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Roelse

(10) **Patent No.: US 9,270,465 B2**
(45) **Date of Patent: Feb. 23, 2016**

(54) **CONTROL WORD PROTECTION**

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(73) Assignee: **Irdeto B.V.**, Hoofddorp (NL)

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US 2013/0251146 A1 Sep. 26, 2013

(30) **Foreign Application Priority Data**

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H04L 9/00 (2006.01)
H04L 9/32 (2006.01)
(Continued)

(52) **U.S. Cl.**
CPC ***H04L 9/3234*** (2013.01); ***H04L 9/08*** (2013.01); ***H04L 9/0825*** (2013.01);
(Continued)

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CPC H04L 2209/601; H04L 2209/603; H04L 9/3234; H04L 9/08; H04L 9/0825; H04L 9/0877; H04L 9/0897; H04L 63/61; H04L 63/0853; H04L 2209/60; H04N 21/63345; H04N 7/1675; H04N 21/4623; H04N 21/4405; H04N 21/26606; H04N 21/4181; H04N 21/4367
USPC 713/150, 170; 380/210
See application file for complete search history.

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(Continued)

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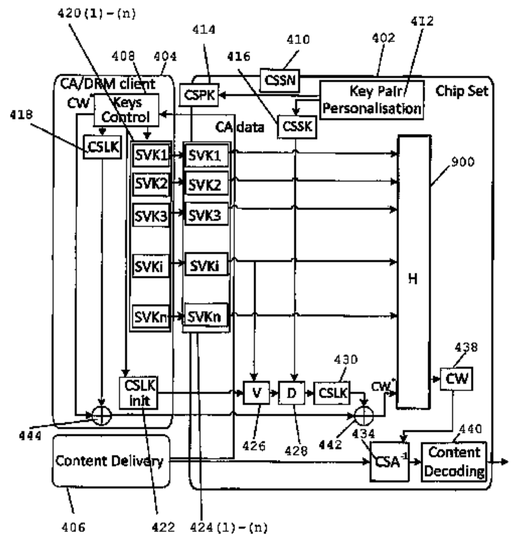
Primary Examiner — Jung Kim
Assistant Examiner — Thomas Ho
(74) *Attorney, Agent, or Firm* — Marc S. Kaufman; Reed Smith LLP

(57) **ABSTRACT**

A method for securely obtaining a control word in a chip set of a receiver, said control word for descrambling scrambled content received by the receiver, the method comprising, at the chip set: receiving a secured version of a virtual control word from a conditional access/digital rights management client communicably connected to the chip set; obtaining the virtual control word from the secured version of the virtual control word; and using a first cryptographic function to produce a given output from an input that comprises the virtual control word and either a plurality of signature verification keys or one or more values derived from a plurality of signature verification keys, each signature verification key being associated with a conditional access/digital rights management system, the given output comprising at least one control word, wherein the first cryptographic function has the property that it is infeasible to determine a key pair including a signature key and a signature verification key and an input for the first cryptographic function comprising the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input.

20 Claims, 17 Drawing Sheets



(51) **Int. Cl.**

H04L 9/08	(2006.01)
H04N 21/266	(2011.01)
H04N 21/418	(2011.01)
H04N 21/4367	(2011.01)
H04N 21/4405	(2011.01)
H04N 21/6334	(2011.01)
H04N 21/8352	(2011.01)
H04N 7/167	(2011.01)
H04L 29/06	(2006.01)
H04N 21/4623	(2011.01)

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

CPC ***H04L 9/0886*** (2013.01); ***H04L 9/0897*** (2013.01); ***H04N 7/1675*** (2013.01); ***H04N 21/26606*** (2013.01); ***H04N 21/4181*** (2013.01); ***H04N 21/4367*** (2013.01); ***H04N 21/4405*** (2013.01); ***H04N 21/63345*** (2013.01); ***H04N 21/8352*** (2013.01); *H04L 9/0877* (2013.01); *H04L 63/061* (2013.01); *H04L 63/0853* (2013.01); *H04L 2209/60* (2013.01); *H04N 21/4623* (2013.01)

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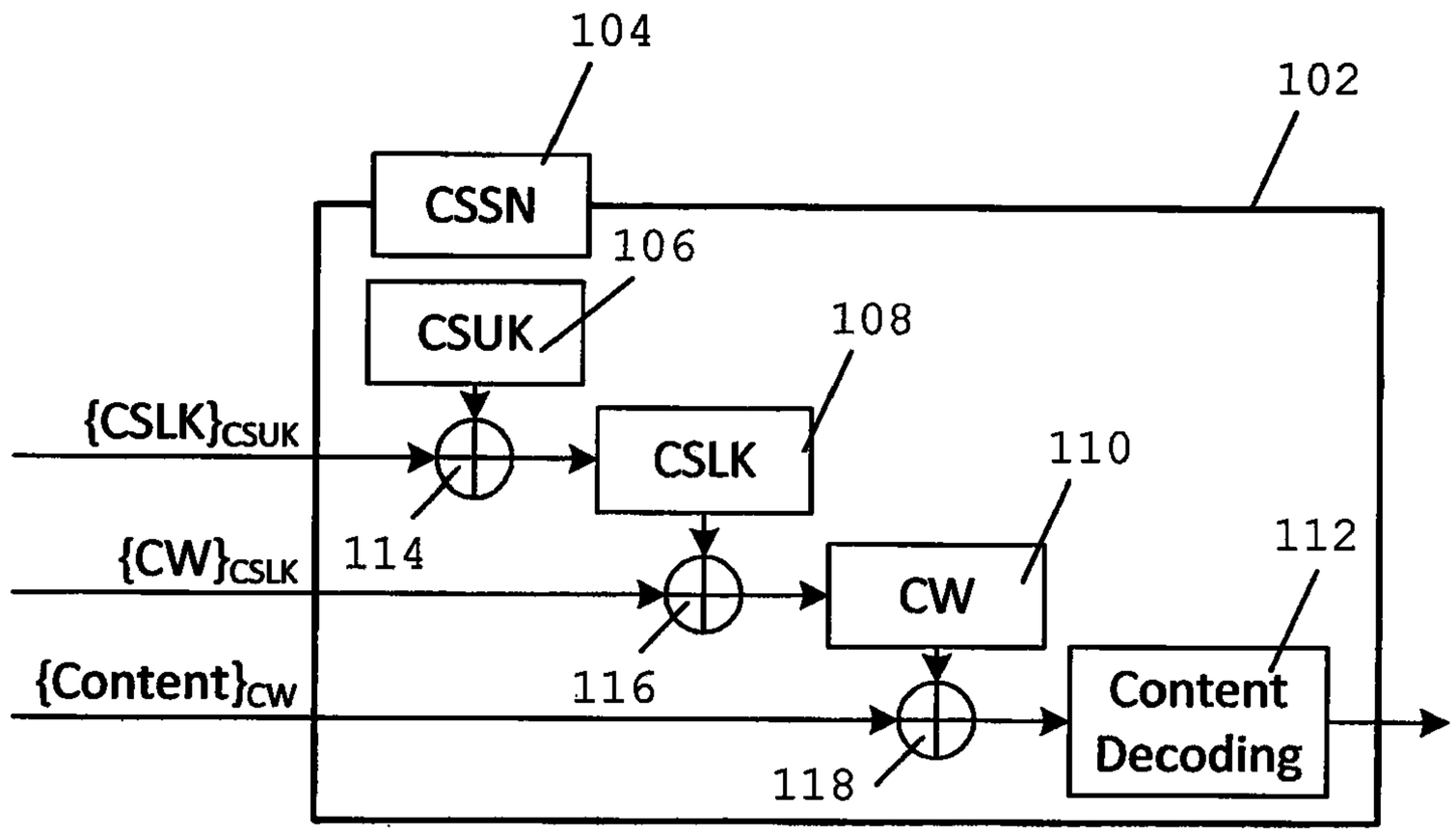
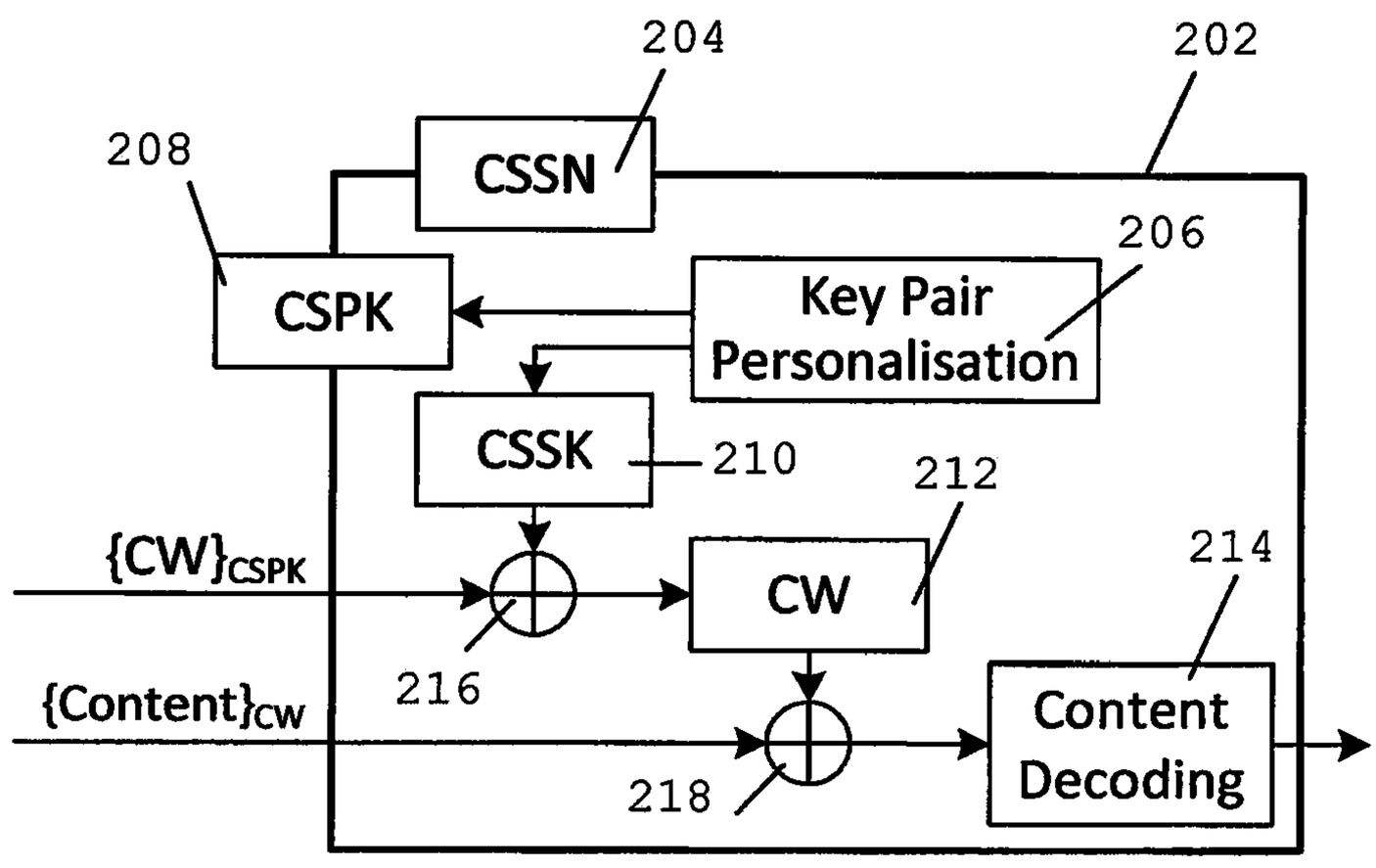


Figure 1



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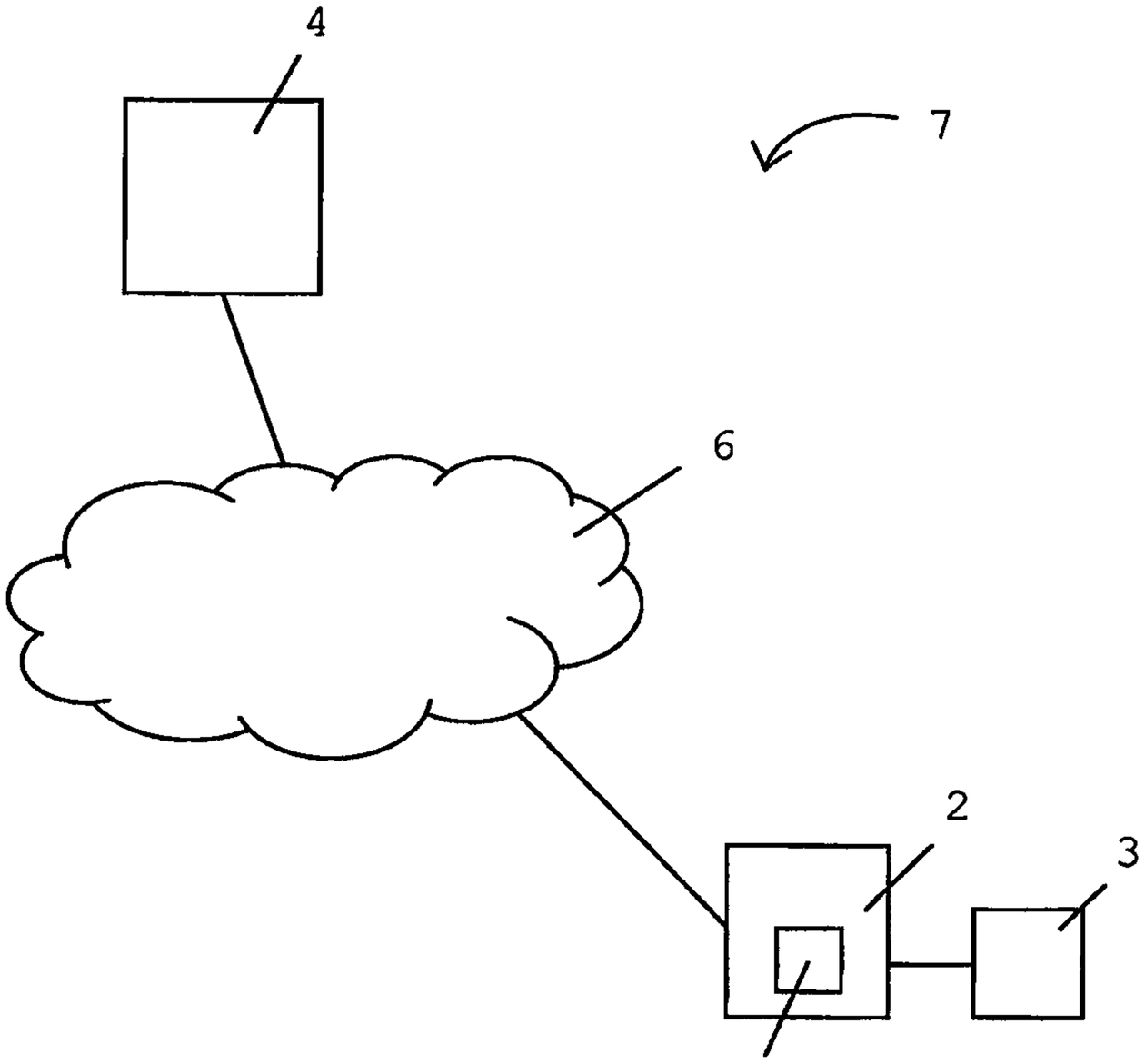

