US006557030B1

(12) United States Patent
Hoang

(10) Patent No.: US 6,557,030 B1
(45) Date of Patent: Apr. 29, 2003

(54) **SYSTEMS AND METHODS FOR PROVIDING VIDEO-ON-DEMAND SERVICES FOR BROADCASTING SYSTEMS**

(75) Inventor: **Khoi Hoang**, Newark, CA (US)

(73) Assignee: **PrediWave Corp.**, Fremont, CA (US)

(*) Notice: Subject to any disclaimer, the term of this patent is extended or adjusted under 35 U.S.C. 154(b) by 63 days.

(21) Appl. No.: **09/584,832**

(22) Filed: **May 31, 2000**

(51) **Int. Cl.**[7] **B06F 15/16**

(52) **U.S. Cl.** **709/217**; 709/203; 709/219; 709/234; 707/104.1; 725/97; 725/145

(58) **Field of Search** 709/203, 219, 709/231, 232, 234; 707/102, 104.1; 725/95, 97, 145

(56) **References Cited**

U.S. PATENT DOCUMENTS

4,945,563 A		7/1990	Horton et al.	
4,963,995 A		10/1990	Lang	358/335
5,132,992 A		7/1992	Yurt et al.	
5,521,630 A		5/1996	Chen et al.	
5,557,316 A		9/1996	Hoarty et al.	348/7
5,604,528 A		2/1997	Edwards et al.	
5,612,742 A		3/1997	Krause et al.	
5,619,249 A		4/1997	Billock et al.	
5,632,681 A		5/1997	Bakoglu et al.	
5,654,746 A		8/1997	McMullan, Jr. et al.	
5,745,758 A	*	4/1998	Shaw et al.	
5,751,282 A		5/1998	Girard et al.	345/327
5,751,709 A	*	5/1998	Rathnavelu	
5,768,539 A		6/1998	Metz et al.	
5,781,228 A		7/1998	Sposato	
5,790,423 A		8/1998	Lau et al.	
5,805,804 A		9/1998	Laursen et al.	395/200.02
5,815,146 A		9/1998	Youden et al.	345/327
5,850,258 A		12/1998	Kang	
5,856,973 A		1/1999	Thompson	370/389
5,892,535 A		4/1999	Allen et al.	348/9

(List continued on next page.)

OTHER PUBLICATIONS

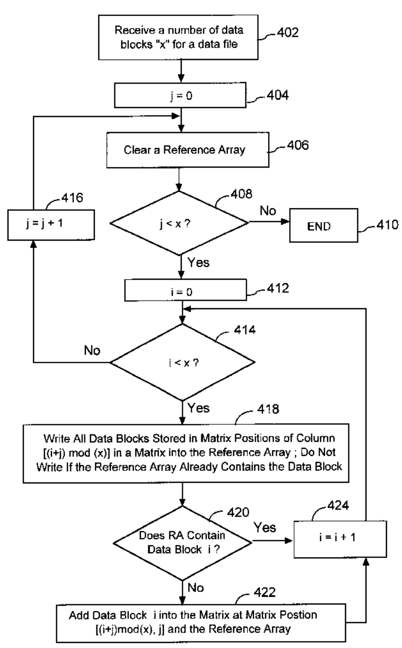
Video on Demand Technologies and Demonstrations, Final Report, Marek Podgorny and Geoffrey C. Fox, Northeast Parallel Architectures Center, Contract No.: F–30602–94–C–0256, Mar. 1997, pp. 1–108.

Primary Examiner—Le Hien Luu
Assistant Examiner—Stephan Willett
(74) *Attorney, Agent, or Firm*—Perkins Coie LLP

(57) **ABSTRACT**

A method for sending data to a client to provide data-on-demand services comprises the steps of: receiving a data file, specifying a time interval, parsing the data file into a plurality of data blocks based on the time interval such that each data block is displayable during a time interval, determining a required number of time slots to send the data file, allocating to each time slot at least a first of the plurality of data blocks and optionally one or more additional data blocks, such that starting from any of the time slots, (i) the data file can be displayed by accessing the first of the plurality of data blocks; (ii) at a consecutive time slot, a next data block sequential to a prior displayed data block is available for displaying; and (iii) repeating step (ii) until all of the plurality of data blocks for the data file has been displayed, and sending the plurality of data blocks based on the allocating step.

10 Claims, 5 Drawing Sheets



U.S. PATENT DOCUMENTS

5,909,594	A	*	6/1999	Ross et al.	
5,915,094	A	*	6/1999	Kouloheris et al.	709/219
5,949,948	A		9/1999	Krause et al.	386/6
5,961,603	A		10/1999	Kunkel et al.	
5,978,649	A		11/1999	Khan	
5,995,092	A		11/1999	Yuen et al.	
6,005,599	A	*	12/1999	Asai et al.	
6,011,798	A	*	1/2000	McAlpine	
6,012,080	A	*	1/2000	Ozden et al.	
6,018,765	A		1/2000	Durana et al.	709/217
6,028,847	A	*	2/2000	Beanland	
6,029,045	A		2/2000	Picco et al.	
6,029,046	A		2/2000	Khan et al.	
6,049,332	A	*	4/2000	Boetje	
6,049,539	A		4/2000	Lee et al.	
6,055,560	A		4/2000	Mills et al.	709/200
6,055,571	A		4/2000	Fulp et al.	
6,058,122	A		5/2000	Hwang et al.	370/522
6,075,570	A		6/2000	Usui et al.	348/569
6,076,062	A		6/2000	Van Streenbrugge	
6,112,023	A	*	8/2000	Dave et al.	
6,118,821	A		9/2000	Matsumoto et al.	
6,128,467	A		10/2000	Rege	455/4.2
6,160,546	A		12/2000	Thompson et al.	345/327
6,167,085	A	*	12/2000	Saunders et al.	
6,169,767	B1		1/2001	Strolle et al.	
6,198,723	B1	*	3/2001	Parruck et al.	
6,199,076	B1		3/2001	Logan et al.	707/501
6,212,681	B1		4/2001	Ikeda	
6,215,526	B1		4/2001	Barton et al.	348/473
6,219,355	B1		4/2001	Brodigan	370/486
6,222,530	B1	*	4/2001	Sequeira	
6,233,389	B1		5/2001	Barton	386/46
6,246,695	B1		6/2001	Seazholtz et al.	370/468
6,263,019	B1		7/2001	Ryan	
6,263,114	B1	*	7/2001	Saunders	
6,266,369	B1		7/2001	Wang et al.	
6,389,075	B2		5/2002	Want et al.	
6,477,579	B1		11/2002	Kunkel et al.	

