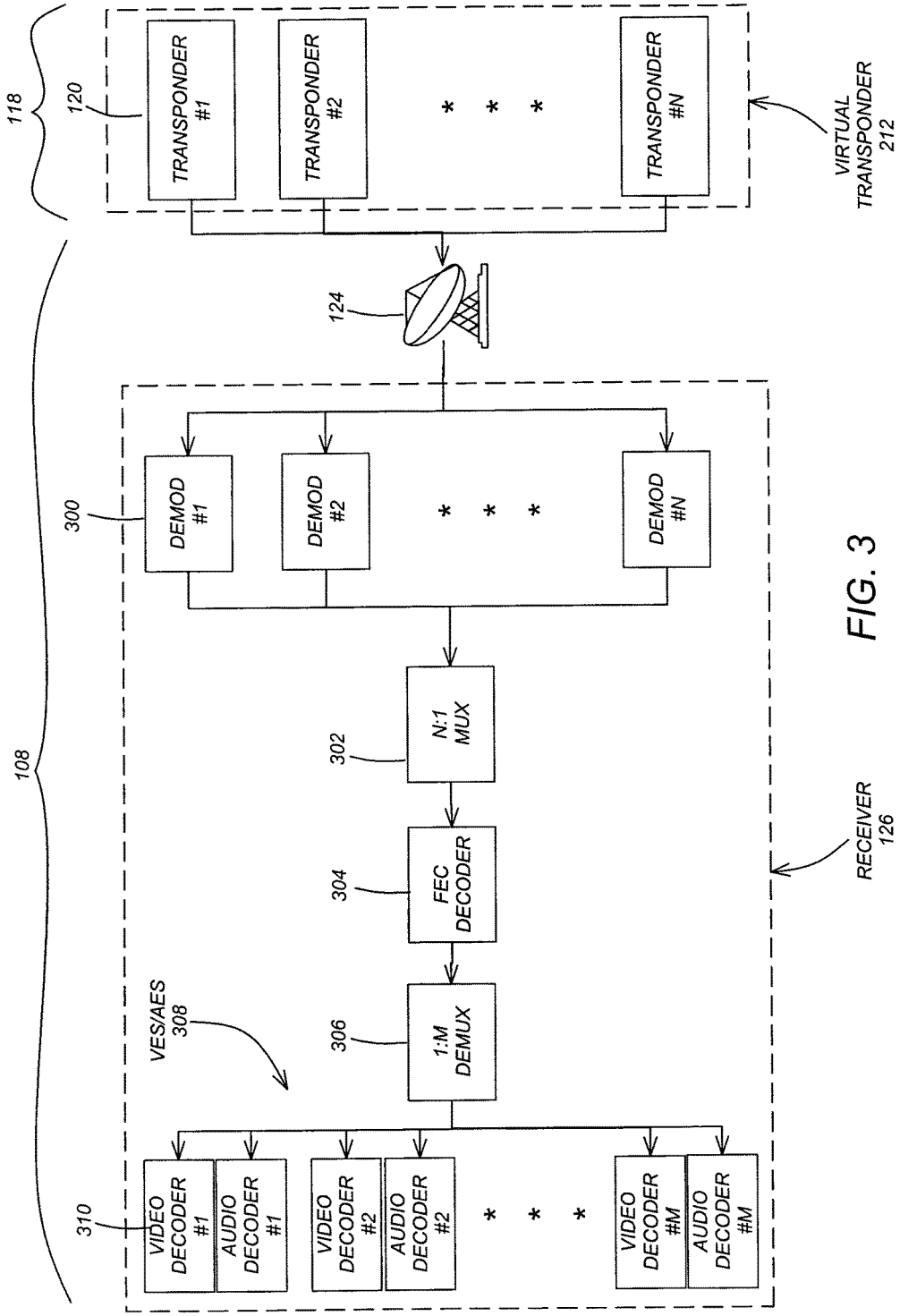
118
120
TRANSPONDER #1
TRANSPONDER #2
TRANSPONDER #N
VIRTUAL TRANSPONDER 212
124
108
300
DEMOD #1
DEMOD #2
DEMOD #N
302
N:1 MUX
304
FEC DECODER
306
1:M DEMUX
VES/AES 308
310
VIDEO DECODER #1
AUDIO DECODER #1
VIDEO DECODER #2
AUDIO DECODER #2
VIDEO DECODER #M
AUDIO DECODER #M
RECEIVER 126