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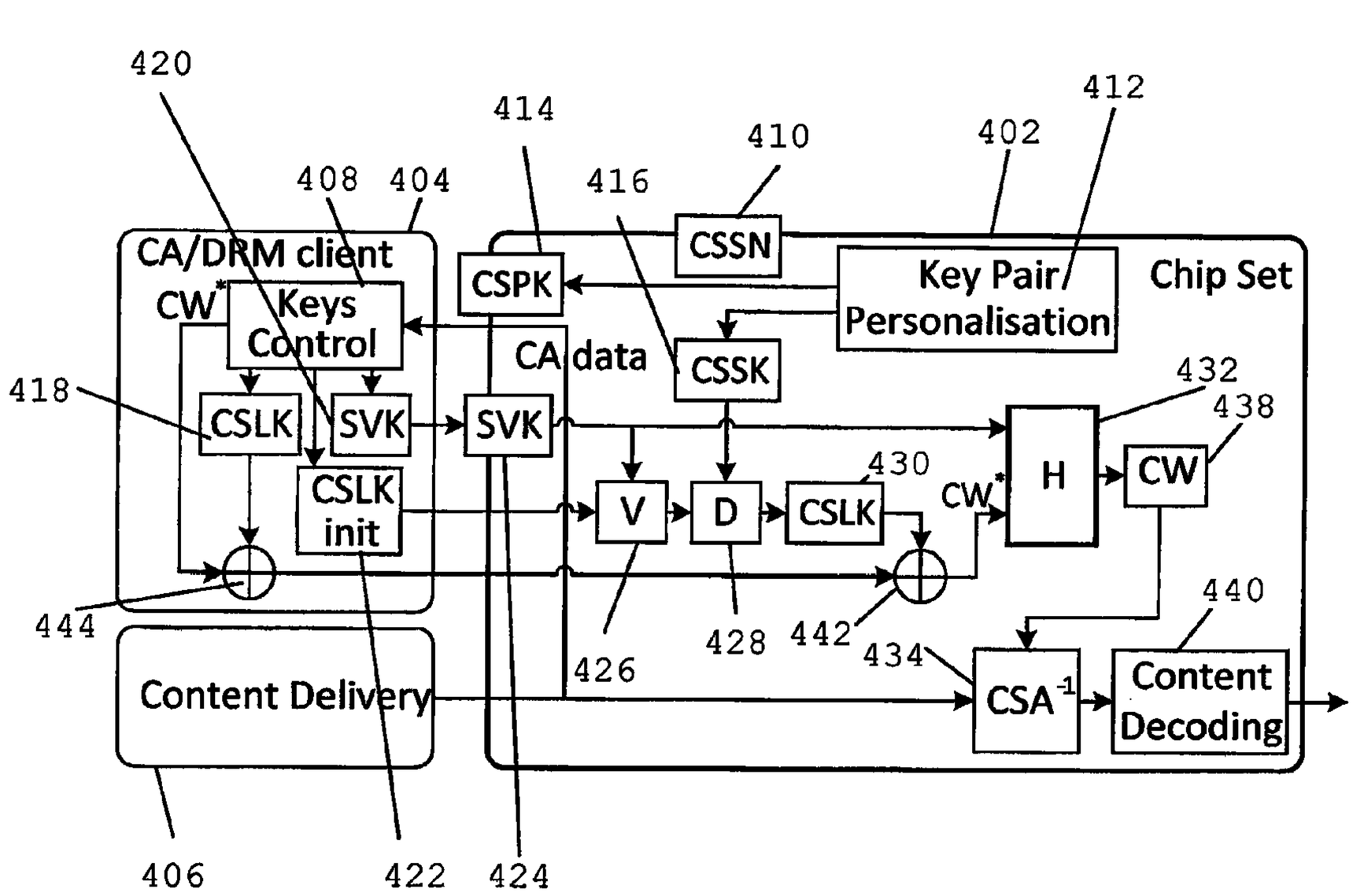
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414
410
412
402
408
404
416
CA/DRM client
CSPK
CSSN
Key Pair
Personalisation
Chip Set
CW*
Keys
Control
CA data
CSSK
418
CSLK
SVK
SVK
432
438
CSLK
init
V
D
CSLK
430
CW*
H
CW
444
426
428
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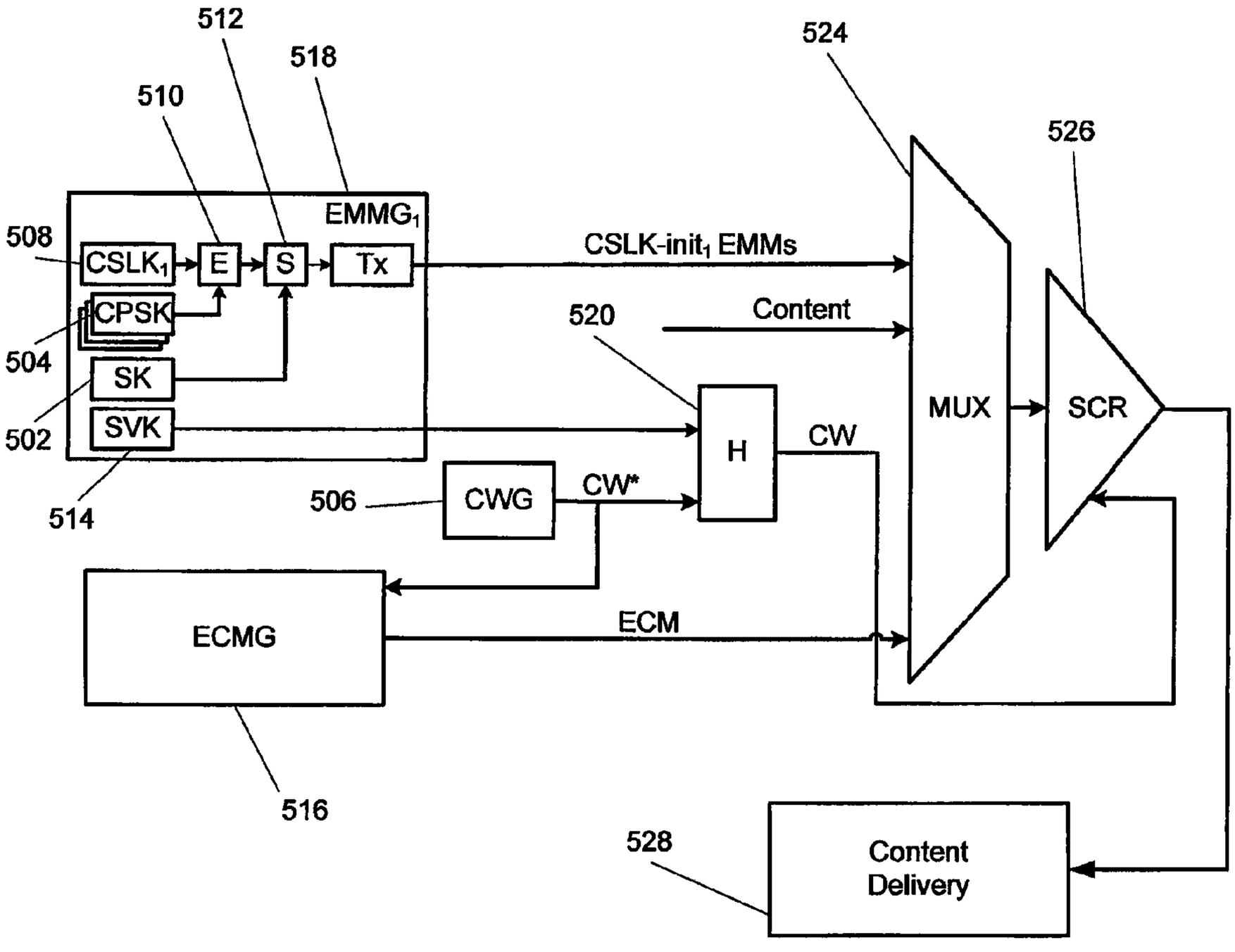
434
440
Content Delivery
CSA-1
Content
Decoding
406
422
424

Figure 4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EMMG1
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E
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Tx
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CPSK
504
520
Content
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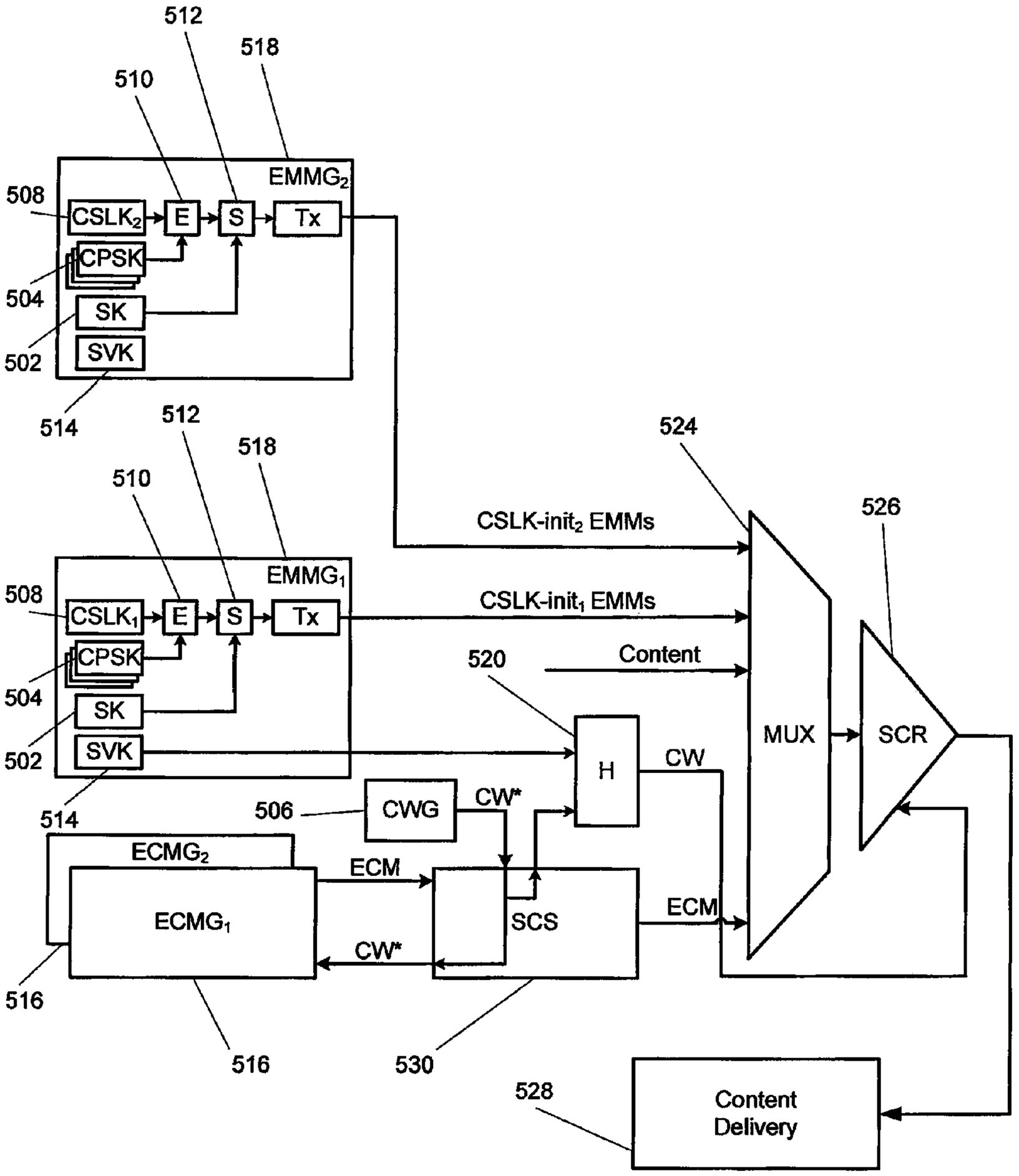
MUX
SCR
SVK
502
H
CW
514
506
CWG
CW*
ECMG
ECM
516
528
Content
Delivery

Figure 5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CSLK-init2 EMMs
526
EMMG1
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CSLK1
E
S
Tx
CSLK-init1 EMMs
CPSK
504
Content
520
SK
MUX
SCR
502
SVK
H
CW
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ECMG2
ECM
ECMG1
SCS
ECM
CW*
516
516
530
528
Content
Delivery