* cited by examiner

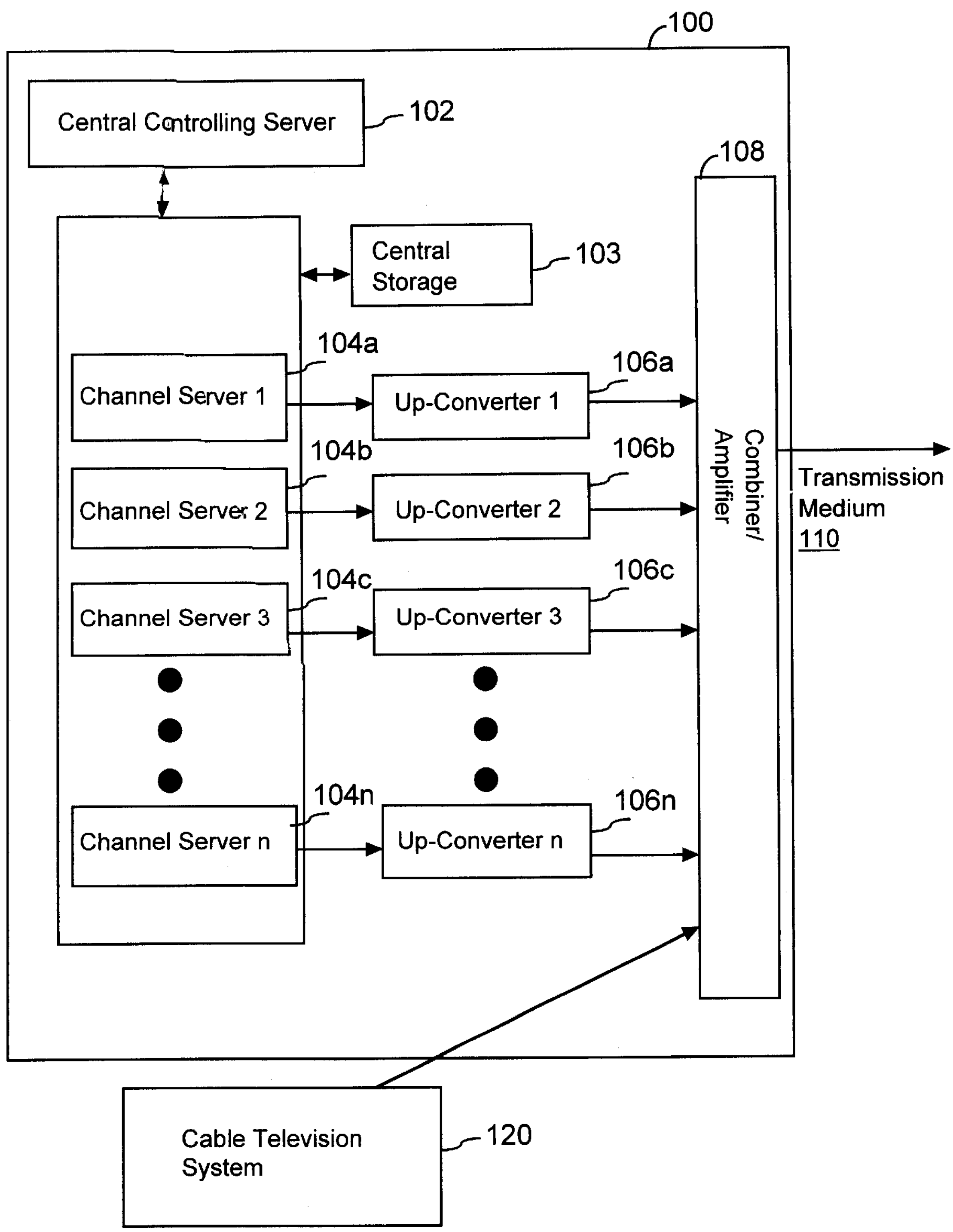

100
Central Controlling Server
102
108
Central Storage
103
104a
106a
Channel Server 1
Up-Converter 1
104b
106b
Combiner/ Amplifier
Channel Server 2
Up-Converter 2
Transmission Medium 110
104c
106c
Channel Server 3
Up-Converter 3
104n
106n
Channel Server n
Up-Converter n
Cable Television System
120

FIG. 1A

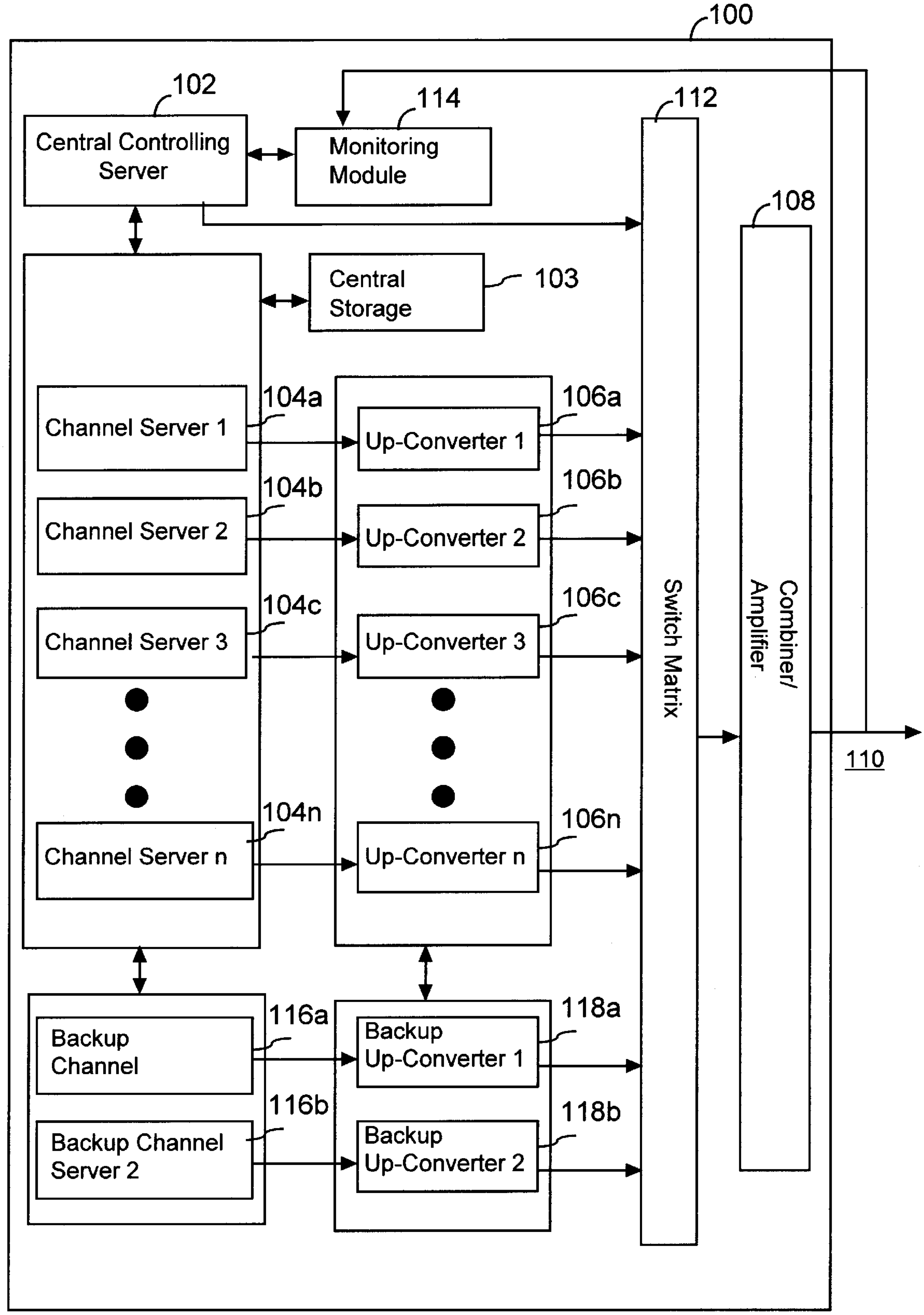

100
102
Central Controlling Server
114
Monitoring Module
112
108
Central Storage
103
Channel Server 1
104a
Up-Converter 1
106a
Channel Server 2
104b
Up-Converter 2
106b
Channel Server 3
104c
Up-Converter 3
106c
Switch Matrix
Combiner/ Amplifier
110
Channel Server n
104n
Up-Converter n
106n
Backup Channel
116a
Backup Up-Converter 1
118a
Backup Channel Server 2
116b
Backup Up-Converter 2
118b