FIG. 3

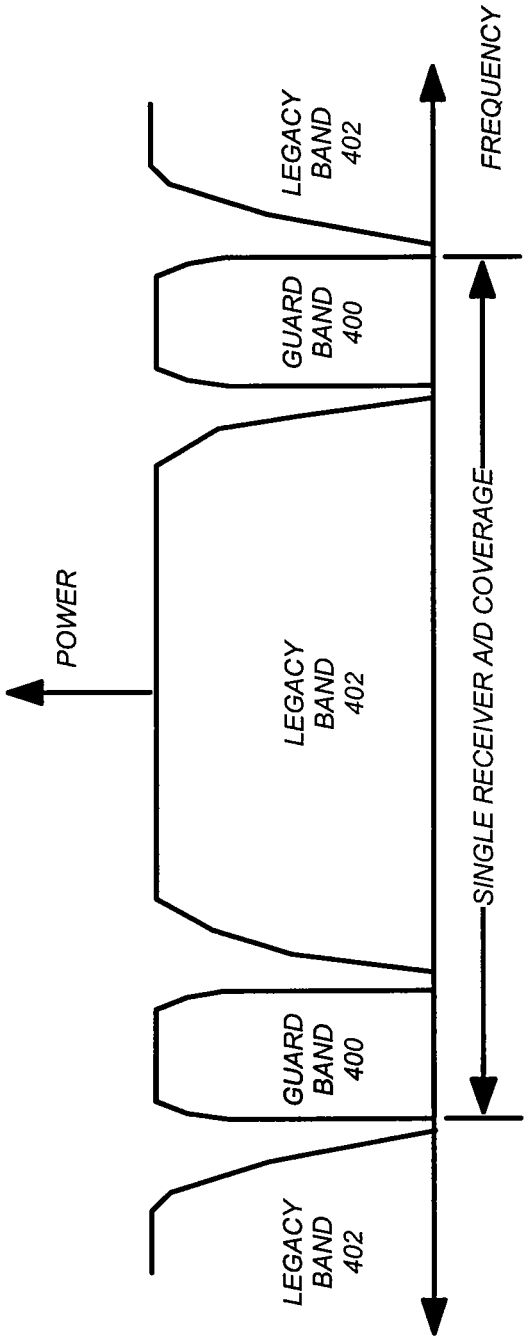
POWER
LEGACY BAND 402
GUARD BAND 400
LEGACY BAND 402
GUARD BAND 400
LEGACY BAND 402
SINGLE RECEIVER A/D COVERAGE
FREQUENCY