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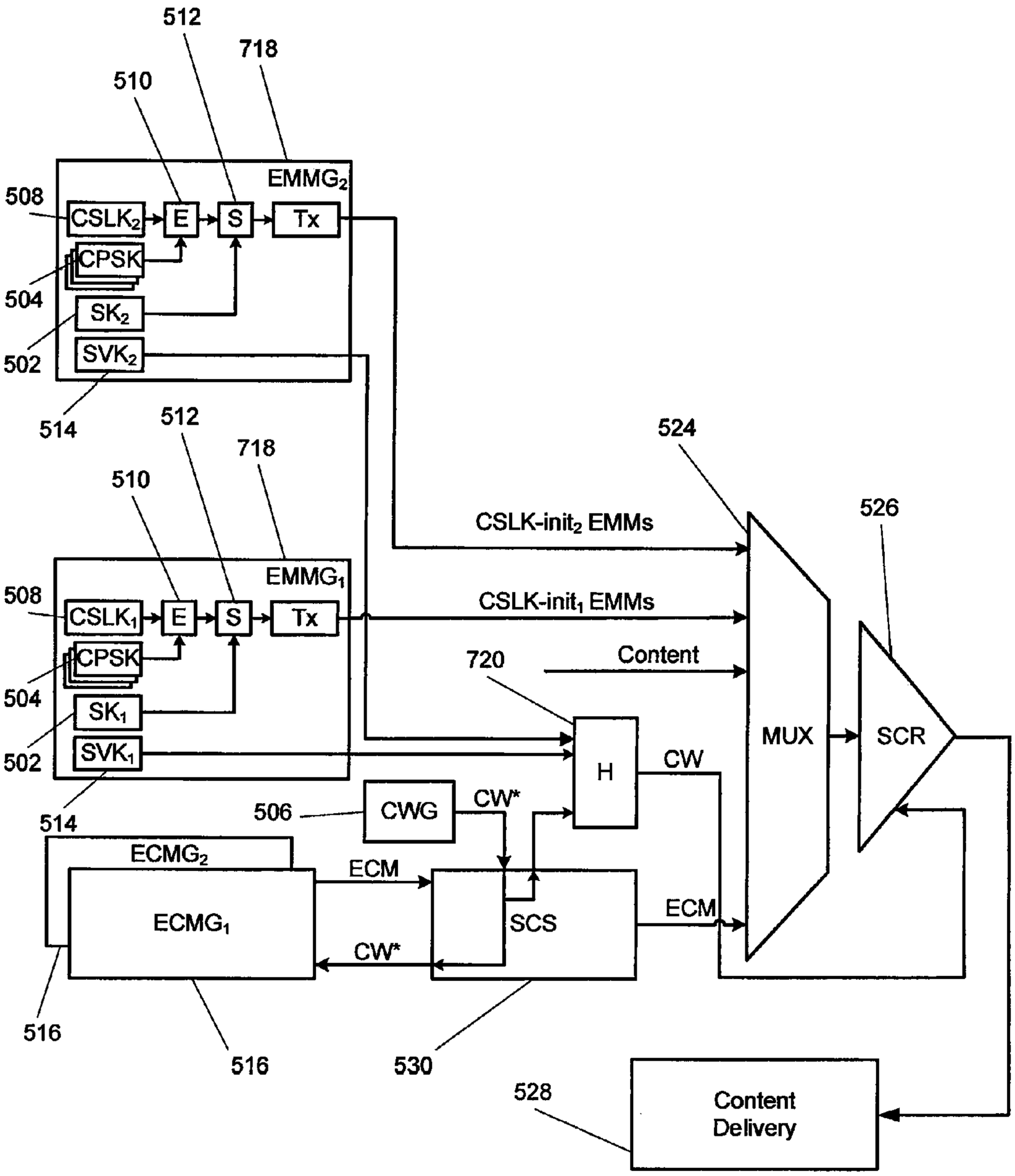
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502
SVK2
514
512
718
510
524
526
CSLK-init2 EMMs
EMMG1
508
CSLK1
CSLK-init1 EMMs
504
720
Content
SK1
502
SVK1
MUX
SCR
H
CW
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CW*
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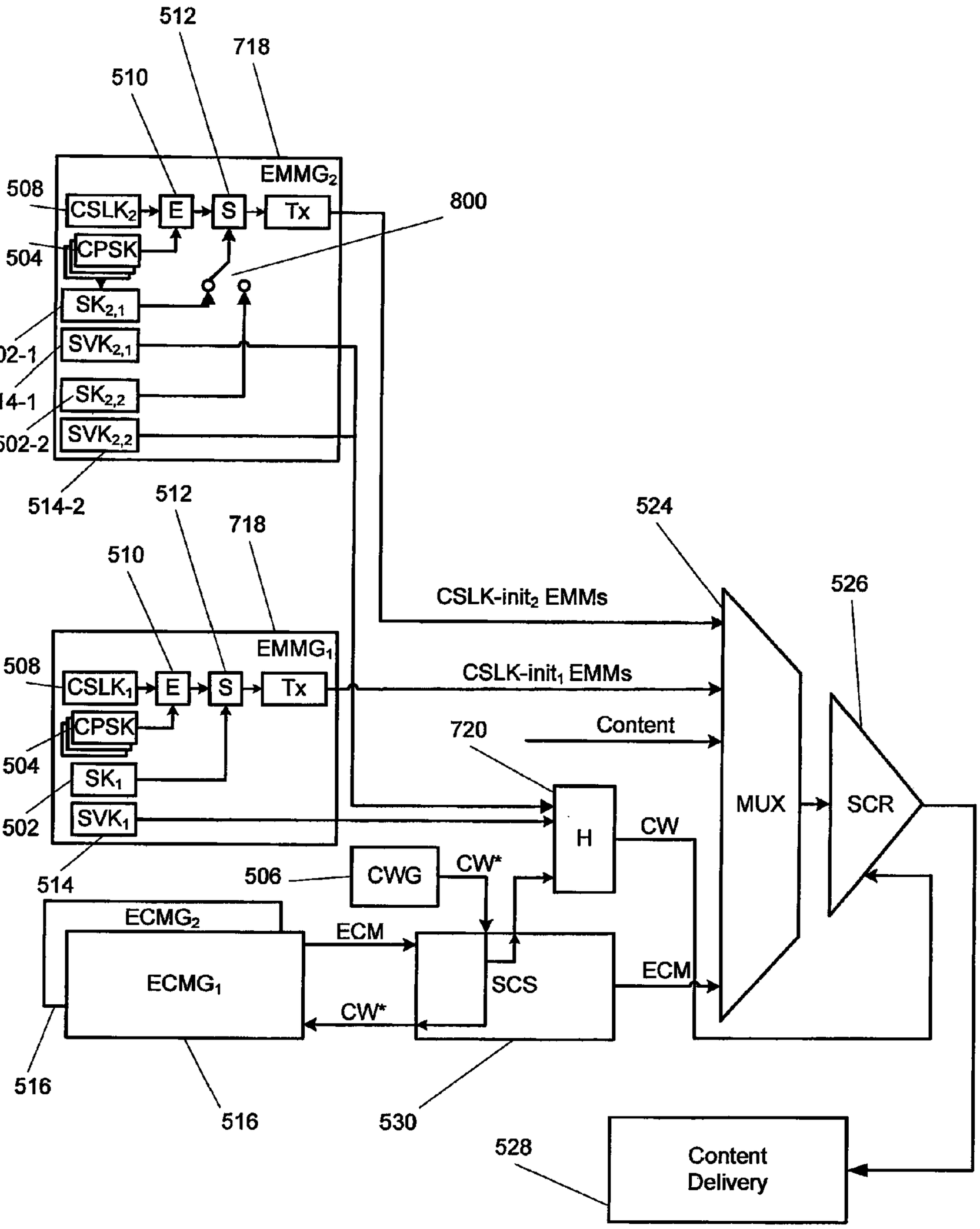
530
528
Content
Delivery

Figure 7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Tx
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504
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SVK2,1
502-1
514-1
SK2,2
SVK2,2
502-2
514-2
512
718
524
510
526
CSLK-init2 EMMs
EMMG1
508
CSLK1
E
S
Tx
CSLK-init1 EMMs
720
Content
504
CPSK
SK1
MUX
SCR
H
CW
502
SVK1
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CWG
CW*
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ECMG1
SCS
ECM
CW*
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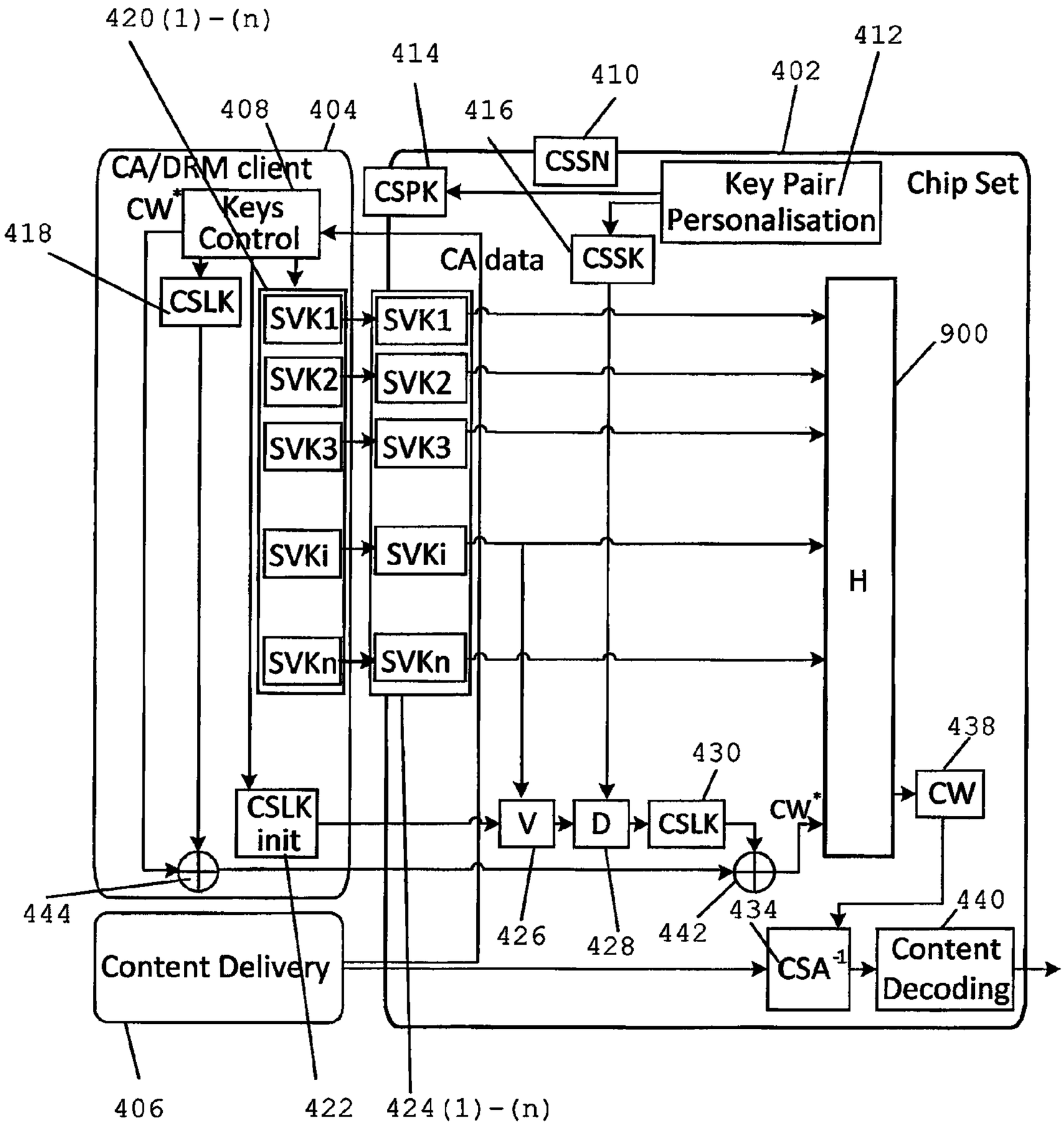
516
530
528
Content
Delivery

Figure 8


420(1)-(n)
414
412
410
402
408
404
416
CA/DRM client
CW*
Keys Control
CSSN
CSPK
Key Pair Personalisation
Chip Set
418
CA data
CSSK
CSLK
SVK1
SVK2
SVK3
SVKi
SVKn
900
H
438
430
CW
CSLK init
V
D
CSLK
CW*
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426
428
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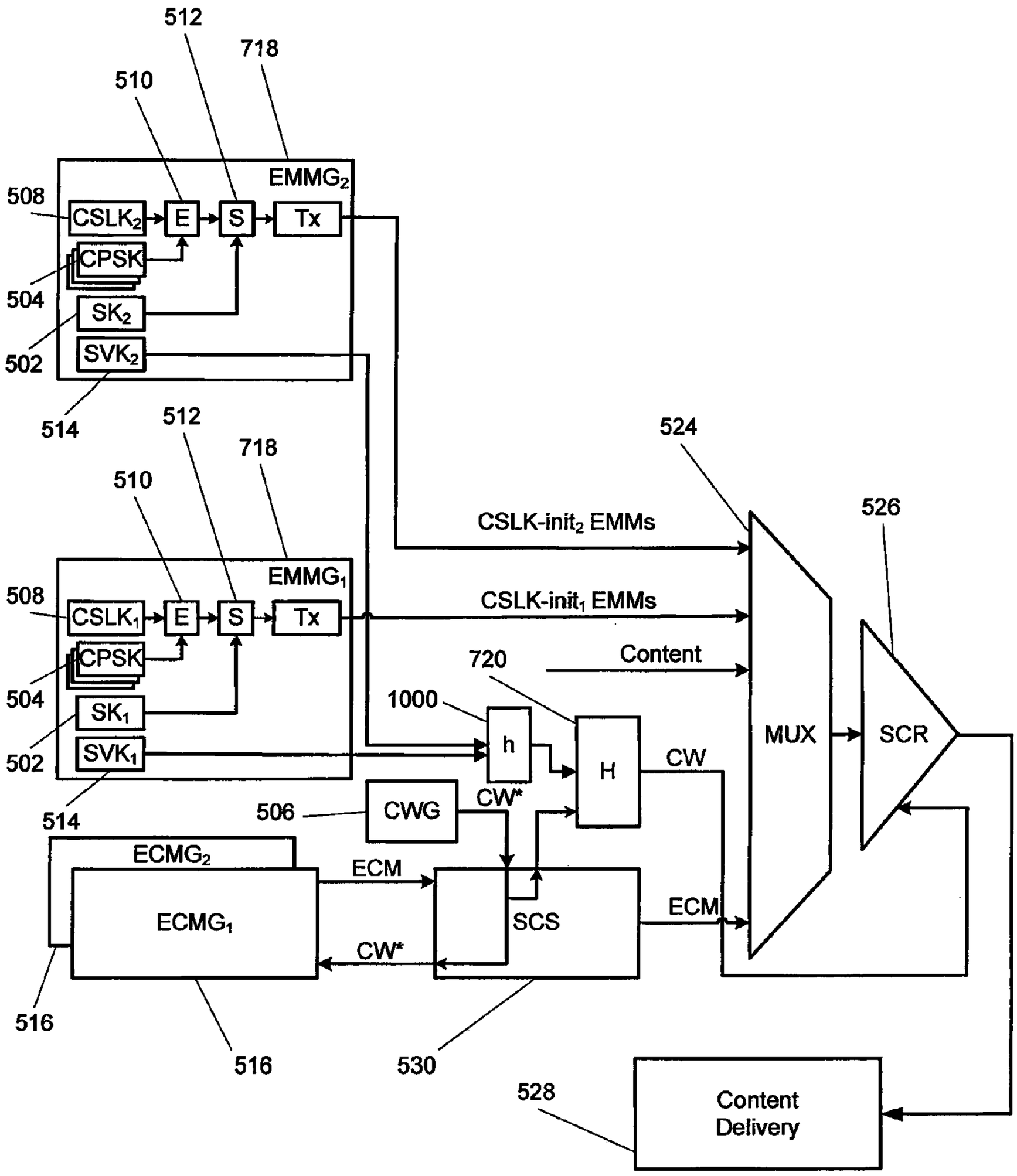
434
440
Content Delivery
CSA-1
Content Decoding
406
422
424(1)-(n)