FIG. 1B

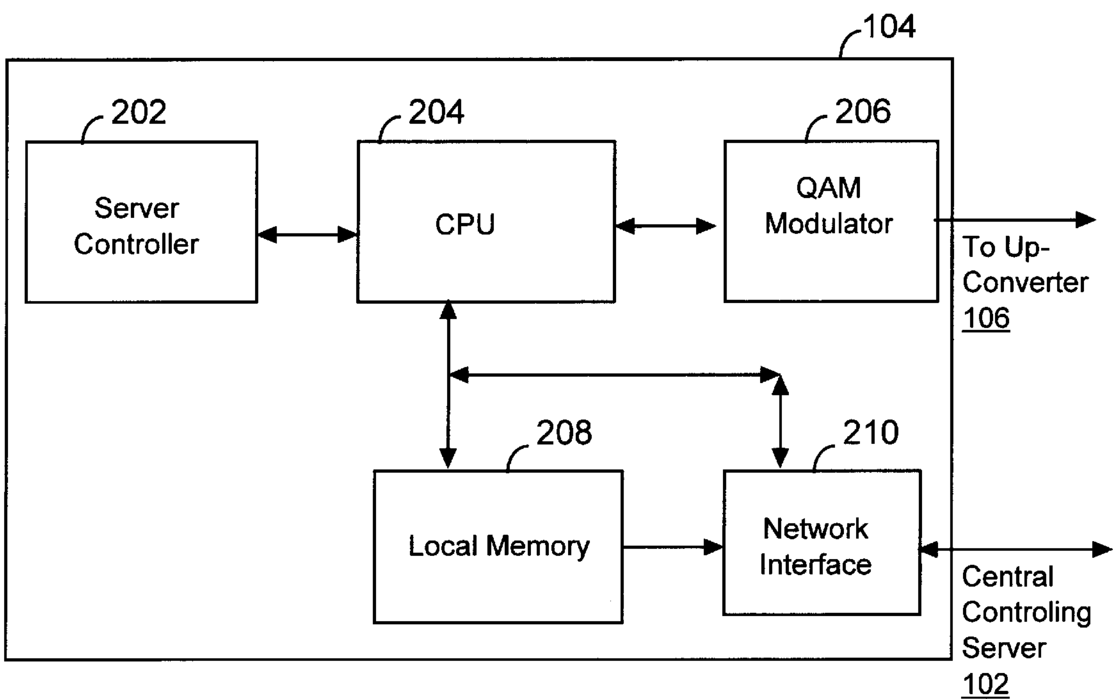

104
202
Server Controller
204
CPU
206
QAM Modulator
To Up-Converter 106
208
Local Memory
210
Network Interface
Central Controling Server 102

FIG. 2

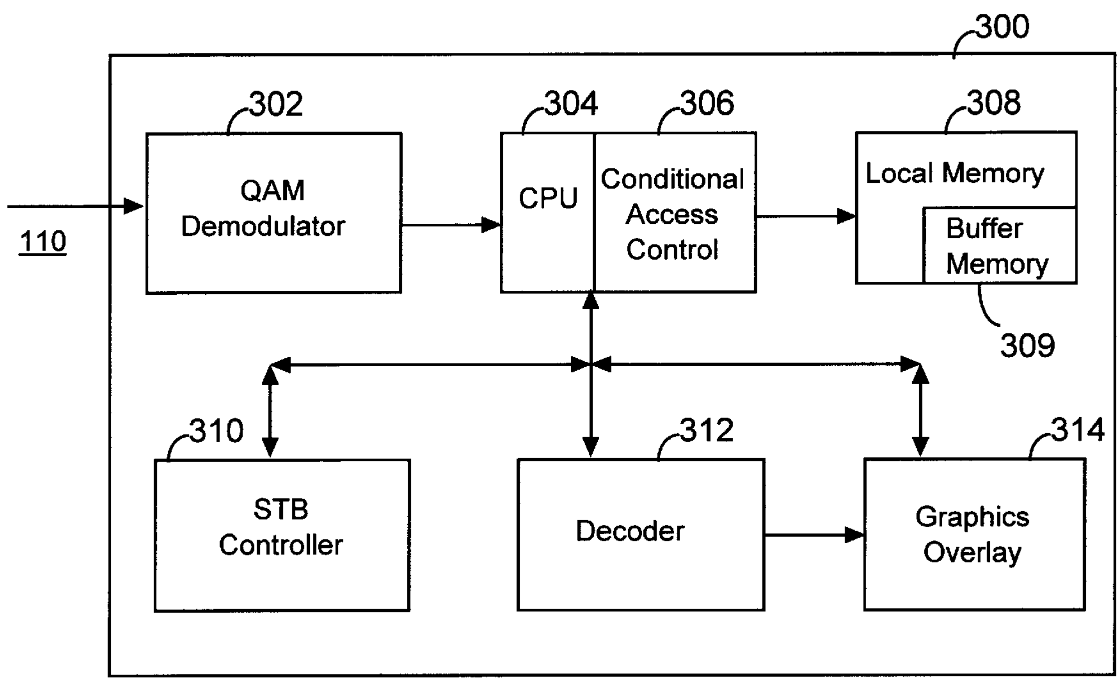

300
302
QAM Demodulator
304
CPU
306
Conditional Access Control
308
Local Memory
Buffer Memory
309
110
310
STB Controller
312
Decoder
314
Graphics Overlay

FIG. 3

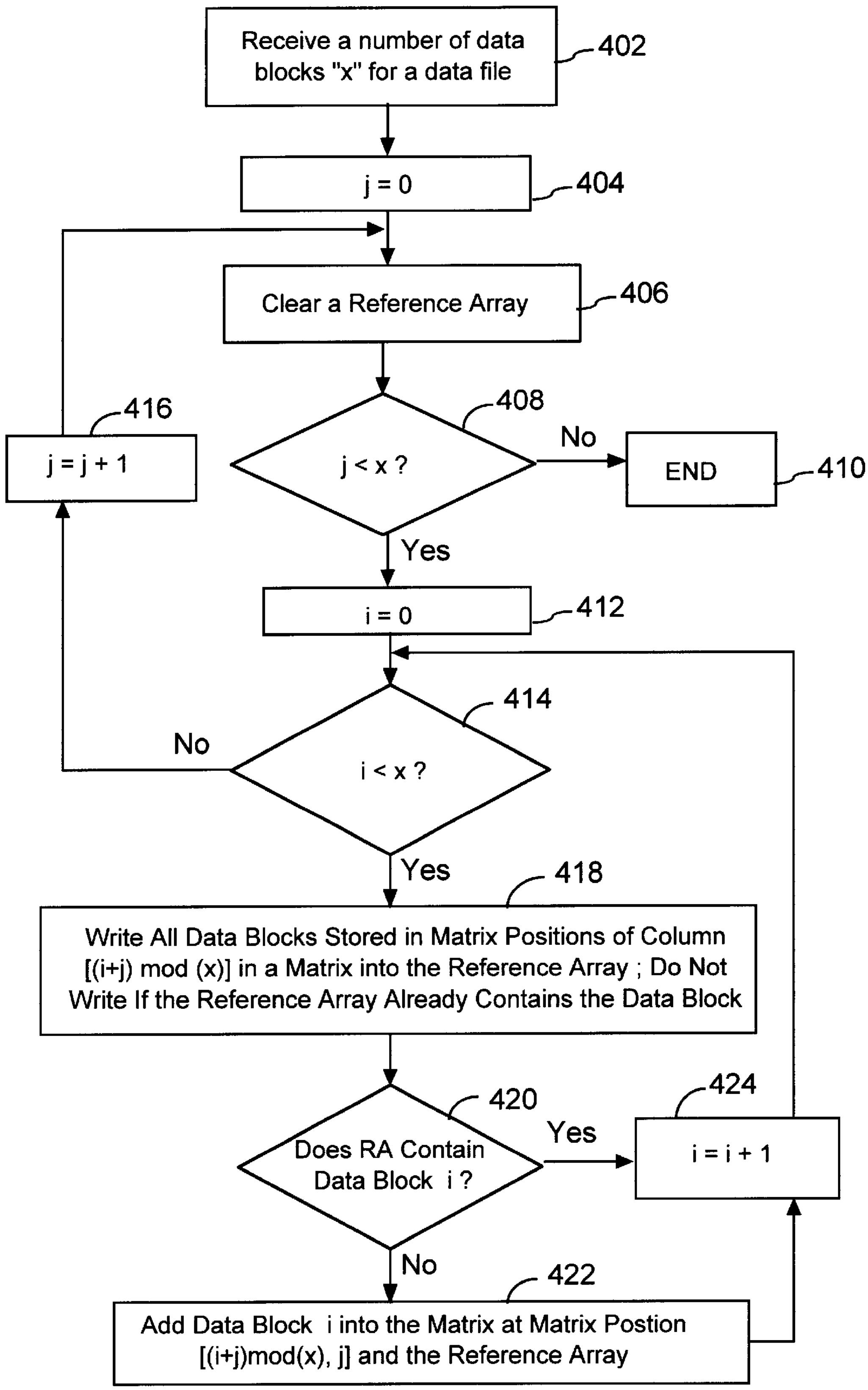

Receive a number of data blocks "x" for a data file
402
j = 0
404
Clear a Reference Array
406
408
j < x ?
No
END
410
416
j = j + 1
Yes
i = 0
412
414
No
i < x ?
Yes
418
Write All Data Blocks Stored in Matrix Positions of Column [(i+j) mod (x)] in a Matrix into the Reference Array ; Do Not Write If the Reference Array Already Contains the Data Block
420
Does RA Contain Data Block i ?
Yes
424
i = i + 1
No
422
Add Data Block i into the Matrix at Matrix Postion [(i+j)mod(x), j] and the Reference Array

FIG. 4

SYSTEMS AND METHODS FOR PROVIDING VIDEO-ON-DEMAND SERVICES FOR BROADCASTING SYSTEMS

BRIEF DESCRIPTION OF THE INVENTION

This invention relates generally to data-on-demand systems. In particular, this invention relates to video-on-demand systems.