FIG. 4

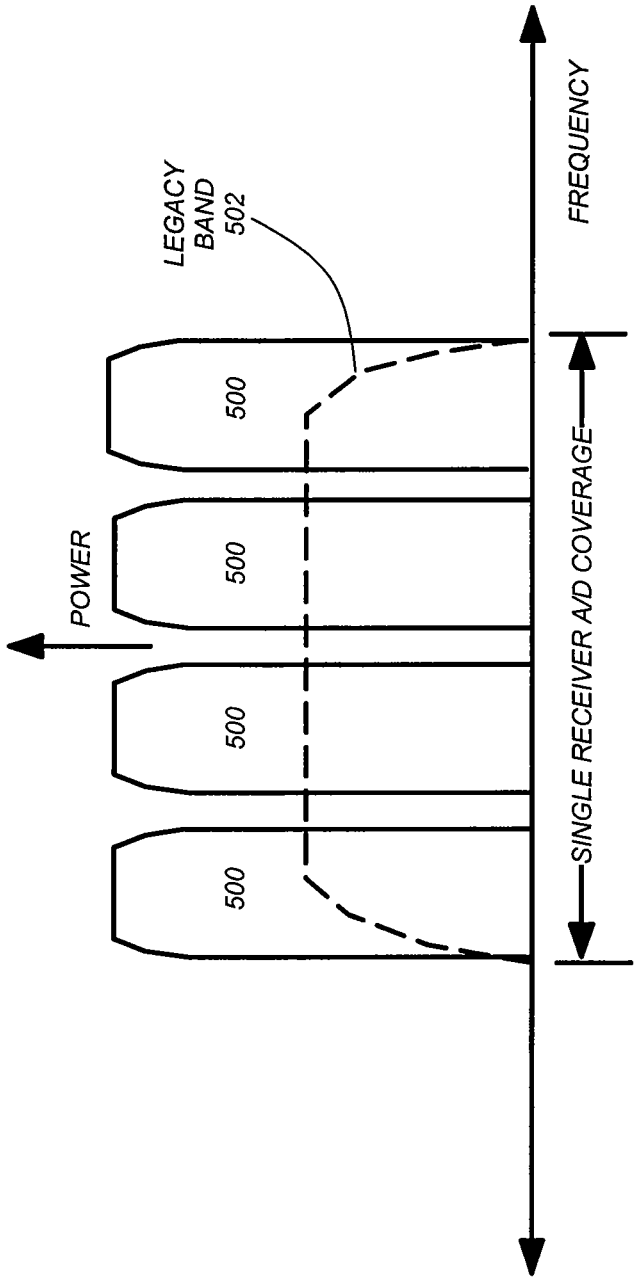
POWER
500
500
500
500
LEGACY BAND 502
SINGLE RECEIVER A/D COVERAGE
FREQUENCY

FIG. 5

COMBINING TRANSPONDER BANDWIDTHS FOR SOURCE AND FORWARD ERROR CORRECTION ENCODING EFFICIENCY

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention relates to systems and methods for the spectral efficient transmission of signals, and more particularly, for combining transponder bandwidths for source and forward error correction encoding efficiency.

2. Description of the Related Art

Digital Direct Broadcast Systems (DBS), such as DIRECTV®, which is provided by the assignee of the present invention, have become very successful. However, as such systems evolve, there is an increasing demand for additional bandwidth to carry an ever-increasing set of audio, video and data services.

Guard bands represent an attractive source of bandwidth that is still available. For example, in the current DIRECTV® frequency plan, a symbol rate of 20 MHz and an excess bandwidth ratio of 0.2 are used for a transponder, and a guard band of 5.16 MHz exists between adjacent transponders of the same polarization. This is a legacy configuration from earlier satellite communication standards for analog frequency modulation (FM) transmissions, wherein analog FM transmissions require a higher carrier-to-noise ratio (CNR) (on the order of 14 dB), and are therefore more susceptible to spectral re-growth effects from traveling wave tube amplifier (TWTA) non-linearity and other imperfections. Actually, the designed guard band has provided more than enough margin for analog FM transmissions to reject spread signal energy due to adjacent channel interference.

In comparison, the digital DBS signal requires a lower CNR, on the order of 7.6 dB with the prevailing quadrature phase shift keying (QPSK) modulation and concatenated forward error correction (FEC) codes with a code rate of 6/7. With the advent of turbo codes, which provide higher coding gains than conventional codes, the required CNR drops even lower, to around 5.4 dB for the same code rate. Again, other factors being equal, signals with smaller CNRs are less susceptible to noise and interference effects. Therefore, the existing guard band for the current DIRECTV® frequency plan may be reduced or even eliminated with only a small impact on communication performance. Eliminating the existing guard band would increase spectral efficiency by a factor of 21%. A throughput increase of this ratio would be achieved by increasing the symbol rate without the need to increase the code rate.

Consequently, there is a need in the art for methods and systems that allow for efficient use of a fragmented signal spectrum, such as from a plurality of non-contiguous guard bands. There is also a need in the art for methods and systems that reduce FEC code latency. The present invention satisfies these needs.

SUMMARY OF THE INVENTION

To address the requirements described above, the present invention discloses an apparatus and method for combining transponder bandwidths, comprising a wide-band virtual transponder for transmitting a single data stream using existing the frequency plan. The wide-band virtual transponder is comprised of a plurality of relatively narrow-band physical transponders. The narrow-band physical transponders each use a different portion of a signal spectrum, wherein the different portions may comprise non-contiguous portions of the signal spectrum, such as guard bands, or contiguous portions of the signal spectrum, such as a combination of legacy bands and guard bands in the signal spectrum.