Figure 9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Tx
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SK2
SVK2
502
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512
718
510
524
526
CSLK-init2 EMMs
EMMG1
508
CSLK1
E
S
Tx
CSLK-init1 EMMs
Content
720
504
1000
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CW
MUX
SCR
SK1
SVK1
502
CW*
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CW*
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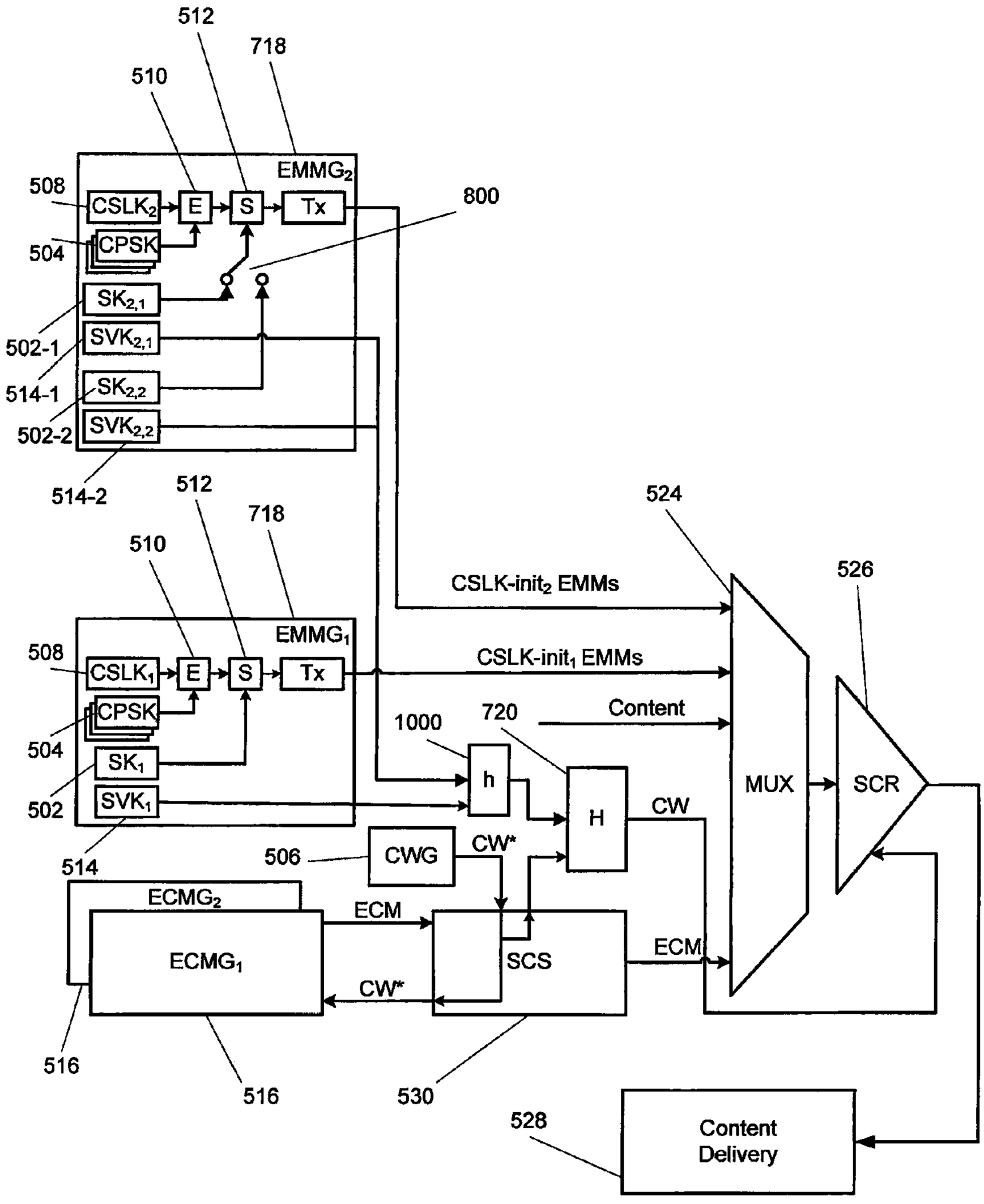
516
530
528
Content
Delivery

Figure 10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SVK2,2
502-2
514-2
524
512
718
510
526
CSLK-init2 EMMs
EMMG1
508
CSLK1
E
S
Tx
CSLK-init1 EMMs
504
CPSK
1000
720
Content
SK1
h
MUX
SCR
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SVK1
H
CW
CW*
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ECMG1
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CW*
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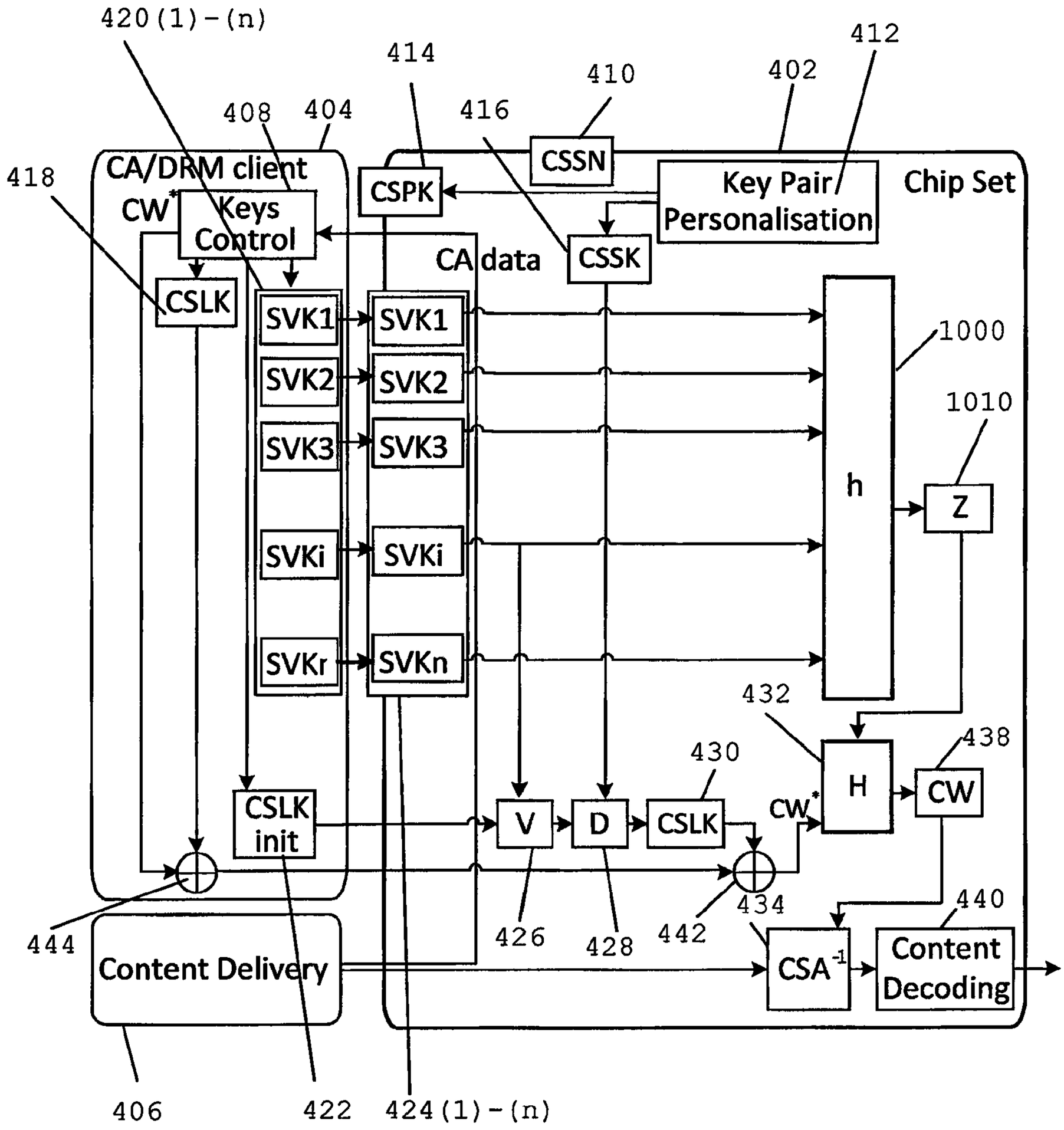
528
Content
Delivery

Figure 11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CA/DRM client
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Keys Control
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CSSN
Key Pair Personalisation
Chip Set
CA data
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SVK2
SVK3
SVKi
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SVKn
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CSLK init
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Content Decoding
Content Delivery
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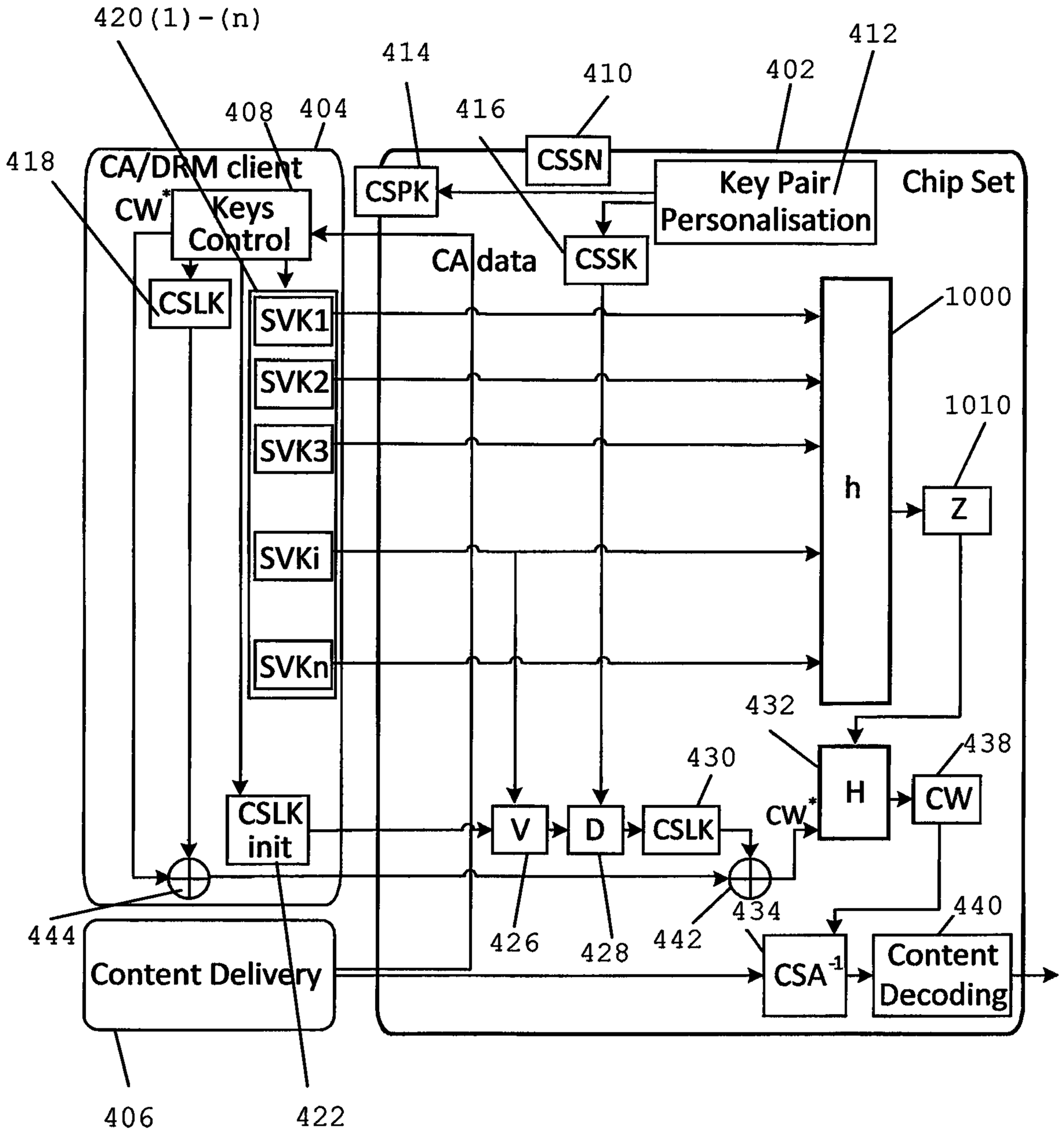
424(1)-(n)

Figure 12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Content Delivery
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Content Decoding
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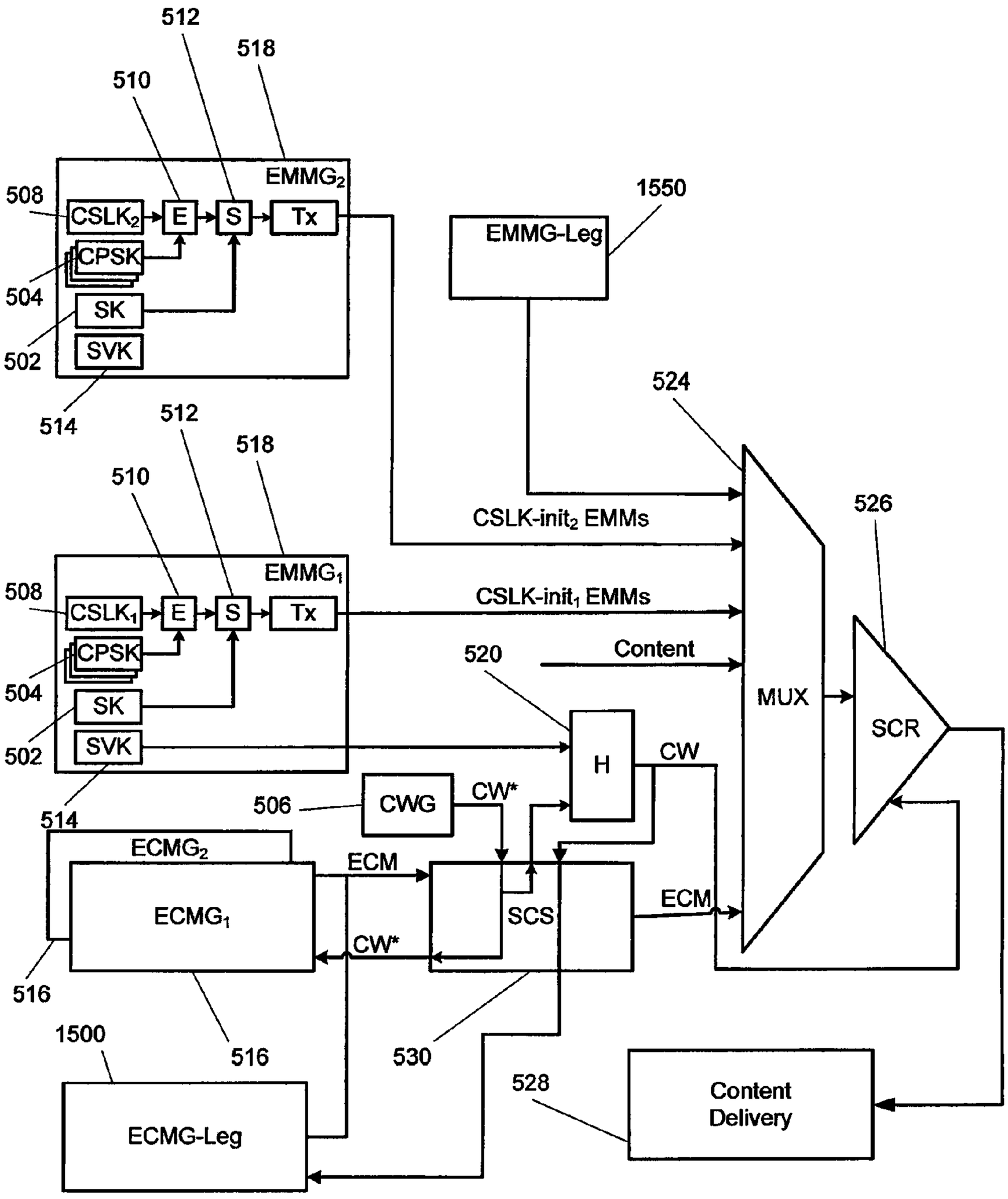
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EMMG1
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CSLK-init1 EMMs
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SVK
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CWG
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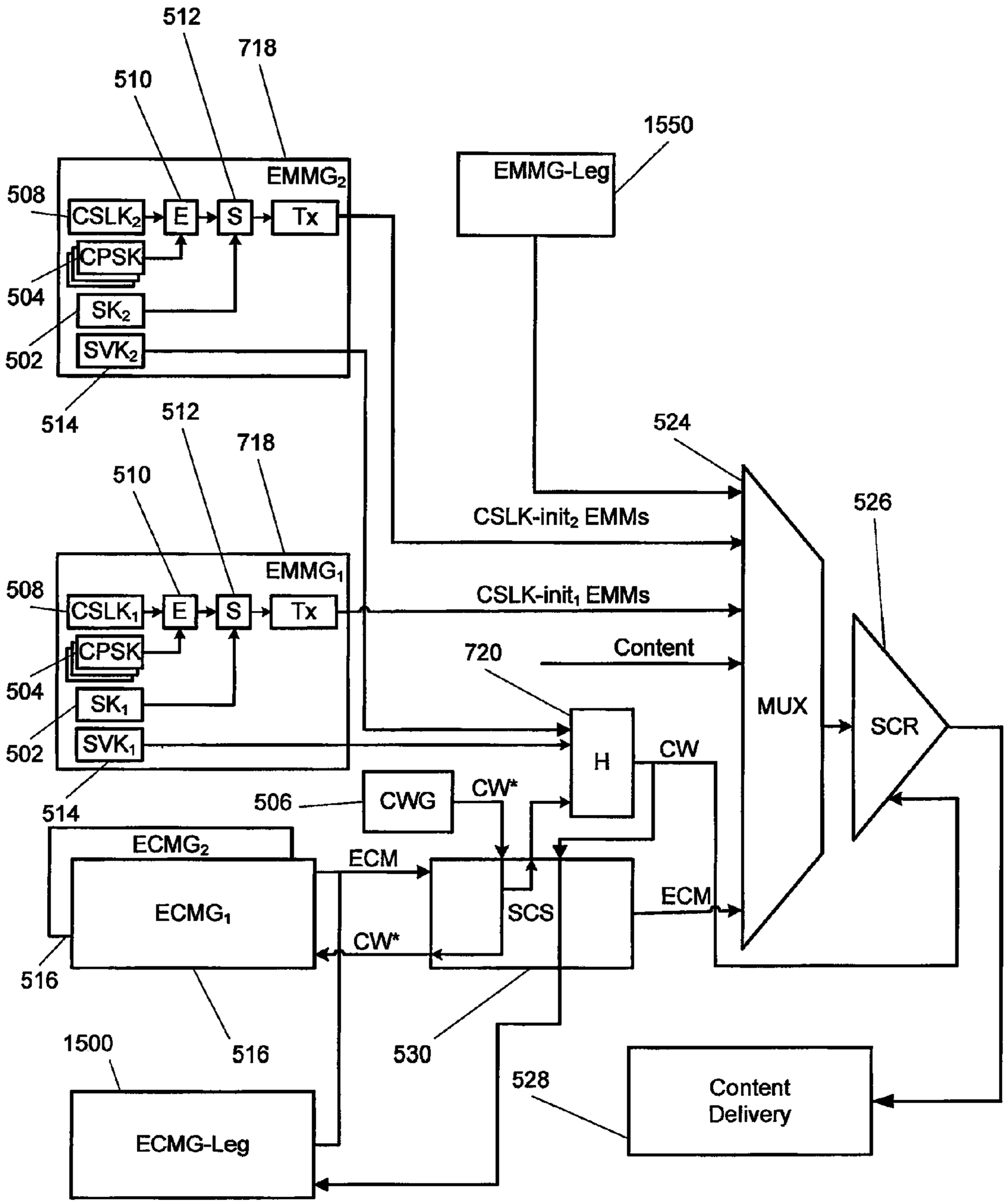
ECMG-Leg
Content
Delivery