BACKGROUND OF THE INVENTION

Video-on-demand (VOD) systems are one type of data-on-demand (DOD) system. In VOD systems, video data files are provided by a server or a network of servers to one or more clients on a demand basis.

In a conventional VOD architecture, a server or a network of servers communicates with clients in a standard hierarchical client-server model. For example, a client sends a request to a server for a data file (e.g., a video data file). In response to the client request, the server sends the requested file to the client. In the standard client-server model, a client's request for a data file can be fulfilled by one or more servers. The client may have the capability to store any received data file locally in non-volatile memory for later use. The standard client-server model requires a two-way communications infrastructure. Currently, two-way communications requires building new infrastructure because existing cables can only provide one-way communications. Examples of two-way communications infrastructure are hybrid fiber optics coaxial cables (HFC) or all fiber infrastructure. Replacing existing cables is very costly and the resulting services may not be affordable to most users.

In addition, the standard client-server model has many mitations when a service provider (e.g., a cable company) attempts to provide VOD services to a large number of clients. One limitation of the standard client-server model is that the service provider has to implement a mechanism to continuously listen and fulfill every request from each client within the network; thus, the number of clients who can receive service is dependent on the capacity of such a mechanism. One mechanism uses massively-parallel computers having large and fast disk arrays as local servers. However, even the fastest existing local server can only deliver video data streams to about 1000 to 2000 clients at one time. Thus, in order to service more clients, the number of local servers must increase. Increasing local servers requires more upper level servers to maintain control of the local servers.

Another limitation of the standard client-server model is that each client requires its own bandwidth. Thus, the total required bandwidth is directly proportional to the number of subscribing clients. Cache memory within local servers has been used to improve bandwidth limitation but using cache memory does not solve the problem because cache memory is also limited.

Presently, in order to make video-on-demand services more affordable for clients, existing service providers are increasing the ratio of clients per local server above the local server's capabilities. Typically, a local server, which is capable of providing service to 1000 clients, is actually committed to service 10,000 clients. This technique may work if most of the subscribing clients do not order videos at the same time. However, this technique is set up for failure because most clients are likely to want to view videos at the same time (i.e., evenings and weekends), thus, causing the local server to become overloaded.

Thus, it is desirable to provide a system that is capable of providing on-demand services to a large number of clients over virtually any transmission medium without replacing existing infrastructure.

SUMMARY OF THE INVENTION

In an exemplary embodiment, at a server side, a method for sending data to a client to provide data-on-demand services comprises the steps of: receiving a data file, specifying a time interval, parsing the data file into a plurality of data blocks based on the time interval such that each data block is displayable during the time interval, determining a required number of time slots to send the data file, allocating to each time slot at least a first of the plurality of data blocks and optionally one or more additional data blocks, such that the plurality of data blocks is available in sequential order to a client accessing the data file during any time slot, and sending the plurality of data blocks based on the allocating step. In one embodiment, the parsing step includes the steps of: determining an estimated data block size, determining a cluster size of a memory in a channel server, and parsing the data file based on the estimated data block size and the cluster size. In another embodiment, the determining step includes the step of assessing resource allocation and bandwidth availability.

In an exemplary embodiment, at a client side, a method for processing data received from a server to provide data-on-demand services comprises the steps of: (a) receiving a selection of a data file during a first time slot; (b) receiving at least one data block of the data file during a second time slot; (c) during a next time slot: receiving any data block not already received, sequentially displaying a data block of the data file, and repeating step (c) until all data blocks of the data file has been received and displayed. In one embodiment, the method for processing data received from a server is performed by a set-top box at the client side.

In an exemplary embodiment, a data file is divided into a number of data blocks and a scheduling matrix is generated based on the number of data blocks. At the server side, the scheduling matrix provides a send order for sending the data blocks, such that a client can access the data blocks in sequential order at a random time. In an exemplary embodiment, a method for generating a scheduling matrix for a data file comprises the steps of: (a) receiving a number.of data blocks [x] for a data file; (b) setting a first variable [j] to zero; (c) setting a second variable [i] to zero; (d) clearing all entries in a reference array; (e) writing at least one data block stored in matrix positions of a column [(i+j) modulo x] in a matrix to a reference array, if the reference array does not already contain the data block; (f) writing a data block [i] into the reference array and a matrix position [(i+j) modulo x, j] of the matrix, if the reference array does not contain the data block [i]; (g) incrementing the second variable [i] by one and repeating step (e) until the second variable [i] is equal to the number of data blocks [x]; and (h) incrementing the first variable [j] by one and repeating the step (c) until the first variable [j] is equal to the number of data blocks [x]. In one embodiment, a scheduling matrix is generated for each data file in a set of data files and a convolution method is applied to generate a delivery matrix based on the scheduling matrices for sending the set of data files.

A data-on-demand system comprises a first set of channel servers, a central controlling server for controlling the first set of channel servers, a first set of up-converters coupled to the first set of channel servers, a combiner/amplifier coupled to the first set of up-converters, and a combiner/amplifier adapted to transmit data via a transmission medium. In an exemplary embodiment, the data-on-demand system further comprises a channel monitoring module for monitoring the system, a switch matrix, a second set of channel servers, and a second set of up-converters. The channel monitoring module is configured to report to the central controlling server when system failure occurs. The central controlling server, in response to report from the channel monitoring module, instructs the switch matrix to replace a defective channel server in the first set of channel servers with a channel server in the second set of channel servers and a defective up-converter in the first set of up-converters with an up-converter in the second set of up-converters.

A method for providing data-on-demand services comprises the steps of calculating a delivery matrix of a data file, sending the data file in accordance with the delivery matrix, such that a large number of clients is capable of viewing the data file on demand. In one embodiment, the data file includes a video file.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. **1**A illustrates an exemplary DOD system in accordance with an embodiment of the invention.

FIG. **1**B illustrates an exemplary DOD system in accordance with another embodiment of the invention.

FIG. **2** illustrates an exemplary channel server in accordance with an embodiment of the invention.

FIG. **3** illustrates an exemplary set-top box in accordance with an embodiment of the invention.

FIG. **4** illustrates an exemplary process for generating a scheduling matrix in accordance with an embodiment of the invention.

DETAILED DESCRIPTION OF THE INVENTION

FIG. **1**A illustrates an exemplary DOD system **100** in accordance with an embodiment of the invention. In this embodiment, the DOD system **100** provides data files, such as video files, on demand. However, the DOD system **100** is not limited to providing video files on demand but is also capable of providing other data files, for example, game files on demand. The DOD system **100** includes a central controlling server **102**, a central storage **103**, a plurality of channel servers **104***a*–**104***n*, a plurality of up-converters **106***a*–**106***n*, and a combiner/amplifier **108**. The central controlling server **102** controls the channel servers **104**. The central storage **103** stores data files in digital format. In an exemplary embodiment, data files stored in the central storage **103** are accessible via a standard network interface (e.g., ethernet connection) by any authorized computer, such as the central controller server **102**, connected to the network. Each channel server **104** is assigned to a channel and is coupled to an up-converter **106**. The channel servers **104** provide data files that are retrieved from the central storage **103** in accordance with instructions from the central controlling server **102**. The output of each channel server **104** is a quadrature amplitude modulation (QAM) modulated intermediate frequency (IF) signal having a suitable frequency for the corresponding up-converter **106**. The QAM-modulated IF signals are dependent upon adopted standards. The current adopted standard in the United States is the data-over-cable-systems-interface-specification (DOCSIS) standard, which requires an approximately 43.75 MHz IF frequency. The up-converters **106** convert IF signals received from the channel servers **104** to radio frequency signals (RF signals). The RF signals, which include frequency and bandwidth, are dependent on a desired channel and adopted standards. For example, under the current standard in the United States for a cable television channel **80**, the RF signal has a frequency of approximately 559.25 MHz and a bandwidth of approximately 6 MHz. The outputs of the up-converters **106** are applied to the combiner/amplifier **108** The combiner/amplifier **108** amplifies, conditions, and combines the received RF signals then outputs the signals out to a transmission medium **110**.