A plurality of elementary streams are multiplexed to create the single data stream, wherein the single data stream is forward error correction encoded and demultiplexed into a plurality of transponder streams for transmission by the plurality of narrow-band physical transponders. Upon receipt, the transponder streams are multiplexed to recover the single data stream, wherein the recovered single data stream is forward error correction decoded and demultiplexed to recover the plurality of elementary streams.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

FIG. **1** is a diagram illustrating an exemplary direct broadcast satellite system according to a preferred embodiment of the present invention;

FIG. **2** is a block diagram that further illustrates an exemplary signal transmission system according to the preferred embodiment of the present invention;

FIG. **3** is a block diagram that further illustrates an exemplary signal reception system according to the preferred embodiment of the present invention;

FIG. **4** illustrates the insertion of guard-band signals between legacy band signals according to the preferred embodiment of the present invention; and

FIG. **5** illustrates the construction of high spectral-efficiency signals according to the preferred embodiment of the present invention.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

In the following description of the preferred embodiment, reference is made to the accompanying drawings which form a part hereof, and in which is shown by way of illustration a specific embodiment in which the invention may be practiced. It is to be understood that other embodiments may be utilized and structural changes may be made without departing from the scope of the present invention.

Overview

The present invention combines transponder bandwidths using a wide-band "virtual" transponder comprised of a plurality of narrow-band physical transponders for transmitting a single data stream. A plurality of elementary streams are statistically multiplexed for compression to create the single data stream. The single data stream is forward error correction encoded for channel impairment correction. Thereafter, the single encoded data stream is demultiplexed into a plurality of transponder streams, and each transponder stream is modulated and transmitted to the plurality of narrow-band physical transponders. The narrow-band physical transponders, in turn, re-transmit the plurality of transponder streams. Upon receipt from the plurality of narrow-band physical transponders, the transponder streams are demodulated and multiplexed to recover the single data

stream. The recovered single data stream is forward error correction decoded and demultiplexed to recover the plurality of elementary streams.

Using this technique, the present invention allows for the efficient use of a signal spectrum represented by the transmissions from each transponder. Specifically, the narrow-band physical transponders each use a different portion of a signal spectrum, wherein the different portions may comprise non-contiguous portions of the signal spectrum, such as guard bands, or the different portions may comprise a combination of legacy bands and guard bands in the signal spectrum. Without this technique, the limited throughput of a typical narrow bandwidth might not support the many channels that are required for efficient statistical multiplexing.

The present invention also reduces FEC code latency. The time duration of an FEC code for a lone signal provided by the guard band is quite long, due to the small symbol rate a narrow-band signal can support. By "pooling" the bandwidths of multiple narrow-band signals for the FEC code, the effective symbol rate is increased, resulting in a significant reduction in code length and therefore code latency. This can be important since more powerful and longer turbo codes are increasingly used in quasi-error free communication.

Direct Broadcast Satellite System

FIG. **1** is a diagram illustrating an exemplary direct broadcast satellite system **100** according to a preferred embodiment of the present invention. The system **100** includes a control center **102** operated by a service provider in communication with an uplink center **104** via a link **106** and with receiving stations **108** via a link **110**. The control center **102** provides broadcast materials to the uplink center **104** and coordinates with the receiving stations **108** to offer various services, including key management for encryption and decryption, etc.

The uplink center **104** receives the broadcast materials from the control center **102** and, using an antenna **112** and transmitter **114**, transmits the broadcast materials via uplink **116** to one or more satellites **118**, each of which may include one or more transponders **120**. The satellites **118** receive and process the broadcast materials, and re-transmit the broadcast materials to receiving stations **108** via a downlink **122** using transponders **120**. Receiving stations **108** receive the broadcast materials from the satellites **118** via an antenna **124**, and decrypt and decode the broadcast materials using a receiver **126**.