Figure 14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526
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CSLK1
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CSLK-init1 EMMs
CPSK
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Content
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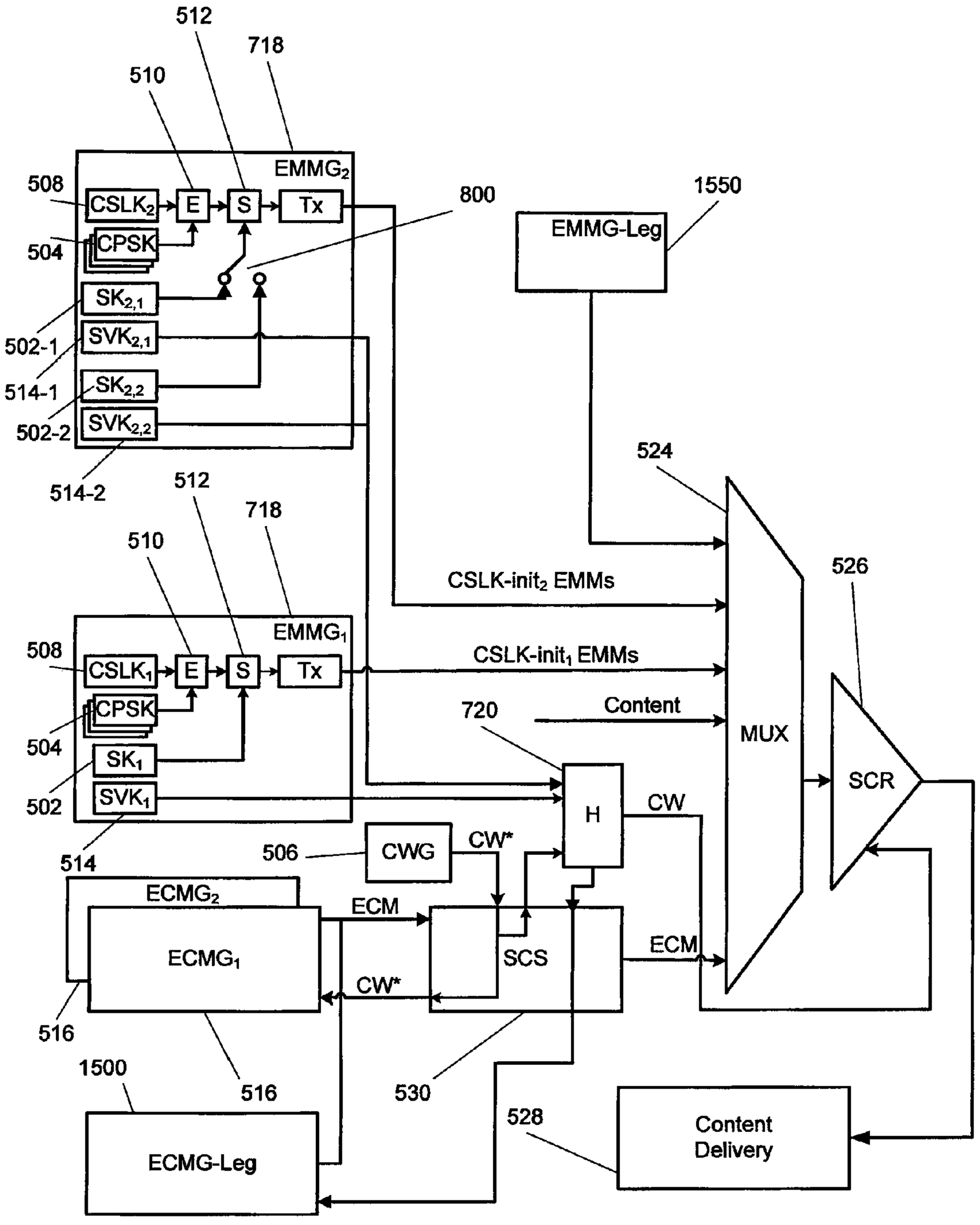
Delivery
ECMG-Leg

Figure 15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Content
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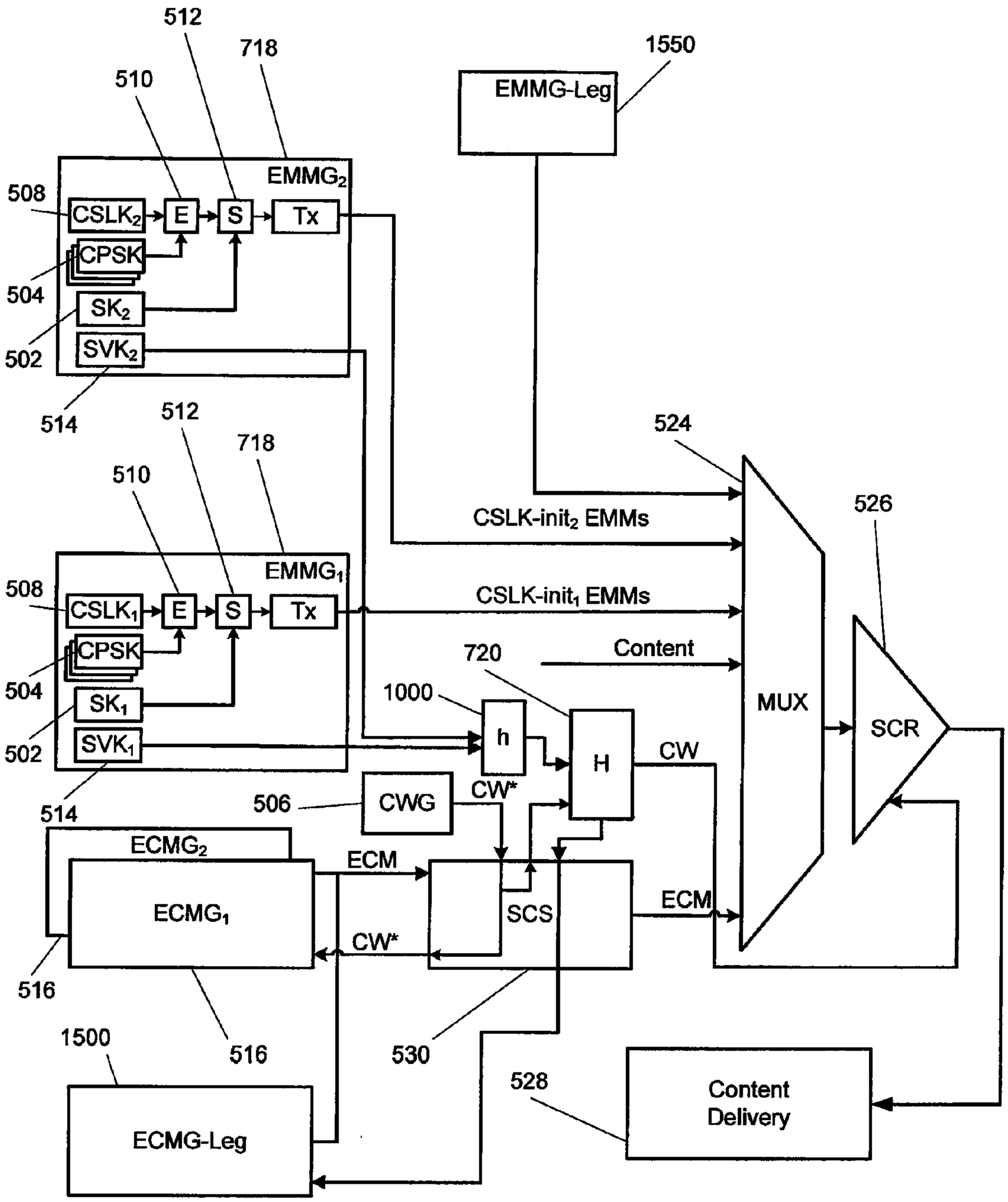
ECMG-Leg
Content
Delivery

Figure 16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512
718
510
524
526
CSLK-init2 EMMs
EMMG1
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CSLK1
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S
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CSLK-init1 EMMs
CPSK
720
Content
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MUX
SCR
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SVK1
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506
CWG
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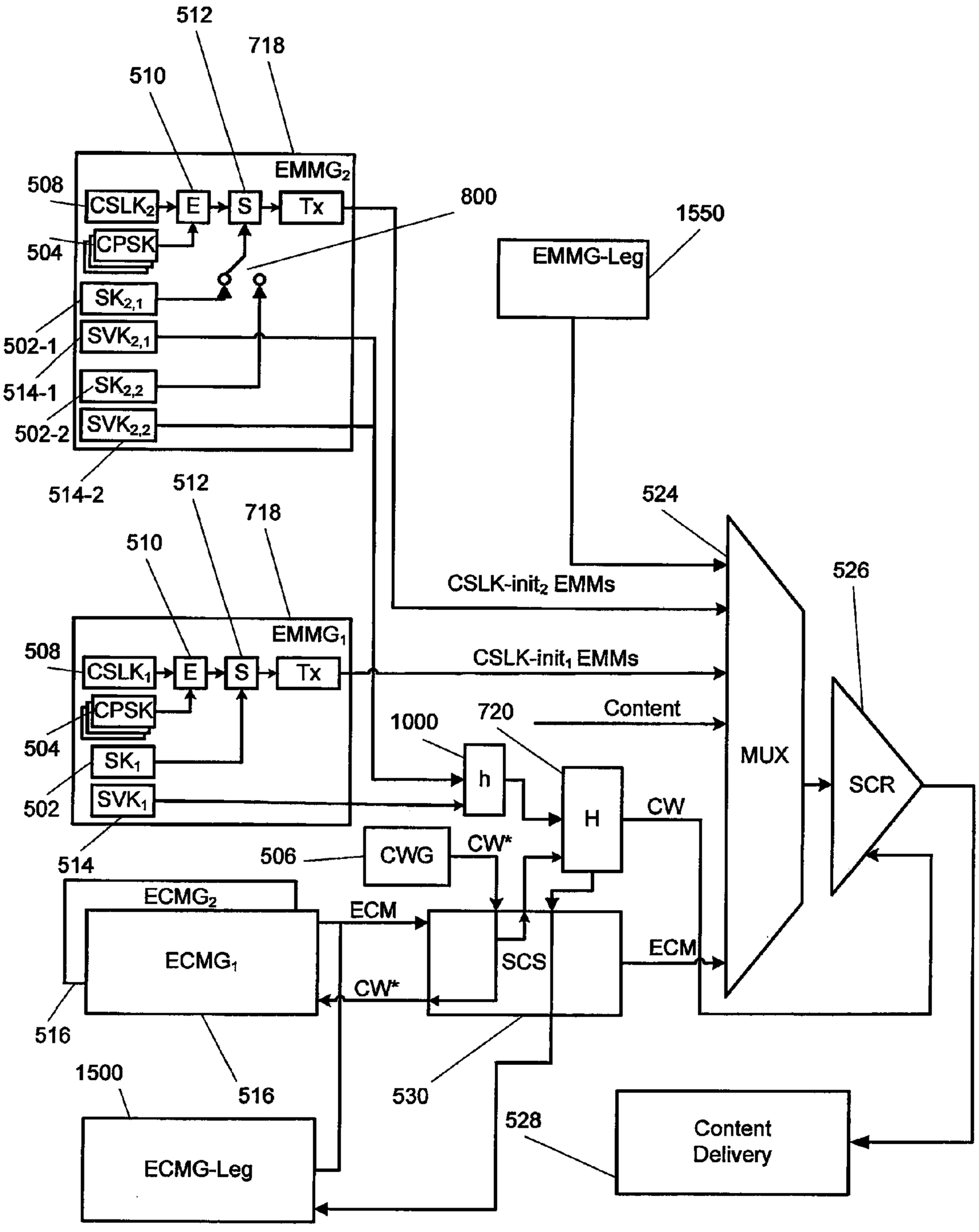
ECMG-Leg
Content
Delivery

Figure 17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SK2,2
502-2
SVK2,2
514-2
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718
510
524
EMMG1
CSLK-init2 EMMs
526
508
CSLK1
CSLK-init1 EMMs
504
CPSK
1000
720
Content
h
MUX
SCR
SK1
502
SVK1
H
CW
514
506
CWG
CW*
ECMG2
ECM
ECMG1
SCS
ECM
CW*
516
516
1500
530
528
Content
Delivery
ECMG-Leg

Figure 18

CONTROL WORD PROTECTION

FIELD OF THE INVENTION

The present invention relates to methods and apparatus for securely obtaining a control word in a chip set of a receiver. The present invention also relates to methods and systems for providing a control word to a chip set of a receiver. The present invention also relates to computer programs for carrying out such methods, as well as computer readable media storing such computer programs.