In an exemplary embodiment, the central controlling server **102** includes a graphics user interface (not shown) to enable a service provider to schedule data delivery by a drag-and-drop operation. Further, the central controlling server **102** authenticates and controls the channel servers **104** to start or stop according to delivery matrices. In an exemplary embodiment, the central controlling server **102** automatically selects a channel and calculates delivery matrices for transmitting data files in the selected channel. The central controlling server **102** provides offline addition, deletion, and update of data file information (e.g., duration, category, rating, and/or brief description). Further, the central controlling server **102** controls the central storage **103** by updating data files and databases stored therein.

In an exemplary embodiment, an existing cable television system **120** may continue to feed signals into the combiner/amplifier **108** to provide non-DOD services to clients. Thus, the DOD system **100** in accordance with the invention does not disrupt present cable television services.

FIG. **1**B illustrates another exemplary embodiment of the DOD system **100** in accordance with the invention. In addition to the elements illustrated in FIG. **1**A, the DOD system **100** includes a switch matrix **112**, a channel monitoring module **114**, a set of back-up channel servers **116***a*–**116***b*, and a set of back-up up-converters **118***a*–**118***b*. In one embodiment, the switch matrix **112** is physically located between the up-converters **106** and the combiner/amplifier **108**. The switch matrix **112** is controlled by the central controlling server **102**. The channel monitoring module **114** comprises a plurality of configured set-top boxes, which simulate potential clients, for monitoring the health of the DOD system **100**. Monitoring results are communicated by the channel monitoring module **114** to the central controlling server **102**. In case of a channel failure (i.e., a channel server failure, an up-converter failure, or a communication link failure), the central controlling server **102** through the switch matrix **112** disengages the malfunctioning component and engages a healthy backup component **116** and/or **118** to resume service.

In an exemplary embodiment, data files being broadcasted from the DOD system **100** are contained in motion pictures expert group (MPEG) files. Each MPEG file is dynamically divided into data blocks and sub-blocks mapping to a particular portion of a data file along a time axis. These data blocks and sub-blocks are sent during a pre-determined time in accordance with three-dimensional delivery matrices provided by the central controlling server **102**. A feedback channel is not necessary for the DOD system **100** to provide DOD services. However, if a feedback channel is available, the feedback channel can be used for other purpose, such as billing or providing Internet services.

FIG. **2** illustrates an exemplary channel server **104** in accordance with an embodiment of the invention. The channel server **104** comprises a server controller **202**, a CPU **204**, a QAM modulator **206**, a local memory **208**, and a network interface **210**. The server controller **202** controls the overall operation of the channel server **104** by instructing the CPU **204** to divide data files into blocks (further into sub-blocks and data packets), select data blocks for transmission in accordance with a delivery matrix provided by the central controlling server **102**, encode selected data, compress encoded data, then deliver compressed data to the QAM modulator **206**. The QAM modulator **206** receives data to be transmitted via a bus (i.e., PCI, CPU local bus) or Ethernet connections. In an exemplary embodiment, the QAM modulator **206** may include a downstream QAM modulator, an upstream quadrature amplitude modulation quadrature phase shift keying (QAM/QPSK) burst demodulator with forward error correction decoder, and/or an upstream tuner. The output of the QAM modulator **206** is an IF signal that can be applied directly to an up-converter **106**.

The network interface **210** connects the channel server **104** to other channel servers **104** and to the central controlling server **102** to execute the scheduling and controlling instructions from the central controlling server **102**, reporting status back to the central controlling server **102**, and receiving data files from the central storage **103**. Any data file retrieved from the central storage **103** can be stored in the local memory **208** of the channel server **104** before the data file is processed in accordance with instructions from the server controller **202**. In an exemplary embodiment, the channel server **104** may send one or more DOD data streams depending on the bandwidth of a cable channel (e.g., 6, 6.5, or 8 MHz), QAM modulation (e.g., QAM **64** or QAM **256**), and a compression standard/bit rate of the DOD data stream (i.e., MPEG-1 or MPEG-2).

FIG. **3** illustrates an exemplary set-top box (STB) **300** in accordance with an embodiment of the invention. The STB **300** comprises a QAM demodulator **302**, a CPU **304**, a conditional access module **306** (e.g., a smart card system), a local memory **308**, a buffer memory **309**, a STB controller **310**, a decoder **312**, and a graphics overlay module **314**. The STB controller **310** controls the overall operation of the STB **300** by controlling the CPU **302** and the QAM demodulator **302** to select data in response to a client's request, decode selected data, decompress decoded data, re-assemble decoded data, store decoded data in the local memory **308** or the buffer memory **309**, and deliver stored data to the decoder **312**. In an exemplary embodiment, the STB controller **310** controls the overall operation of the STB **300** based on data packet headers in the data packets received from the transmission medium **110**. In an exemplary embodiment, the local memory **308** comprises non-volatile memory (e.g., a hard drive) and the buffer memory **309** comprises volatile memory.

In one embodiment, the QAM demodulator **302** comprises transmitter and receiver modules and one or more of the following: privacy encryption/decryption module, forward error correction decoder/encoder, tuner control, downstream and upstream processors, CPU and memory interface circuits. The QAM demodulator **302** receives modulated IF signals, samples and demodulates the signals to restore data.

The conditional access module **306** permits a decoding process when access is granted after authentication and/or when appropriate fees have been charged. Access condition is determined by the service provider.

In an exemplary embodiment, when access is granted, the decoder **312** decodes at least one data block to transform the data block into images displayable on an output screen. The decoder **312** supports commands from a subscribing client, such as play, stop, pause, step, rewind, forward, etc.

The graphics overlay module **314** enhances displayed graphics quality by, for example, providing alpha blending or picture-in-picture capabilities. In an exemplary embodiment, the graphics overlay module **314** can be used for graphics acceleration during game playing mode, for example, when the service provider provides games-on-demand services using the system in accordance with the invention.

In an exemplary embodiment, although data files are broadcasted to all cable television subscribers, only the DOD subscriber who has a compatible STB **300** will be able to decode and enjoy data-on-demand services. In one exemplary embodiment, permission to obtain data files on demand can be obtained via a smart card system in the conditional access control module **306**. A smart card may be rechargeable at a local store or vending machine set up by a service provider. In another exemplary embodiment, a flat fee system provides a subscriber unlimited access to all available data files.

In an exemplary embodiment, data-on-demand interactive features permit a client to select at any time an available data file. The amount of time between when a client presses a select button and the time the selected data file begins playing is referred to as a response time. As more resources are allocated (e.g., bandwidth, server capability) to provide DOD services, the response time gets shorter. In an exemplary embodiment, a response time can be determined based on an evaluation of resource allocation and desired quality of service.

In an exemplary embodiment, a selected response time determines the duration of a time slot. The duration of a time slot (TS) is the time interval for playing a data block at normal speed by a client. In an exemplary embodiment, a data file, such as a video file, is divided into a number of data blocks such that each data block can support the playing of the data file for the duration of a time slot.