Signal Transmission

FIG. **2** is a block diagram that further illustrates an exemplary signal transmission system according to the preferred embodiment of the present invention. The control center **102** includes a plurality M of video and/or audio encoders **200** that each encode a video and/or audio source into a video elementary stream (VES) and/or audio elementary stream (AES) **202**. The resulting M video and/or audio elementary streams **202** are statistically multiplexed at **204**, wherein the value M:**1** indicates a multiplexing ratio that matches the throughput of the system. The resulting single data stream is then FEC encoded at **206**. After encoding, the single encoded data stream is demultiplexed at **208** into N transponder data streams, wherein the value 1:N indicates a demultiplexing ratio that matches the number of transponders **120** being used. In the uplink center **104**, each of the N transponder data streams is separately modulated **210** by the transmitter **114**, and then uplinked via antenna **112** to the satellites **118**. A plurality N of the transponders **120** on the satellites **118** (where N may comprise all of the transponders **120** or a subset of the transponders **120**) are treated as a "virtual" transponder **212**, wherein each of the N transponder data streams is routed to a different one of the N transponders **120** for re-transmission. Note that all N transponders do not have to be of the same bandwidth, and together they may carry a combination of legacy and guard-band signals as may be desired.

Signal Reception

FIG. **3** is a block diagram that further illustrates an exemplary signal reception system according to the preferred embodiment of the present invention. As in FIG. **2**, a plurality N of the transponders **120** on the satellites **118** (where N may comprise all of the transponders **120** or a subset of the transponders **120**) are treated as a "virtual" transponder **212**, wherein each of the N transponder data streams is routed to a different one of the N transponders **120** for re-transmission. At the receiving stations **108**, each of the N transponder data streams is downlinked from the satellites **118** via antenna **124** and receiver **126**. In the receiver **126**, each of the N transponder data streams is separately demodulated **300**. After demodulation, the N transponder data streams are properly time-aligned and multiplexed at **302** to recover the single encoded data stream. The single encoded data stream is then FEC decoded at **304**. The resulting single data stream is statistically demultiplexed at **306** to recover the M plurality of video and/or audio elementary streams **308**. Each of the M video and/or audio elementary stream **308** are decoded by one of a plurality M of video and/or audio decoders **310** to complete the signal reception.

Spectrum Examples

There are a number of advantages to the present invention. One advantage is that the present invention allows efficient use of a fragmented signal spectrum, such as from non-contiguous guard bands. Consider the example shown in FIG. **4**, which illustrates the insertion of guard band signals **400** between legacy band signals **402**. In this example, the rate ratio between the legacy band **402** and the guard band **400** is approximately 4:1. To use these guard bands **400**, the N transponder data streams described in FIGS. **2** and **3** are transmitted by the N transponders **120** in N guard bands. Alternatively, the N transponder data streams described in FIGS. **2** and **3** are transmitted by the N transponders **120** in a combination of N legacy bands and guard bands.

Another advantage is that the present invention allows narrow-band transponders **120** to simultaneously achieve high CNR and statistical-multiplexing efficiencies. Consider the example shown in FIG. **5**, which illustrates the construction of high spectral-efficiency signals **500** in the legacy band **502**. For high-throughput communication, spectral efficiency dictates a CNR that may be beyond current satellite TWTA power availability. For a given TWTA power, reducing the signal bandwidth can increase the CNR enough to meet the requirement. Multiple transponders **120**, properly configured and spaced in the frequency domain in this way, can cover the entire signal bandwidth of interest. While each narrow-bandwidth signal might not support good statistical-multiplexing efficiency, the combined signal may do so with the present invention.

Yet another advantage is that the present invention reduces FEC code latency. The combined bandwidth provided by the present invention increases the effective symbol rate, thereby resulting in a shortened time duration of a given FEC.

Other Considerations

The communications system described herein is assumed to operate with a constant-envelope signal on all transponders **120**. Typically, a single-carrier QPSK or 8PSK signal is used to maximize TWTA power efficiency. Either single-channel or multiple-channel receivers **126** may be used with the present invention.

In a single-channel receiver **126** design, a single tuner with a fast, single-set, analog-to-digital (A/D) converter covers several transponder **120** signals that comprise a part or all of the virtual transponder **212**. For example, if two guard bands **400** on either side of a legacy signal band **402** in FIG. **4** are to be combined, then the A/D converter of the receiver **126** must cover the bandwidth depicted in FIG. **4**. After A/D conversion, digital filtering in the receiver **126** would be used to select the two guard bands **400**, demodulating the signals to extract relevant information for further processing.