BACKGROUND OF THE INVENTION

Conditional access/digital rights management (CA/DRM) systems for digital video broadcast (DVB) transmissions are well known and widely used in conjunction with pay television (TV) services. Such systems provide secure transmission of a broadcast stream comprising one or more services to a digital receiver contained for example in a set-top box or a mobile terminal supporting broadcast services. To protect the broadcast services from unauthorized viewing, the data packets are scrambled (encrypted) at the transmitter side with an encryption key commonly referred to as a control word. A CA/DRM system implements the selective distribution of the control words to authorized receivers only. Further security is provided by periodically changing the control words so they are only valid for a certain period. Typically control words are transmitted in encrypted form to the receiver using so-called entitlement control messages (ECMs).

In the receiver an ECM is filtered out of a transport stream and sent to a secure computing environment, referred to as a CA/DRM client (e.g., a CA/DRM client can be a smart card with embedded software or it can be an obfuscated software module executed inside the receiver). The CA/DRM client subsequently decrypts the ECM using a higher-level key, which is common to all CA/DRM clients that are authorized to access the TV channels associated with the control words included in the ECM. The control word is returned to the receiver, which loads the control word into the descrambler for descrambling data.

Control word piracy is a significant problem in digital video broadcasting (DVB) systems. A common attack uses the fact that a control word is a shared key that unlocks content on all receivers. An adversary can break part of the key delivery infrastructure to obtain control words and redistribute the control words to unauthorized receivers. For instance, sometimes adversaries are able to intercept a control word that is transmitted from the CA/DRM client to the receiver and re-distribute it over local networks or over the Internet. The re-distributed control word is then used to descramble the scrambled services without a legitimate authorized CA/DRM client. A security requirement is therefore that the confidentiality and the authenticity of a control word should be protected.

In some cases, a chip set supports a key hierarchy to secure the control word delivery based on secret keys installed during the manufacturing process. FIG. **1** of the accompanying drawings shows a prior art example of chip set **102** of a receiver to load keys to descramble content. Decryption modules **114**, **116** and **118** use encrypted input data and an input key to obtain decrypted output data. The chip manufacturer personalizes the chip set with a pseudo-random secret value for the symmetric chip set unique key CSUK and assigns a non-secret chip set serial number CSSN to the chip set for future identification. Elements **104** and **106** are read-only memory locations, for storing CSSN and CSUK, respectively. Elements **108** and **110** are read-and-write memory locations for temporary storing decrypted output data. As shown, content decoder **112** decodes the descrambled content. Dataflows between elements are indicated by arrows. Labels along the arrows identify the dataflows.

As shown in FIG. **1**, a content stream scrambled with control word CW, denoted by $\{\text{Content}\}_{CW}$, is received in the chip set **102**. To provide the control word needed to descramble the content, chip set **102** supports secure loading of the associated CW using input $\{\text{CW}\}_{CSLK}$, which denotes the CW encrypted with a symmetric chip set load key CSLK. Said CSLK is received at chip set **102** encrypted with the symmetric chip set unique key CSUK, which is denoted by input $\{\text{CSLK}\}_{CSUK}$. To decrypt $\{\text{CSLK}\}_{CSUK}$, CSUK is needed. The CSUK and the chip set serial number CSSN associated with the particular chip set are typically pre-installed in memory locations on the chip set (element **104** and element **106**, respectively) and cannot be altered. In operation, CSUK is retrieved from secured storage (i.e., element **106**) in chip set **102** and is used to decrypt the CSLK from $\{\text{CSLK}\}_{CSUK}$ using decryption module **114**. Once decrypted, CSLK is stored in memory (i.e., element **108**), and can be used to decrypt $\{\text{CW}\}_{CSLK}$ using decryption module **116**. Lastly, the clear control word stored in memory (i.e., element **110**) is used by decryption module **118** to descramble incoming scrambled content $\{\text{Content}\}_{CW}$, such that the content may be decoded by the chip set using content decoder **112**. Content decoder **112** can be external to the chip set **102** and is typically a part of the receiver.

Typically, for vertical market receivers, a chip manufacturer supplies a list of (CSSN, CSUK) pairs to a CA/DRM supplier, enabling the loading of a value for the chip set load key CSLK into a chip set, using the method depicted in FIG. **1**. Known conditional access systems use a key loading mechanism, such as shown in FIG. **1**, by sending an entitlement management message (EMM) and an ECM from a head-end system to the CA/DRM client. For the example in FIG. **1**, the EMM includes the CSLK (intended for the CA/DRM client, and protected using the confidential and authentic channel offered by the CA/DRM system) and its encrypted version $\{\text{CSLK}\}_{CSUK}$ (intended for the chip set **102**). The ECM includes an encrypted CW. The CA/DRM client provides $\{\text{CSLK}\}_{CSUK}$ to the chip set and may use the CSLK as a key for loading a sequence of control words. That is, the CA/DRM client may use CSLK to re-encrypt a CW included in an ECM, resulting in a message $\{\text{CW}\}_{CSLK}$ that is sent to the chip set **102**. Typically, CSLK is unique to a particular combination of CA/DRM client and chip set, and consequently, only that chip set can decrypt $\{\text{CW}\}_{CSLK}$ received from the CA/DRM client (so sharing a CW loading message $\{\text{CW}\}_{CSLK}$ is not possible).

For horizontal market receivers, a CA/DRM system operator shall be able to swap a CA/DRM system. In the solution described above for vertical market receivers, the secret master key associated with the receiver (that is, the key CSUK) is known to a CA/DRM supplier. From a security perspective, this property is undesirable for horizontal market receivers. A reason for this is that the current CA/DRM supplier may publish the secret master key CSUK after the CA/DRM system has been swapped, compromising the security of the receiver. A security requirement for horizontal receivers is therefore that the scheme shall not require that any of the receiver's secrets known to a CA/DRM supplier need to be known to any other CA/DRM supplier. This requirement is not satisfied in the scheme described above.

While the example in FIG. **1** depicts a method that uses symmetric cryptographic algorithms, it is also possible to use

asymmetric, or public-key, cryptography as shown in FIG. **2** of the accompanying drawings.

FIG. **2** shows a typical chip set implementing the loading of a control word using an asymmetric cryptographic algorithm to protect the confidentiality of the control word. Chip set **202**, associated with chip set serial number CSSN includes element **204** (read-only memory storage location), element **208** and element **210** for storing a key pair (read-and-write memory storage locations), and element **212** for temporarily storing a clear control word (read-and-write memory location). To protect the authenticity of the key pair, preferably element **208** and element **210** are write-once memory locations.

Instead of loading a pair (CSSN, CSUK) during manufacturing and sending the pairs to the CA/DRM suppliers and their operators (as performed in the example shown in FIG. **1**), the chip manufacturer of chip set **202** shown in FIG. **2** personalizes chip set **202** by activating key pair personalization module **206** that generates a random key pair consisting of a chip set public key CSPK and a chip set secret key CSSK. The CSPK and CSSK are stored in elements **208** and **210**, respectively. Alternatively, the key pair personalization module **206** may be implemented outside the chip set **202** (e.g., in a chip set personalization system available to the chip set manufacturer), and the manufacturer may load CSSK into the chip set **202** during its personalization. After this, the manufacturer can delete CSSK from its system(s).

The manufacturer maintains pairs of numbers, each pair comprising of a chip set serial number CSSN and its associated chip set public key CSPK. The list of (CSSN, CSPK) pairs can be made available to all CA/DRM suppliers. Notice that only the authenticity of these pairs needs to be protected, as the numbers CSSN and CSPK are not secret. The CSPK is used to encrypt a CW that only the receiver with the corresponding CSSK can decrypt (using decryption module **216**). That is, the encrypted control word $\{CW\}_{CSPK}$ is a unique data pattern as no other receiver will generate the same random key pair (CSPK, CSSK), so sharing a CW loading message $\{CW\}_{CSPK}$ is not possible. The decrypted CW, stored temporarily in element **212** is then used to decrypt $\{Content\}_{CW}$ by decryption module **218** to produce the descrambled content. The descrambled content is then subsequently decoded using content decoder **214**.

The benefit of the public-key solution depicted as in FIG. **2** is that the chip set secret key CSSK does not need to be known to any CA/DRM supplier. However, as CSPK is a public key, it is also available to an adversary. In particular, an adversary can use a CSPK to distribute a given control word CW to the receiver associated with that CSPK, e.g., after CW is compromised from another receiver. That is, this method does not protect the authenticity of a CW loading message.

A second, independent mechanism for protecting the authenticity of a CW loading message may be added to the public-key solution depicted in FIG. **2**. For instance, a message authentication code (MAC) can be used to protect the authenticity of a CW loading message $\{CW\}_{CSPK}$. A MAC is a symmetric cryptographic technique, based on a secret key K_{MAC} shared between the CA/DRM client and the chip set. In particular, the CA/DRM client uses K_{MAC} as a key to generate a MAC value of a CW loading message $\{CW\}_{CSPK}$. The computed MAC value can be appended to the message. After receiving the message and the MAC value, the chip set uses K_{MAC} to verify the MAC value. Alternatively, a method based on public-key cryptography (i.e., an asymmetric digital signature) can be used for protecting the authenticity of a CW loading message $\{CW\}_{CSPK}$. In such a solution, the manufacturer loads a public key associated with a digital signature scheme into the receiver during the personalization phase. This public key can be used as a root key of an authenticity mechanism. The receiver can use the authenticity mechanism to verify the authenticity of a CW loading message $\{CW\}_{CSPK}$.

However, for both authenticity schemes (symmetric and asymmetric), the master key used for signing a message is a secret key. This implies that the requirement that the scheme shall not require that any of the receiver's secrets known to a CA/DRM supplier need to be known to any other CA/DRM supplier is not satisfied if this master key is distributed to a CA/DRM supplier.

To fulfil this requirement and to protect the confidentiality and authenticity of a control word, the role of the chip manufacturer as a trusted party can be extended (or an additional trusted party can be used). For example, an additional key layer can be introduced in both schemes, and the trusted party can manage the root keys of such a scheme. However, this implies that the trusted party needs to manage (at least) one secret associated with a receiver after its personalization is completed. For liability reasons, this role of the trusted party is not desirable for chip set manufacturers. This implies that an additional trusted party would be needed.

There is a need for an improved solution for loading control words onto chip sets that solves the problems described above. That is, there is a need for a scheme with the following properties: (i) the confidentiality and the authenticity of a CW are protected (ii) CA/DRM systems can use the scheme independently without the need to share a secret key, and (iii) after the personalization of a receiver, the trusted party no longer needs to manage any secret keys associated with the receiver (chip set).

SUMMARY OF THE INVENTION

According to a first aspect of the invention, there is provided a method for securely obtaining a control word in a chip set of a receiver, said control word for descrambling scrambled content received by the receiver, the method comprising, at the chip set: receiving a secured version of a virtual control word from a conditional access/digital rights management client communicably connected to the chip set; obtaining the virtual control word from the secured version of the virtual control word; and using a first cryptographic function to produce a given output from an input that comprises the virtual control word and either a plurality of signature verification keys or one or more values derived from a plurality of signature verification keys, each signature verification key being associated with a conditional access/digital rights management system, the given output comprising at least one control word, wherein the first cryptographic function has the property that it is infeasible to determine a key pair including a signature key and a signature verification key and an input for the first cryptographic function comprising the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input.

The method may comprise receiving and storing the signature verification keys of the plurality of signature verification keys, wherein said first cryptographic function is arranged to use said stored signature verification keys as a part of the input to the first cryptographic function.

The method may comprise: receiving the plurality of signature verification keys; generating a derived value from the received plurality of signature verification keys; and storing the generated derived value; wherein said first cryptographic

function is arranged to use said stored derived value as a part of the input to the first cryptographic function.

The method may comprise: receiving, at the chip set, a secured version of a chip set load key, wherein the secured version of the chip set load key is secured to protect the authenticity and confidentiality of the chip set load key; and obtaining the chip set load key from the secured version of the chip set load key.

The secured version of the virtual control word may be a virtual control word encrypted using the chip set load key; in which case obtaining the virtual control word from the secured version of the virtual control word may comprise using the chip set load key to decrypt the secured version of the virtual control word.

The secured version of the chip set load key may comprise the chip set load key encrypted using a public key associated with the chip set and a signature based on the chip set load key using a signature key associated with a conditional access/digital rights management system, in which case obtaining the chip set load key from the secured version of the chip set load key may comprise: verifying the signature using a signature verification key corresponding to the signature key associated with the conditional access/digital rights management system, wherein the signature verification key is one of the plurality of signature verification keys; and decrypting the encrypted chip set load key using a secret key associated with the chip set, the secret key corresponding to the public key associated with the chip set.

The method may comprise the chip set storing the chip set load key obtained from the secured version of the chip set load key so that the stored chip set load key can be used to decrypt secured versions of virtual control words received by the chip set.

The method may comprise: receiving the plurality of signature verification keys along with the secured version of the virtual control word; and determining whether the signature based on the stored chip set load key was verified using one of the received signature verification keys and, if it is determined that the signature based on the stored chip set load key was not verified using one of the received signature verification keys, not using the stored chip set load key to decrypt the secured version of the virtual control word received by the chip set.

The receiver may be one receiver in a plurality of receivers, each receiver in the plurality of receivers having a corresponding chip set that has an associated secret key, and the secret keys associated with the chip sets of the receivers in the plurality of receivers are different from each other.

According to a second aspect of the invention, there is provided a method for providing a control word to a chip set of a receiver, the control word to enable the receiver to descramble scrambled content transmitted to the receiver, the method comprising: generating a virtual control word at a head-end system; transmitting the virtual control word from the head-end system to a conditional access/digital rights management client via the receiver, wherein the conditional access/digital rights management client is communicably connected to the chip set; using a first cryptographic function to produce a given output from an input that comprises the virtual control word and either a plurality of signature verification keys or one or more values derived from a plurality of signature verification keys, each signature verification key being associated with a conditional access/digital rights management system, the given output comprising at least one control word, wherein the first cryptographic function has the property that it is infeasible to determine a key pair including a signature key and a signature verification key and an input for the first cryptographic function comprising the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input; scrambling content using the control word to produce scrambled content; and transmitting the scrambled content to the chip set.

The receiver may be associated with a conditional access/digital rights management system, in which case the method may comprise transmitting to the chip set a secured version of a chip set load key, wherein the secured version of the chip set load key is secured to protect the authenticity and confidentiality of the chip set load key, the chip set load key to enable the receiver to access the virtual control word.

The secured version of the chip set load key may comprise the chip set load key encrypted using a public key associated with the chip set and a signature based on the chip set load key using a signature key associated with the conditional access/digital rights management system associated with the receiver and corresponding to one of the plurality of signature verification keys.

The method may comprise transmitting the control word from the head-end system to a second conditional access/digital rights management client via a second receiver, wherein the second conditional access/digital rights management client is communicably connected to a second chip set of the second receiver.

In the above aspects and embodiments, at least two of the signature verification keys in the plurality of signature verification keys may be associated with the same conditional access/digital rights management system.