In one embodiment, the number of data blocks (NUM__OF__BLKS) for each data file can be calculated as follows:

Estimated__BLK__Size=(DataFile__Size*TS)/DataFile__Length (1)

BLK SIZE=(Estimated BLK Size+CLUSTER__SIZE−1 Byte)/CLUSTER__SIZE (2)

BLK__SIZE__BYTES=BLK__SIZE*CLUSTER__SIZE (3)

NUM__OF__BLKS=(DataFile__Size+BLK__SIZE__BYTES−1 Byte)/BLK__SIZE__BYTES (4)

In equations (1) to (4), the Estimated__BLK__Size is an estimated block size (in Bytes); the DataFile__Size is the data file size (in Bytes); TS represents the duration of a time slot (in seconds); DataFile__Length is the duration of the data file (in seconds); BLK SIZE is the number of clusters needed for each data block; CLUSTER__SIZE is the size of a cluster in the local memory **208** for each channel server **104** (e.g., 64 KBytes); LK__SIZE__BYTES is a block size in Bytes. In this embodiment number of blocks (NUM__OF__BLKS) is equal to the data file size (in Bytes) plus a data block size in Bytes minus 1 Byte and divided by a data block size in Bytes. Equations (1) to (4) illustrate one specific embodiment. A person of skill in the art would recognize that other methods are available to calculate a number of data blocks for a data file. For example, dividing a data file into a number of data blocks is primarily a function of an estimated block size and the cluster size of the local memory **208** of a channel server **104**. Thus, the invention should not be limited to the specific embodiment presented above.

FIG. **4** illustrates an exemplary process for generating a scheduling matrix for sending a data file in accordance with an embodiment of the invention. In an exemplary embodiment, this invention uses time division multiplexing (TDM) and frequency division multiplexing (FDM) technology to compress and schedule data delivery at the server side. In an exemplary embodiment, a scheduling matrix is generated for each data file. In one embodiment, each data file is divided into a number of data blocks and the scheduling matrix is generated based on the number of data blocks. Typically, a scheduling matrix provides a send order for sending data blocks of a data file from a server to clients, such that the data blocks are accessible in sequential order by any client who wishes to access the data file at a random time.

At step **402**, a number of data blocks (x) for a data file is received. A first variable, j, is set to zero (step **404**). A reference array is cleared (step **406**). The reference array keeps track of data blocks for internal management purposes. Next, j is compared to x (step **408**). If j is less than x, a second variable, i, is set to zero (step **412**). Next, i is compared to x (step **414**). If i is less than x, data blocks stored in the column [(i+j) modulo (x)] of a scheduling matrix are written into the reference array (step **418**). If the reference array already has such data block(s), do not write a duplicate copy. Initially, since the scheduling matrix does not yet have entries, this step can be skipped. Next, the reference array is checked if it contains data block i (step **420**). Initially, since all entries in the reference array has been cleared at step **406**, there would be nothing in the reference array. If the reference array does not contain data block i, data block i is added into the scheduling matrix at matrix position [(i+j) modulo (x), j] and the reference array (step **422**). After the data block i is added to the scheduling matrix and the reference array, i is incremented by 1, such that i=i+1 (step **424**), then the process repeats at step **414** until i x. If the reference array contains data block i, i is incremented by 1, such that i=i+1 (step **424**), then the process repeats at step **414** until i=x. When i=x, j is incremented by 1, such that j=j+1 (step **416**) and the process repeats at step **406** until j=x. The entire process ends when j=x (step **410**).

In an exemplary embodiment, if a data file is divided into six data blocks (x=6), the scheduling matrix and the reference arrays are as follows:

Scheduling Matrix (SM)

TS0	TS1	TS2	TS3	TS4	TS5
[0,0] blk0	[1,0] blk1	[2,0] blk2	[3,0] blk3	[4,0]blk4	[5,0] blk5
[0,1]	[1,1] blk0	[2,1]	[3,1]	[4,1]	[5,0]
[0,2]	[1,2]	[2,2] blk0	[3,2] blk1	[4,2]	[5,1]
[0,3]	[1,3]	[2,3]	[3,3] blk0	[4,3]	[5,2] blk2
[0,4]	[1,4] blk3	[2,4]	[3,4]	[4,4]blk0	[5,3] blk1
[0,5]	[1,5]	[2,5]	[3,5] blk4	[4,5]	[5,4] blk0

Reference Array (RA)

	space0	space1	space2	space3	space4	space5
TS0	blk0	blk1	blk2	blk3	blk4	blk5
TS1	blk1	blk0	blk2	blk3	blk4	blk5
TS2	blk2	blk0	blk3	blk1	blk4	blk5
TS3	blk3	blk1	blk0	blk4	blk5	blk2
TS4	blk4	blk0	blk5	blk2	blk1	blk3
TS5	blk5	blk2	blk1	blk0	blk3	blk4

Appendix A attached to this application describes a step-by-step process of the exemplary process illustrated in FIG. **4** to generate the above scheduling matrix and reference arrays. In this exemplary embodiment, based on the scheduling matrix above, the six data blocks of the data file are sent in the following sequence:

TS0 => blk0
TS1 => blk0, blk1, blk3
TS2 => blk0, blk2
TS3 => blk0, blk1, blk3, blk4
TS4 => blk0, blk4
TS5 => blk0, blk1, blk2, blk5

In another exemplary embodiment, a look-ahead process can be used to calculate a look-ahead scheduling matrix to send a predetermined number of data blocks of a data file prior to a predicted access time. For example, if a predetermined look-ahead time is the duration of one time slot, for any time slot greater than or equal to time slot number four, data block **4** (blk**4**) of a data file should be received by a STB **300** at a subscribing client at or before TS**3**, but blk**4** would not be played until TS**4**. The process steps for generating a look-ahead scheduling matrix is substantially similar to the process steps described above for FIG. **4** except that the look-ahead scheduling matrix in this embodiment schedules an earlier sending sequence based on a look-ahead time. Assuming a data file is divided into six data blocks, an exemplary sending sequence based on a look-ahead scheduling matrix, having a look-ahead time of the duration of two time slots, can be represented as follows:

TS0 => blk0
TS1 => blk0, blk1, blk3, blk4
TS2 => blk0, blk2
TS3 => blk0, blk1, blk3, blk4, blk5
TS4 => blk0, blk5
TS5 => blk0, blk1, blk2

A three-dimensional delivery matrix for sending a set of data files is generated based on the scheduling matrices for each data file of the set of data files. In the three-dimensional delivery matrix, a third dimension containing IDs for each data file in the set of data files is generated. The three-dimensional delivery matrix is calculated to efficiently utilize available bandwidth in each channel to deliver multiple data streams. In an exemplary embodiment, a convolution method, which is well known in the art, is used to generate a three-dimensional delivery matrix to schedule an efficient delivery of a set of data files. For example, a convolution method may include the following policies: (1) the total number of data blocks sent in the duration of any time slot (TS) should be kept at a smallest possible number; and (2) if multiple partial solutions are available with respect to policy (1), the preferred solution is the one which has a smallest sum of data blocks by adding the data blocks to be sent during the duration of any reference time slot, data blocks to be sent during the duration of a previous time slot (with respect to the reference time slot), and data blocks to be sent during the duration of a next time slot (with respect to the reference time slot). For example, assuming an exemplary system sending two short data files, M and N, where each data file is divided into six data blocks, the sending sequence based on a scheduling matrix is as follows:

TS0 => blk0
TS1 => blk0, blk1, blk3
TS2 => blk0, blk2
TS3 => blk0, blk1, blk3, blk4
TS4 => blk0, blk4
TS5 => blk0, blk1, blk2, blk5

Applying the exemplary convolution method as described above, possible combinations of delivery matrices are as follows:

	Total Data Blocks
Option 1: Send video file N at shift 0 TS	
TS0 => M0, N0	2
TS1 => M0, M1, M3, N0, N1, N3	6
TS2 => M0, M2, N0, N2	4
TS3 => M0, M1, M3, M4, N0, N1, N3, N4	8
TS4 => M0, M4, N0, N4	4
TS5 => M0, M1, M2, M5, N0, N1, N2, N5	8
Option 2: Send video file N at shift 1 TS	
TS0 => M0, N0, N1, N3	4
TS1 => M0, M1, M3, N0, N2	5
TS2 => M0, M2, N0, N1, N3, N4	6
TS3 => M0, M1, M3, M4, N0, N4	6
TS4 => M0, M4, N0, N1, N2, N5	6
TS5 => M0, M1, M2, M5, N0	5
Option 3: Send video file N at shift 2 TS	
TS0 => M0, N0, N2	3
TS1 => M0, M1, M3, N0, N1, N3, N4	7
TS2 => M0, M2, N0, N4	4
TS3 => M0, M1, M3, M4, N0, N1, N2, N5	8
TS4 => M0, M4, N0	3
TS5 => M0, M1, M2, MS, N0, N1, N3	7
Option 4: Send video file N at shift 3 TS	
TS0 => M0, N0, N1, N3, N4	5
TS1 => M0, M1, M3, N0, N4	5
TS2 => M0, M2, N0, N1, N2, N5	6
TS3 => M0, M1, M3, M4, N0	5
TS4 => M0, M4, N0, N1, N3	5
TS5 => M0, M1, M2, M5, N0, N2	6
Option 5: Send video file N at shift 4 TS	
TS0 => M0, N0, N4	3
TS1 => M0, M1, M3, N0, N1, N2, N5	7
TS2 => M0, M2, N0	3
TS3 => M0, M1, M3, M4, N0, N1, N3	7
TS4 => M0, M4, N0, N2	4
TS5 => M0, M1, M2, M5, N0, N1, N3, N4	8
Option 6: Send video file N at shift 5 TS	
TS0 => M0, N0, N1, N2, N5	5
TS1 => M0, M1, M3, N0	4
TS2 => M0, M2, N0, N1, N3	5
TS3 => M0, M1, M3, M4, N0, N2	6
TS4 => M0, M4, N0, N1, N3, N4	6
TS5 => M0, M1, M2, M5, N0, N4	6

Applying policy (1), options **2**, **4**, and **6** have the smallest maximum number of data blocks (i.e., 6 data blocks) sent during any time slot. Applying policy (2), the optimal delivery matrix in this exemplary embodiment is option **4** because option **4** has the smallest sum of data blocks of any reference time slot plus data blocks of neighboring time slots (i.e., 16 data blocks). Thus, optimally for this embodiment, the sending sequence of the data file N should be shifted by three time slots. In an exemplary embodiment, a three-dimensional delivery matrix is generated for each channel server **104**.

When data blocks for each data file are sent in accordance with a delivery matrix, a large number of subscribing clients can access the data file at a random time and the appropriate data blocks of the data file will be timely available to each subscribing client. In the example provided above, assume the duration of a time slot is equal to 5 seconds, the DOD system **100** sends data blocks for data files M and N in accordance with the optimal delivery matrix (i.e., shift delivery sequence of data file N by three time slots) in the following manner:

Time 00:00:00→**M0 N0 N1 N3 N4**
Time 00:00:05→**M0 M1 M3 N0 N4**
Time 00:00:10→**M0 M2 N0 N1 N2 N5**
Time 00:00:15→**M0 M1 M3 M4 N0**
Time 00:00:20→**M0 M4 N0 N1 N3**
Time 00:00:25→**M0 M1 M2 M5** NO **N2**
Time 00:00:30→**M0 N0 N1 N3 N4**
Time 00:00:35→**M0 M1 M3 N0 N4**
Time 00:00:40→**M0 M2 N0 N1 N2 N5**
Time 00:00:45→**M0 M1 M3 M4 N0**
Time 00:00:50→**M0 M4 N0 N1 N3**
Time 00:00:55→**M0 M1 M2 M5 N0 N2**

If at time 00:00:00 a client A selects movie M, the STB **300** at client A receives, stores, plays, and rejects data blocks as follows:

Time 00:00:00 =>	Receive M0 => play M0, store M0.
Time 00:00:05 =>	Receive M1, M3 => play M1, store M0, M1, M3.
Time 00:00:10 =>	Receive M2 => play M2, store M0, M1, M2 M3.
Time 00:00:15 =>	Receive M4 => play M3, store M0, M1, M2, M3, M4.
Time 00:00:20 =>	Receive none => play M4, store M0, M1, M2, M3, M4.
Time 00:00:25 =>	Receive M5 => play M5, store M0, M1, M2, M3, M4, M5.

If at time 00:00:10, a client B selects movie M, the STB **300** at client B receives, stores, plays, and rejects data blocks as follows:

Time 00:00:10 =>	Rcv M0, M2 => play M0, store M0, M2.
Time 00:00:15 =>	Rcv M1, M3, M4 => play M1, store M0, M1, M2, M3, M4.
Time 00:00:20 =>	Rcv none => play M2, store M0, M1, M2, M3, M4.
Time 00:00:25 =>	Rcv M5 => play M3, store M0, M1, M2, M3, M4, M5.
Time 00:00:30 =>	Rcv none => play M4, store M0, M1, M2, M3, M4, M5.
Time 00:00:35 =>	Rcv none => play M5, store M0, M1, M2, M3, M4, M5.

If at time 00:00:15, a client C selects movie N, the STB **300** of the client C receives, stores, plays, and rejects data blocks as follows:

Time 00:00:15 =>	Rcv N0 => play N0, store N0.
Time 00:00:20 =>	Rcv N1 N3 => play N1, store N0, N1, N3.
Time 00:00:25 =>	Rcv N2 => play N2, store N0, N1, N2, N3.
Time 00:00:30 =>	Rcv N4 => play N3, store N0, N1, N2, N3, N4.
Time 00:00:35 =>	Rcv none => play N4, store N0, N1, N2, N3, N4.
Time 00:00:40 =>	Rcv N5 => play N5, store N0, N1, N2, N3, N4, N5.

If at time 00:00:30, a client D also selects movie N, the STB **300** at the client D receives, stores, plays, and rejects data blocks as follows:

Time 00:00:30 =>	Rcv N0, N1, N3, N4 => play N0, store N0, N1, N3, N4.
Time 00:00:35 =>	Rcv none => play N1, store N0, N1, N3, N4.
Time 00:00:40 =>	Rcv N2, N5 => play N2, store N0, N1, N2, N3, N4, N5.
Time 00:00:45 =>	Rcv none => play N3, store N0, N1, N2, N3, N4, N5.
Time 00:00:50 =>	Rcv none => play N4, store N0, N1, N2, N3, N4, N5.
Time 00:00:55 =>	Rcv none => play N5, store N0, N1, N2, N3, N4, N5.

As shown in the above examples, any combination of clients can at a random time independently select and begin playing any data file provided by the service provider.

GENERAL OPERATION

A service provider can schedule to send a number of data files (e.g., video files) to channel servers **104** prior to broadcasting. The central controlling server **102** calculates and sends to the channel servers **104** three-dimensional delivery matrices (ID, time slot, and data block send order). During broadcasting, channel servers **104** consult the three-dimensional delivery matrices to send appropriate data blocks in an appropriate order. Each data file is divided into data blocks so that a large number of subscribing clients can separately begin viewing a data file continuously and sequentially at a random time. The size of a data block of a data file is dependent on the duration of a selected time slot and the bit rate of the data stream of the data file.

For example, in a constant bit rate MPEG data stream, each data block has a fixed size of: Block Size (MBytes)= BitRate (Mb/s)×TS (sec)/8 (1).

In an exemplary embodiment, a data block size is adjusted to a next higher multiple of a memory cluster size in the local memory **208** of a channel server **104**. For example, if a calculated data block length is 720 Kbytes according to equation (1) above, then the resulting data block length should be 768 Kbytes if the cluster size of the local memory **208** is 64 Kbytes. In this embodiment, data blocks should be further divided into multiples of sub-blocks each having the same size as the cluster size. In this example, the data block has twelve sub-blocks of 64 KBytes.

A sub-block can be further broken down into data packets. Each data packet contains a packet header and packet data. The packet data length depends on the maximum transfer unit (MTU) of a physical layer where each channel server's CPU sends data to. In the preferred embodiment, the total size of the packet header and packet data should be less than the MTU. However, for maximum efficiency, the packet data length should be as long as possible.