Alternatively, a multiple channel receiver **126** design may include a tuner and A/D converter for each physical transponder **120**. Compared with a single-tuner receiver **126**, the tuners and A/Ds in this embodiment are replicated in the receiver **126**, but the A/Ds can be slower, as they only need to cover a narrow-band signal from one of the transponders **120**.

Conclusion

In conclusion, the present invention allows efficient use of a signal spectrum, such as non-contiguous guard bands or a combination of legacy bands and guard bands, and allows narrow-band transponders to achieve high CNR and statistical-multiplexing efficiencies at the same time. In addition, the present invention works with any modulation or FEC schemes. Moreover, the present invention requires only a moderate increase in system and receiver complexity.

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching.

It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto. The above specification, examples and data provide a complete description of the manufacture and use of the apparatus and method of the invention. Since many embodiments of the invention can be made without departing from the scope of the invention, the invention resides in the claims hereinafter appended.

What is claimed is:

1. A method for transmitting a plurality of M concurrent elementary data streams from a first entity to a plurality of receivers via N narrow band physical transponders, each of the N narrow band physical transponders communicatively coupled to only one of a plurality of antennas, comprising the steps of:

generating, in the first entity, a single data stream from the M elementary data streams;

error correction encoding the single data stream comprising the M elementary data streams;

demultiplexing the single data stream into N transponder streams;

separately modulating and wirelessly transmitting each of the N transponder streams; and

receiving and wirelessly transmitting, in a second entity, the N transponder streams via a wide-band virtual transponder comprised of the N narrow band physical transponders, each of the N narrow band physical transponders directly transmitting an associated one of the N transponder streams to the plurality of receivers via the coupled antenna on a different portion of a signal spectrum than the other N narrow-band transponders;

wherein at least two of the different portions of the signal spectrum are non-contiguous in frequency.

2. The method of claim **1**, wherein the step of generating the single data stream comprises the step of:

statistically multiplexing the M elementary data streams to produce the single data stream.

3. The method of claim **1**, further comprising the steps of:

receiving the N transponder streams from the N transponders in one of the plurality of receivers; and

multiplexing the received N transponder streams to recover the single data stream.

4. The method of claim **1**, wherein:

the method further comprises the step of demultiplexing the encoded single data stream into the N transponder streams; and

wherein the signal spectrum comprises a guard frequency band of a legacy signal spectrum.

5. The method of claim **1**, further comprising the steps of:

receiving the N transponder streams from the N transponders in one of the plurality of receivers;

multiplexing the received N transponder streams to recover the encoded single data stream;

decoding the recovered encoded single data stream; and

demultiplexing the recovered data stream to recover at least one of the M elementary data streams.

6. The method of claim **1**, wherein at least one of the N narrow band transponders has a bandwidth different than at least one of the other N narrow band transponders.

7. The method of claim **1**, wherein the number of concurrent elementary data streams M is selected to match the throughput of the system.

8. The method of claim **1**, wherein the single data stream is time demultiplexed into the N transponder streams.

9. An apparatus for transmitting a plurality of M concurrent elementary data streams from a first entity to a plurality of receivers via N narrow band physical transponders, each of the N narrow band physical transponders communicatively coupled to only one of a plurality of antennas, comprising:

a multiplexer, for generating, in a first entity, a single data stream from the M elementary streams;

an encoder for encoding the single data stream comprising the M elementary data streams;

a demultiplexer, for demultiplexing the single data stream into N transponder streams;

a transmitter, for separately modulating and wirelessly transmitting each of the N transponder streams; and

a wide-band virtual transponder, disposed in a second entity, for receiving and wirelessly transmitting the N transponder streams via a wide-band virtual transponder comprised of N narrow band physical transponders, each of the N narrow band physical transponders for

directly transmitting an associated one of the N transponder streams to the plurality of receivers via the coupled antenna on a different portion of a signal spectrum than the other N narrow-band transponders;

wherein at least two of the different portions of the signal spectrum are non-contiguous in frequency.

10. The apparatus of claim **9**, wherein the multiplexer is a statistical multiplexer.

11. The apparatus of claim **9**, wherein each of the plurality of receivers comprises:

a tuner for receiving the N transponder streams from the N transponders; and

a multiplexer for multiplexing the received N transponder streams to recover the single data stream.