In the above aspects and embodiments, at least two of the signature verification keys in the plurality of signature verification keys may be associated with different conditional access/digital rights management systems.

In the above aspects and embodiments, a derived value may be produced by providing the plurality of signature verification keys to a second cryptographic function, wherein the second cryptographic function has the property that it is infeasible to generate a key pair including a signature key and a signature verification key and an input for the second cryptographic function comprising the generated signature verification key such that the second cryptographic function produces that derived value from the generated input.

In the above aspects and embodiments, the one or more derived values may comprise, for each signature verification key in the plurality of signature verification keys, a corresponding cryptographic hash value of that signature verification key.

According to a third aspect of the invention, there is provided a chip set, for a receiver, for securely obtaining a control word, the chip set arranged to carry out a method according to the first aspect of the invention (and embodiments thereof) as set out above.

According to fourth aspect of the invention, there is provided a head-end system of a content delivery network, the head-end system arranged to carry out a method according to the second aspect of the invention (and embodiments thereof) as set out above.

According to a fifth aspect of the invention, there is provided a receiver comprising the chip set according to the third aspect of the invention.

According to a sixth aspect of the invention, there is provided a system comprising the head-end system according to fourth aspect of the invention and one or more chip sets according to the third aspect of the invention.

According to a seventh aspect of the invention, there is provided a computer program which, when executed, carries

out a method according to the first or second aspect of the invention (and embodiments thereof) as set out above.

BRIEF DESCRIPTION OF THE DRAWINGS

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

FIG. **1** schematically illustrates a prior art chip set using symmetric cryptography;

FIG. **2** schematically illustrates another prior art chip set using asymmetric cryptography;

FIG. **3** schematically illustrates an exemplary system according to an embodiment of the invention;

FIG. **4** schematically illustrates an example method of using a chip set;

FIG. **5** schematically illustrates a method for use in a head-end system of a content delivery network;

FIG. **6-8** schematically illustrate methods for use in a head-end system of a content delivery network that makes use of DVB SimulCrypt;

FIG. **9** schematically illustrates an example method of using a chip set;

FIGS. **10-12** schematically illustrate modified versions of the systems and methods illustrated, respectively, in FIGS. **7-9**;

FIG. **13** schematically illustrates a variation of the chip set of FIG. **12**; and

FIGS. **14-18** correspond to FIGS. **6**, **7**, **8**, **10** and **11** respectively and include one or more legacy ECM generators and one or more legacy EMM generators.

DETAILED DESCRIPTION OF EMBODIMENTS OF THE INVENTION

In the description that follows and in the Figures, certain embodiments of the invention are described. However, it will be appreciated that the invention is not limited to the embodiments that are described and that some embodiments may not include all of the features that are described below. It will be evident, however, that various modifications and changes may be made herein without departing from the broader spirit and scope of the invention as set forth in the appended claims.

FIG. **3** schematically illustrates an exemplary system **7** according to an embodiment of the invention. The system **7** comprises a head-end system **4** arranged to communicate with one or more receivers **2** via a distribution network **6**.

The head-end system **4** transmits (or sends or communicates) a content stream scrambled using one or more control words (i.e. $\{\text{Content}\}_{CW}$) to a receiver **2** via the distribution network **6**. The head-end system **4** may transmit one or more ECMs and EMMs to the receiver **2** via the distribution network **6** so that the receiver **2** can access the one or more control words and thereby descramble the scrambled content stream. It will be appreciated, however, that whilst embodiments of the invention will be described with reference to ECMs and EMMs, embodiments of the invention are not limited to making use of ECMs and EMMS. The head-end system **4** may use any methods and systems described in relation to FIGS. **5-8**, **10**, **11** and **14-18** to scramble the content and provide descrambling information (e.g. ECMs and EMMs) to the receiver **2**.

The distribution network **6** may be any network capable of communicating or broadcasting descrambling information (e.g. ECMs, EMMs) and scrambled content streams to the receiver **2**. For example, the distribution network **6** may comprise one or more of a cable network, a satellite communication network, a terrestrial broadcast network, the internet, etc.

The (scrambled) content stream may comprise any kind of content data, such as one or more of video data, audio data, image data, text data, application/software data, program guide data, etc.

The receiver **2** may be any type of receiver (or client device) for receiving ECMs, EMMs and scrambled content streams. For example, the receiver **2** may be a set-top box, a receiver integrated into a content output device (such as a television or radio), a mobile terminal supporting broadcast services, a personal computer, etc. The receiver **2** may include, or be communicatively coupled to, a device for outputting or reproducing descrambled and decoded content to a user (such as a screen/monitor and/or one or more speakers).

The receiver **2** includes a chip set **1** for descrambling and/or decoding scrambled and/or encoded content. The chip set **1** may be communicatively connected to a CA/DRM client **3**. In general, the receiver **2** receives, filters and forwards ECMs and EMMs to the CA/DRM client **3** for further processing. The CA/DRM client **3** accesses conditional access (CA) data from the received ECMs and EMMs and can then load control words onto the chip set **1** using any methods and systems as described in relation to FIGS. **4**, **9**, **12** and **13**. The CA/DRM client **3** may be a secure device removable from the receiver **2**, such as a smart card (and may therefore comprise a processor and memory for carrying out the CA/DRM client functionality to be described below). Additionally or alternatively, the CA/DRM client **3** may be integral with the receiver **2** and may be implemented as a hardware component of the receiver **2** and/or in software running in a secured environment of the receiver **2** and/or in obfuscated software running in the receiver **2**.

The bandwidth required for transmitting conditional access messages (EMMs and/or ECMs) using the methods and systems described below is comparable to the bandwidth required by existing mechanisms to securely load control words onto a chip set. This is important as bandwidth is a valuable resource and the solutions described below ought not degrade the overall performance of the system **7**. The methods and systems described below provide a solution for protecting the confidentiality and authenticity of a control word that allows every CA/DRM system and CA/DRM system operator to establish a key loading mechanism independently, that is, without the need to share any secrets between CA/DRM systems (with the obvious exception of sharing control words in a SimulCrypt operation, as control words are, by definition, shared in a SimulCrypt operation). In addition, no trusted party in the scheme needs to manage any secret associated with a receiver (chip set) after its personalization is completed. This implies that the role of the trusted party is comparable to the role of the chip set manufacturers in currently available vertical market receiver solutions. In addition, the new methods and systems can recover from a security breach in which the root key pair of the authenticity mechanism is compromised, a security feature not offered by existing solutions.

FIG. **4** schematically illustrates an example method of using a chip set. By way of illustration, the method is implemented using a chip set **402** and a CA/DRM client **404**. A content delivery module **406** (e.g. of a head-end system **4**) may provide conditional access data (such as ECMs and EMMs) and a scrambled content stream to the chip set **402** of a receiver **2**. The chip set **402** may pass the conditional access data to the CA/DRM client **404** for further processing.

When manufactured, the chip set **402** may be personalized with a key pair. During the personalization phase, this key pair

is associated with a chip set serial number CSSN. The CSSN may be stored in a memory element **410** of the chip set **402**. The key pair includes a chip set public key CSPK (which is stored in a memory element **414** of the chip set **402**) and a corresponding chip set secret (private) key CSSK (which is stored in a memory element **416** of the chip set **402**). The key pair is preferably generated in the chip set **402** (e.g., using key pair personalization module **412**). Alternatively, the key pair personalization module **412** may be implemented outside the chip set **402** (e.g., in a chip set personalization system available to the chip set manufacturer), and the manufacturer may load CSSK and CSPK into the chip set **402** during its personalization. After this, the manufacturer can delete CSSK from its system(s). As will become apparent, the associated public-key cryptosystem is used to protect the confidentiality of control words needed to descramble scrambled content received by the chip set **402**. The use of public-key cryptography allows the chip manufacturer to publish both the CSSN and the CSPK for every chip set that is produced. The manufacturer of the chip sets **402** maintains pairs of numbers, each pair comprising of a chip set serial number CSSN and its associated chip set public key CSPK. The list of (CSSN, CSPK) pairs can be made available to all CA/DRM systems. During the distribution to a CA/DRM system, only the authenticity of this information should preferably be protected.

To prevent an adversary from also using the CSPK to successfully generate and use CW loading messages in a chip set, the systems and methods described below have an additional mechanism that requires the chip set **402** to verify the authenticity of a CW loading message. This mechanism prevents an adversary from issuing control words to the chip set **402** even with the knowledge of the chip set's published CSPK.

The systems and methods described below achieve this by using another asymmetric key pair that is associated with a CA/DRM system associated with the head-end system **4**. This key pair includes a (public) signature verification key SVK and a corresponding (secret/private) signature key SK associated with the CA/DRM system. This key pair is for use in an asymmetric cryptographic scheme consisting of a signature generation algorithm and a corresponding signature verification algorithm. The key pair (SK, SVK) is preferably generated by the CA/DRM system associated with the head-end system **4**, and its secret key SK does not need to be known to any CA/DRM supplier.

The CA/DRM client **404** may include a communication module for receiving ECMs and/or EMMs and/or other conditional access information forwarded by the chip set **402** and/or the receiver **2**. This communication module may be implemented within a keys control module **408** of the CA/DRM client **404**. The keys control module **408** may obtain the SVK from conditional access data that it receives from the content delivery module **406** via the chip set **402**. SVK may be provided by the head-end system **4** to the CA/DRM client **404**.

The signature verification key SVK is stored in a memory element **420** of the CA/DRM client **404**. The CA/DRM client **404** may send the signature verification key SVK to the chip set **402** so that the chip set **402** may store the SVK in a memory element **424** of the chip set **402**.

As will become apparent from the discussion below, a CA/DRM system associated with the head-end system **4** generates a random value CW* (or interchangeably referred to as a "virtual control word"). The virtual control word CW* is not directly used for (de-)scrambling the content. Instead, a value derivable from CW* and SVK, namely the control word CW, is the key used for (de-)scrambling the content. The head-end system **4** sends the virtual control word CW* to the chip set **402** of the receiver **2** using an ECM. The chip set **402** filters and forwards the received ECM to the CA/DRM client **404** as part of the conditional access data forwarded to the CA/DRM client **404**. The keys control module **408** obtains the virtual control word CW* from an ECM that it has received.

The chip set **402** comprises a descrambler **434** for descrambling scrambled content. As mentioned, the chip set **402** does not use CW* directly in the descrambler **434**, but derives a CW from CW* and SVK (stored in the memory element **424**) using a hash function H implemented by a H-module **432** of the chip set **402**. The H-module **432** may merge the two inputs (CW* and SVK) before applying the hash function to the merged inputs to produce the output CW. The H-module **432** may be implemented within a cryptographic/secure module of the chip set **402**. The function H may also be any other suitable cryptographic function (i.e. it need not necessarily be a hash function). Possible implementations of the function H preferably have the following property: given an output CW, it is hard (e.g., difficult, computationally difficult, infeasible or computationally infeasible) to find a key pair (SK*, SVK*) and a virtual control word CW** such that SVK* and CW** map to CW (i.e. such that providing SVK* and CW** as inputs to function H, or as inputs to the H-module **432**, would result in outputting the control word CW). In certain embodiments, "hard" may mean that an adversary may not be able to derive a key pair (SK*, SVK*) and a virtual control word CW**, such that SVK* and CW** map to CW, in polynomial time or space. In other embodiments, "hard" may be defined by specifying a lower bound on the number of operations or on the size of the memory required to find such values. As a third example, one may define "hard" by specifying an upper-bound on the probability that the property is not satisfied.

An example of a function H with this property is the following: (1) merge the inputs CW* and SVK to produce an intermediate result X, e.g., by appending the value of SVK to the value of CW*, (2) apply a 2^{nd} pre-image resistant hash function to the input X to produce the output CW. To see that the preferred property holds for this example, observe that, given the control word CW and the public key SVK, it will be hard for an adversary to determine an SVK* not equal to SVK, and a virtual control word CW** such that SVK* and CW** map to CW. To see this, assume that it is feasible for an adversary to generate such an SVK* and such a CW**. Then, given the output CW and the inputs SVK and CW*, the same method can be applied to generate a second pre-image comprising of SVK* and CW** to the hash function, as SVK* is not equal to SVK. This implies that the hash function is not 2^{nd} pre-image resistant, contradicting the assumption. As a result, the only option for the adversary is to determine a signature key associated with the public key of the CA/DRM system associated with the head-end system **4** (i.e. SVK) which is, by definition, infeasible for an asymmetric scheme. In addition, notice that the function H satisfies the desired property also in case the virtual control word CW* is known (i.e., in case both inputs to the 2^{nd} pre-image resistant hash function are known). This can be seen as follows: given an output CW and the specified inputs to the 2^{nd} pre-image resistant hash function, it is, by definition, infeasible to determine a second, different set of inputs to the 2^{nd} pre-image resistant hash function that map to the given output CW. This implies that the adversary cannot determine a signature verification key different from SVK that maps to the given CW. The only option for the adversary is to determine a signature key associated with SVK, which is, by definition, infeasible for an asymmetric cryptographic scheme.

After applying, the function H, the H-module **432** stores the output CW in a memory element **438** of the chip set **402**. Using CW from the memory element **438**, the descrambling module **434** may descramble content provided by the content delivery module **406** and transmit descrambled content to a content decoder **440** of the chip set **402** for further processing (e.g. video or audio decompression). The content decoder **440** may be implemented in the receiver **2** as a module separate from (or external to) the chip set **402**.

Symmetric encryption is used to protect the confidentiality and the authenticity of a virtual control word CW*. In particular, a symmetric chip set load key CSLK is generated for a chip set **402** (and is preferably unique to that chip set **402**) by a CA/DRM system associated with the head end system **4**. The CSLK (intended for the CA/DRM client **404**, and protected using the confidential and authentic channel offered by the CA/DRM system) is transmitted along with an initialization pattern CSLK-init (intended for the chip set **402**) to the CA/DRM client **404** connected to the chip set **402**. The initialization pattern CSLK-init includes an encrypted version of CSLK (encrypted using the CSPK of the chip set **402**) and, as will be described later, a signature of the encrypted version of CSLK (where the signature is generated using the signature key SK). Hence, the CSLK is encrypted to produce the CSLK-init in such a way that CSLK-init can be processed in the chip set **402** to produce a CSLK value.

In some embodiments, the CSLK (intended for the CA/DRM client **404**, and protected using the confidential and authentic channel offered by the CA/DRM system) and the initialization pattern CSLK-init (intended for the chip set **402**) are transmitted from the head-end system **4** to the chip set **402** using one or more EMMs, and the chip set **402** may filter out the EMM(s) and forward it/them to the keys control module **408** in the CA/DRM client **404**. (If a unique pairing between the CA/DRM client **404** and the chip set **402** is not known within the head-end system **4**, then preferably separate EMMs are used for packaging and transmitting CSLK and the initialization pattern CSLK-init.) The keys control module **408** may then extract CSLK and CSLK-init from the EMM(s) for use by the CA/DRM client **404** and the chip set **402**. The CSLK may be stored in a memory element **418** of the CA/DRM client **404** and the CSLK-init may be stored in a memory element **422** of the CA/DRM client **404**. The CA/DRM client **404** may subsequently forward the initialization pattern CSLK-init to the chip set **402**.