In an exemplary embodiment, data in a packet header contains information that permits the subscriber client's STB **300** to decode any received data and determine if the data packet belongs to a selected data file (e.g., protocol signature, version, ID, or packet type information). The packet header may also contain other information, such as block/sub-block/packet number, packet length, cyclic redundancy check (CRC) and offset in a sub-block, and/or encoding information.

Once received by a channel server **104**, data packets are sent to the QAM modulator **206** where another header is added to the data packet to generate a QAM-modulated IF output signal. The maximum bit rate output for the QAM modulator **206** is dependent on available bandwidth. For example, for a. QAM modulator **206** with 6 MHz bandwidth, the maximum bit rate is 5.05 (bit/symbol)×6 (MHz)=30.3 Mbit/sec.

The QAM-modulated IF signals are sent to the up-converters **106** to be converted to RF signals suitable for a specific channel (e.g., for CATV channel 80, 559.250 MHz and **6**MHz bandwidth). For example, if a cable network has high bandwidth (or bit rate), each channel can be used to provide more than one data stream, with each data stream occupying a virtual sub-channel. For example, three MPEG1 data streams can fit into a 6 MHz channel using QAM modulation. The output of the up-converters **106** is applied to the combiner/amplifier **108**, which sends the combined signal to the transmission medium **110**.

In an exemplary embodiment, the total system bandwidth (BW) for transmitting "N" data streams is BW=N×bw, where bw is the required bandwidth per data stream. For example, three MPEG-1 data streams can be transmitted at the same time by a DOCSIS cable channel having a system bandwidth of 30.3 Mbits/sec because each MPEG-1 data stream occupies 9 Mbits/sec of the system bandwidth.

Typically, bandwidth is consumed regardless of the number of subscribing clients actually accessing the DOD service. Thus, even if no subscribing client is using the DOD service, bandwidth is still consumed to ensure the on-demand capability of the system.

The STB **300**, once turned on, continuously receives and updates a program guide stored in the local memory **308** of a STB **300**. In an exemplary embodiment, the STB **300** displays data file information including the latest program guide on a TV screen. Data file information, such as video file information, may include movieID, movie title, description (in multiple languages), category (e.g., action, children), rating (e.g., R, PG 13), cable company policy (e.g., price, length of free preview), subscription period, movie poster, and movie preview. In an exemplary embodiment, data file information is sent via a reserved physical channel, such as a channel reserved for firmware update, commercials, and/or emergency information. In another exemplary embodiment, information is sent in a physical channel shared by other data streams.

A subscribing client can view a list of available data files arranged by categories displayed on a television screen. When the client selects one of the available data files, the STB **300** controls its hardware to tune into a corresponding physical channel and/or a virtual sub-channel to start receiving data packets for that data file. The STB **300** examines every data packet header, decodes data in the data packets, and determines if a received data packet should be retained. If the STB **300** determines that a data packet should not be retained, the data packet is discarded.

Otherwise, the packet data is saved in the local memory **308** for later retrieval or is temporarily stored in the buffer memory **309** until it is sent to the decoder **312**. To improve performance efficiency by avoiding frequent read/write into the local memory **308**, in an exemplary embodiment, the STB **300** uses a "sliding window" anticipation technique to lock anticipated data blocks in the memory buffer **309** whenever possible. Data blocks are transferred to the decoder **312** directly out of the memory buffer **309** if a hit in an anticipation window occurs. If an anticipation miss occurs, data blocks are read from the local memory **308** into the memory buffer **309** before the data blocks are transferred to the decoder **312** from the memory buffer **309**.

In an exemplary embodiment, the STB **300** responds to subscribing client's commands via infrared (IR) remote control unit buttons, an IR keyboard, or front panel pushbuttons, including buttons to pause, play in slow motion, rewind, zoom and single step. In an exemplary embodiment, if a subscribing client does not input any action for a predetermined period of time (e.g., scrolling program menu, or selecting a category or movie), a scheduled commercial is played automatically. The scheduled commercial is automatically stopped when the subscribing client provides an action (e.g., press a button in a remote control unit). In another exemplary embodiment, the STB **300** can automatically insert commercials while a video is being played. The service provider (e.g., a cable company) can set up a pricing policy that dictates how frequently commercials should interrupt the video being played.

If an emergency information bit is found in a data packet header, the STB **300** pauses any data receiving operation and controls its hardware to tune into the channel reserved for receiving data file information to obtain and decode any emergency information to be displayed on an output screen. In an exemplary embodiment, when the STB **300** is idled, it is tuned to the channel reserved for receiving data file information and is always ready to receive and display any emergency information without delay.

The foregoing examples illustrate certain exemplary embodiments of the invention from which other embodiments, variations, and modifications will be apparent to those skilled in the art. The invention should therefore not be limited to the particular embodiments discussed above, but rather is defined by the following claims.

What is claimed is:

1. A method for generating a scheduling matrix for a data file, said scheduling matrix provides a send order for sending data blocks of a data file, such that said data blocks are available in sequential order to a client receiving said data blocks, said method of comprising the steps of:

(a) receiving a number [x], wherein said number [x] is a number into which said data file is divided;

(b) setting a first variable [j] to zero;

(c) setting a second variable [i] to zero;

(d) clearing all entries in a reference array;

(e) writing into said reference array at least one data block stored in matrix positions of a column [(i+j) modulo x, j] of said scheduling matrix, if said reference array does not contain said at least one data block;

(f) writing a data block [i] into said reference array and a matrix position [(i+j) modulo x, j] of said scheduling matrix, if said reference array does not contain said data block [i];

(g) incrementing said second variable [i] by one and repeating step (e) through step (g) until said second variable [i] is equal to said number [x]; and

(h) incrementing said first variable [j] by one and repeating said step (c) through step (h) until said first variable [j] is equal to said number [x].

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

(i) repeating said steps (a) to (h) to generate a set of scheduling matrices for a set of data files; and

applying a convolution method to generate a delivery matrix based on said set of scheduling matrices for sending said set of data files.

3. A method of calculating a delivery matrix, said delivery-matrix provides a send order for sending data blocks of a set of data files, said method comprising the steps of:

(a) calculating a scheduling matrix for each corresponding data file in a set of data files to form a set of scheduling matrices, wherein;

said scheduling matrix sends out said data blocks using a pattern based on a number [x] into which said each corresponding data file is divided; and

said pattern allows for said data blocks in said each corresponding data file to be accessible in a sequential order at a random time;

(b) generating an identification array containing an identification for each of said set of data files; and

(c) combining said set of scheduling matrices and said identification array to generate a delivery matrix for said set of data files.

4. The method of claim **3**, wherein said combining includes the step of using a convolution method.

5. A computer implemented on-demand data broadcast method comprising the act of preparing a delivery matrix defining a data transmission sequence suitable for broadcast, to a plurality of clients, on-demand data in a non client specific manner, wherein transmission of said on-demand data files requires an amount of transmission bandwidth that is independent of the number of said plurality of clients.

6. A computer implemented method as recited in claim **5**, wherein the act of generating a delivery matrix comprises the act of:

preparing a first scheduling matrix suitable for transmission of a first data file, said first data file being represented by a first plurality of data blocks, said first scheduling matrix providing a first sequence for transmitting said first plurality of data blocks sequentially within time slots in a manner such that any client receiving transmission of said first data file according to said first scheduling matrix may begin accessing said first data file within one time slot.

7. A computer implemented method as recited in claim **6**, wherein the act of preparing a delivery matrix further includes the acts of:

preparing a second scheduling matrix suitable for transmission of a second data file, said second data file being represented by a second plurality of data blocks, said second scheduling matrix providing a second sequence for transmitting said second plurality of data blocks sequentially within time slots in a manner such that any client receiving transmission of said second data file according to said second scheduling matrix may begin accessing said second data file within one time slot; and

generating said delivery matrix through a combination of said first and second scheduling matrices.

8. A computer implemented universal data broadcast method as recited in claim **5** further comprising the act of preparing an electronic program guide (EPG) suitable for broadcast to said plurality of clients.

9. A computer implemented method as recited in claim **5**, wherein said on-demand data includes video data.

10. A computer implemented method as recited in claim **5**, wherein said on-demand data includes game data.

* * * * *