12. The apparatus of claim **9**, wherein:

the apparatus further comprises a demultiplexer for demultiplexing the encoded single data stream into the N transponder streams; and

wherein the signal spectrum comprises a legacy signal spectrum and wherein at least one of the different portions of the signal spectrum comprises a frequency guard band of the legacy signal spectrum.

13. The apparatus of claim **9**, wherein each of the plurality of receivers further comprises:

a tuner for receiving the N transponder streams from the N transponders;

a multiplexer for multiplexing the received N transponder streams to recover the encoded single data stream;

a decoder for decoding the recovered encoded single data stream; and

a demultiplexer for demultiplexing the recovered data stream to recover at least one of the M elementary data streams.

14. The apparatus of claim **9**, wherein at least one of the N narrow band transponders has a bandwidth different than at least one of the other N narrow band transponders.

15. The apparatus of claim **9**, wherein the demultiplexer time demultiplexes the single data stream into the N transponder streams.

16. A method for receiving M concurrent elementary data streams, comprising:

separately demodulating N transponder streams received from a wide band virtual transponder, wherein:

the N transponder streams together comprise the M elementary data streams together error correction encoded as a single data stream that is demultiplexed into the N transponder streams and each of the N transponder streams are directly and wirelessly received from an associated one of N narrow-band transponders via a physical antenna communicatively coupled to only one of the N narrow-band transponders; and

each of the N narrow band transponders transmits the associated transponder stream on a different portion of a signal spectrum than the other N narrow-band transponders;

time-aligning the separately demodulated N transponder streams;

multiplexing the separately demodulated N transponder streams to recover the error correction encoded single data stream comprising the M elementary data streams;

error correction decoding the single data stream comprising the M elementary data streams to recover a decoded single data stream; and

demultiplexing the decoded single data stream to recover the M elementary data streams;

wherein the signal spectrum comprises a plurality of different portions, and at least two of the different portions of the signal spectrum are non-contiguous in frequency.

17. The method of claim **16**, wherein the signal spectrum comprises a legacy signal spectrum and wherein at least one of the different portions of the signal spectrum comprises a guard band of the legacy signal spectrum.

18. The method of claim **16**, wherein the M elementary data streams are statistically multiplexed.

19. The method of claim **16**, wherein at least one of the N narrow band transponders has a bandwidth different than at least one of the other N narrow band transponders.

20. The method of claim **16**, wherein the demultiplexer time demultiplexes the single data stream into the N transponder streams.

21. An apparatus for receiving a plurality of M concurrent elementary data streams, comprising:

a tuner for separately demodulating N transponder streams received from a wide band virtual transponder, wherein:

the N transponder streams together comprise the M elementary data streams together error correction encoded as a single data stream that is demultiplexed into the N transponder streams and each of the N transponder streams are wirelessly received from an associated one of N narrow-band physical transponders via a physical antenna communicatively coupled to only one of the N narrow-band transponders; and

each of the N narrow band transponders transmits the associated transponder stream on a different portion of a signal spectrum than the other N narrow-band transponders;

means for time-aligning the separately demodulated N transponder streams;

a multiplexer for multiplexing the separately demodulated N transponder streams to recover the error correction encoded single data stream comprising the M elementary data streams;

an error correction decoder for decoding the recovered error correction encoded single data stream comprising the M concurrent data streams to recover the single data stream; and

a demultiplexer for demultiplexing the single data stream to recover the M elementary data streams;

wherein the signal spectrum comprises a plurality of different portions, and at least two of the different portions of the signal spectrum are non-contiguous in frequency.

22. The apparatus of claim **21**, wherein the signal spectrum comprises a legacy signal spectrum and wherein at least one of the different portions of the signal spectrum comprises a guard band of the legacy signal spectrum.

23. The apparatus of claim **21**, wherein the M elementary data streams are statistically multiplexed, and the demultiplexer is a statistical demultiplexer.

24. The apparatus of claim **21**, wherein at least one of the N narrow band transponders has a bandwidth different than at least one of the other N narrow band transponders.

25. The apparatus of claim **21**, wherein the single data stream is time demultiplexed into the N transponder streams.

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