The CA/DRM client **404** encrypts CW* (that its keys control module **408** has extracted from an ECM that has been forwarded to the keys control module **408**) with CSLK (stored in memory element **418**) to produce $\{CW^*\}_{CSLK}$ using a symmetric encryption module **444** of the CA/DRM client **404**. The encryption of CW* with CSLK may be performed in any suitable security module in the CA/DRM client **404**. The encrypted version of CW*, $\{CW\}_{CSLK}$, is then transmitted to the chip set **402**, where $\{CW^*\}_{CSLK}$ is to be decrypted using a symmetric decryption module **442** of the chip set **402** (corresponding to the symmetric encryption module **444**). The decryption module **442** use the CSLK value stored in a memory element **430** of the chip set **404** to obtain CW*.

The initialization pattern CLSK-init and/or the encrypted version of CW* may be transmitted from the CA/DRM client to chip set **402** using any suitable transmission module in the CA/DRM client **404** communicably connected with the chip set **402**. The encrypted version of CW* and/or the initialization pattern CLSK-init may be received at chip set **402** using yet another communication module in the chip set **402**.

To obtain the CSLK value, stored in the memory element **430**, for decrypting $\{CW^*\}_{CSLK}$, the chip set **402** includes two cryptographic operations, implemented as a signature verification module **426** and a decryption module **428**. The signature verification module **426** and the decryption module **428** may be implemented in any suitable cryptographic module within the chip set **402**. The chip set **402** uses the signature verification module **426** and the SVK of the CA/DRM system associated with the head-end system **4** (stored in the memory element **424** of the chip set **402**), to verify the authenticity of CSLK-init. If the signature verification module **426** determines that CSLK-init is not authentic (i.e. if the signature has not been generated using an SK associated with SVK), then the chip set **402** may take any suitable subsequent action to ensure that the user of the receiver **2** does not gain access to decrypted content, such as not performing any content decryption until a new CSLK-init message and/or a new SVK have been received so that the new CSLK-init message can be verified. Alternatively, the signature verification module **426** may output a value from which the decryption module **428** will be able to obtain CSLK only if the verification is successful, i.e. if the CSLK-init has been signed using an SK corresponding to the SVK stored in the memory element **424**; otherwise, the signature verification module **426** may output a value from which the decryption module **428** will not be able to obtain CSLK if the verification is not successful, i.e. if the CSLK-init has been not been signed using the SK corresponding to the SVK stored in the memory element **424**. For example, a signature mechanism with message recovery may be used.

After verification of the authenticity of CSLK-init, the encrypted CSLK in CSLK-init is decrypted using the CSSK of the chip set **402** (stored in the memory element **416**). As the CSLK was encrypted by the CSPK of the chip set **402**, only the chip set having the corresponding CSSK may correctly decrypt CSLK from the CSLK-init message.

Once the chip set **402** obtains CSLK, then $\{CW^*\}_{CSLK}$ may be decrypted by the decryption module **442** to obtain CW* using the obtained CSLK. The authenticity of CW* is protected, in that an adversary cannot construct an encrypted CW* message for a given CW* that will produce CW* in the chip set **402** if the authenticity of SVK and the authenticity of the CSLK-init message are protected. The authenticity of the CSLK-init message is protected by signing it with SK. Using the H-module **432** and the SVK value stored in the memory element **424**, SVK and CW* may be merged and processed to produce CW. The H-module protects the authenticity of the signature verification key SVK, in that CW descrambling will fail if SVK is not authentic. That is, if the signature verification key of a key pair (SK*, SVK*), determined by an adversary not knowing the signature key SK, is provided as input to the chip set (e.g., to load a CSLK chosen by the adversary, and using this CSLK to load a given CW*), then the H-module **432** will not output the correct CW, and consequently, the content descrambling will fail.

The symmetric chip set load key CSLK is used to decrypt CW* values that are encrypted with a symmetric encryption algorithm and the key CSLK. The H-module **432** suitably derives the CW from the CW* and the SVK, such that CW may be loaded into the descrambling module **434** to descramble content. This implementation has the benefit that the chip set **402** only needs to perform public-key cryptographic operation(s) when processing a CSLK-init message to initially obtain CSLK. During normal operation, CSLK and SVK can be stored inside the chip set, and the CW processing overhead resembles that of the existing systems.

The computation step associated with the H-module **432** is comparable to that of a normal symmetric encryption (or decryption) step.

To work with the CA/DRM client/chip set configuration described in relation to FIG. **4**, the head-end system **4** is configured to produce the chip set load key initialization pattern (CSLK-init) for each chip set **402**. FIG. **5** schematically illustrates a method for use in such a head-end system **4** of a content delivery network.

Specifically, an EMM generator **518** of the head-end system **4** generates a random chip set load key CSLK for a target chip set **402** (e.g., using a chip set load key generator **508** of the EMM generator **518**). The CSLK may be generated using any pseudo-random number generator. Preferably, the EMM generator **518** uses the chip set load key generator **508** to generate a CSLK that is unique to each chip set **402** in a population of chip sets **402**—i.e. each receiver **2** being serviced by the CA/DRM system at the head-end system **4** has its own CLSK different from the other receivers **2**. This prevents the (unauthorized) sharing of a message $\{CW^*\}_{CSLK}$.

The EMM generator **518** encrypts the generated CSLK using the CSPK of the target chip set **402** (e.g., using a encryption module **510** of the EMM generator **518**).

The EMM generator **518** may comprise a CSPK store **504** that stores the CSPKs of the chip sets **402** being serviced by this CA/DRM system. The encryption module **510** performs an encryption process corresponding to the decryption process performed by the decryption module **428** of the chip set **402**.

The EMM generator **518** uses the SK (as stored in memory element **502** of the EMM generator **518**) to sign the encrypted CSLK to produce the chip set load key initialization pattern CSLK-init (e.g., using a signature module **512** of the EMM generator **518**). The EMM generator **518** then packages the generated CSLK-init along with the CSLK (intended for the CA/DRM client **404**, and protected using the confidential and authentic channel offered by the CA/DRM system) to form an EMM. This EMM is targeted at the CA/DRM client **404** connected to the chip set **402** with the corresponding CSPK or CSSN. If a unique pairing between the CA/DRM client **404** and the chip set **402** is not known within the head-end system **4**, then preferably separate EMMs are generated and used for packaging and transmitting CSLK and CSLK-init.

The head-end system **4** includes a CW generator **506** which generates random values for CW*. The CW generator **506** may generate random values for CW* using any pseudo-random number generator.

The head-end system **4** includes an ECM generator **516** that receives a CW* generated by the CW generator **506** and generates an ECM containing the received CW*.

The head-end system **4** includes a multiplexer **524**. The multiplexer **524** selects the appropriate data to be transmitted to a CA/DRM module (or scrambling module) **526**, choosing at least one of: an ECM output from the ECM generator **516**, an EMM output from the EMM generator **518**, and content. ECMs and/or EMMs may be passed from the multiplexer **524** to a content delivery module **528** for transmission to the chip set **404**. The content passed from the multiplexer **524** is scrambled by the CA/DRM module **526** using CW. This may involve any form of content scrambling technique corresponding to the content descrambling that the content descrambling module **434** is capable of performing. Subsequently, the scrambled content is provided to the content delivery module **528**, which transmits the scrambled content to a receiver **2**.

The head-end system includes an H-module **520** to produce control words for scrambling content in the CA/DRM module **526**. The H-module **520** may be implemented in a cryptographic module. To produce CW, the H-module **520** implements a function H corresponding to the H-module **432** of FIG. **4**. In particular, the H-module derives CW from the CW* value that is generated by the CW generator **506** and that is transmitted in an ECM provided by the ECM generator **516**. The H-module **520** combines the signature verification key SVK stored in a memory element **514** with CW* generated by the CW generator **506** and applies a function H (e.g. a hash function) to convert the CW* value into CW—the above description (and requirements) of the H-module **432** and the function H of the chip set **402** applies to the H-module **520** and its function H. The H-module **432** of the chip set **404** produces the same output CW as the H-module **520** of the head-end system **4** when they are provided with the same input (SVK and CW*).

The methods and systems described above may be used in a system such as the head-end system described in the DVB SimulCrypt specification (DVB=digital video broadcasting)—see ETSI TS 103 197. The DVB SimulCrypt specification allows two or more CA/DRM systems to share a control word CW as a common key. A common head-end system protocol for facilitating the sharing of the CW streams used in scrambling the digital TV content streams is described in the DVB SimulCrypt specification.

FIG. **6** therefore schematically illustrates a method for use in such a head-end system **4** of a content delivery network that makes use of DVB SimulCrypt. In particular, in FIG. **6** the head-end system **4** comprises two CA/DRM systems that have respective EMM generators **518** ($EMMG_1$ and $EMMG_2$) and ECM generators **516** ($ECMG_1$ and $ECMG_2$). As is known, a SimulCrypt synchronizer **530** is used to coordinate the multiple ECM generators **516** (for example, by obtaining the CW* output by the CW generator **506**, providing the CW* to the ECM generators **516** along with any CA/DRM-specific parameters, acquiring the ECMs from the ECM generators **516**, synchronising the timing of the ECMs and their provision to the multiplexer **524**). In the normal DVB system as set out in ETSI TS 103 197, the SimulCrypt synchronizer **530** would pass control words to the scrambling module **526**—however, as discussed above, it is the H-module **520** which generates the actual control words CW used for content scrambling and passes those generated control words CW to the scrambling module **526** (because the ECMs do not make use of CW but make use of CW* instead)—therefore, in FIG. **6** the SimulCrypt synchronizer **530** is shown as providing CW* to the H-module **520**. Hence, a standard SimulCrypt synchronizer **530** may be used, the only difference being that its "control word output" is connected to the H-module **520** instead of directly to the scrambling module **526**.

The two CA/DRM systems in FIG. **6** are potentially run or operated by different content providers/CA system operators. It will be appreciated that any number of CA/DRM systems may be associated with the head-end system **4** and that embodiments of the invention are not limited to just two CA/DRM systems.

In the system shown in FIG. **6**, the participating CA/DRM systems share the (SK, SVK) pair. In particular, the first EMM generator **518** ($EMMG_1$) and the second EMM generator **518** ($EMMG_2$) both have knowledge of, and make use of, the same SK and SVK. In particular, they both generate EMMs for the receivers **2** associated with their respective CA/DRM system as described above, based on a common SK and SVK.

The sharing of a common SK and SVK as set out above has a number of drawbacks. In particular:

A confidential channel between the various CA/DRM systems is required to transport and share the secret key SK.

However, a confidential electronic interface between different CA/DRM systems may not exist (especially if the CA/DRM systems are associated with different CA/DRM suppliers). Therefore it would be desirable to let each CA/DRM system generate its own SK(s) and only share the associated (public) signature verification key(s) SVK(s). For instance, such an SK could be generated inside a hardware security module of a CA/DRM system of the head-end system **4** and does not need to be available unprotected at any point in time.

A renewal of the pair (SK, SVK), e.g. after the secret signature key SK has been compromised, has a similar operational impact for all of the CA/DRM systems participating in the SimulCrypt operation and making use of SK. In particular, new CSLK-init EMMs signed with the new signature key have to be generated and distributed for every participating CA/DRM system and all of the receivers **2** that they are servicing. It would be beneficial to limit the operational impact of a renewal of the pair (SK, SVK).

Embodiments of the invention aim to address these issues. FIG. **7** therefore schematically illustrates a method for use in a head-end system **4** of a content delivery network that makes use of DVB SimulCrypt. In particular, in FIG. **7** the head-end system **4** comprises two CA/DRM systems that have respective EMM generators **718** ($EMMG_1$ and $EMMG_2$) and ECM generators **516** ($ECMG_1$ and $ECMG_2$). This is the same architecture as shown in FIG. **6**, except that the EMM generators **718** ($EMMG_1$ and $EMMG_2$) comprise and make use of respective signature keys SK_1, SK_2 and corresponding respective signature verification keys SVK_1, SVK_2. In particular, the first CA/DRM system has its own signature key SK_1 and its own corresponding signature verification key SVK_1, whilst the second CA/DRM system has its own (different) signature key SK_2 and its own corresponding signature verification key SVK_2. Each CA/DRM system independently generates its own pair (SK_i, SVK_i) and can keep its signature key SK_i secret from all of the other CA/DRM systems—it needs only to publish the signature verification key SVK_i. Recall that this a public key, so its confidentiality does not need to be protected. This implies that there is no longer a need for a protected interface between CA/DRM systems in a SimulCrypt operation.

As with FIG. **6**, the two CA/DRM systems in FIG. **7** are potentially run or operated by different content providers/CA system operators. It will be appreciated that in the system shown in FIG. **7**, any number of CA/DRM systems may be associated with the head-end system **4** and that embodiments of the invention are not limited to just two conditional access end-systems. Hence, in general, there may be n CA/DRM systems and hence n different respective pairs (SK_i, SVK_i).

The H-module **520** of FIG. **6** is replaced by an H-module **720** in the system shown in FIG. **7**. In particular, as each CA/DRM system now has its own signature verification key SVK_i, the H-module **720** is arranged to receive the set of signature verification keys $SVK_1, \ldots, SVK_n$ and the CW* output from the CW generator **506**. The H-module **720** implements a similar function H as the H-module **520**, except that the security requirements are modified to cater for the fact that the H-module **720** operates on a set (or a plurality) of signature verification keys $SVK_1, \ldots, SVK_n$. In particular, the H-module **720** may merge the inputs CW*, $SVK_1, \ldots, SVK_n$ and may then apply a hash function to the merged inputs to produce the output CW. The function H may also be any other suitable cryptographic function (i.e. it need not necessarily be a hash function). Possible implementations of the function H preferably have the following property: given CW, it is hard (e.g., difficult, computationally difficult, infeasible or computationally infeasible) to find or calculate or determine a key pair (SK*, SVK*) and an input to the function H, such that the determined signature verification key SVK* is a signature verification key in the determined input to H, and such that CW is the output of H for this input (i.e. such that providing that input to function H, or as an input to the H-module **720**, would result in outputting the control word CW). In certain embodiments, "hard" may mean that an adversary may not be able to derive such an input in polynomial time or space. In other embodiments, "hard" may be defined by specifying a lower bound on the number of operations or on the size of the memory required to find such an input. As a third example, one may define "hard" by specifying an upper-bound on the probability that the property is not satisfied.

An example of a function H with this property is the following: (1) merge the inputs CW*, $SVK_1, \ldots, SVK_n$ to produce an intermediate result X, e.g., by concatenating these values, (2) apply a 2^{nd} pre-image resistant hash function to the input X to produce the output CW. The analysis provided above when discussing the function H that accepts only a single SVK applies analogously to this modified function H that accepts a set of signature verification keys.

FIG. **8** schematically illustrates a further method for use in a head-end system **4** of a content delivery network that makes use of DVB SimulCrypt. The system and method illustrated in FIG. **8** are the same as those illustrated in FIG. **7**, except that one of the CA/DRM systems has a plurality of pairs ($SK_{i,j}$, $SVK_{i,j}$). In particular, in FIG. **8**, the second CA/DRM system has a first pair ($SK_{2,1}$, $SVK_{2,1}$) and a second pair ($SK_{2,2}$, $SVK_{2,2}$). However, it will be appreciated that a CA/DRM system may have any number of pairs ($SK_{i,j}$, $SVK_{i,j}$) of signature keys and corresponding signature verification keys. The EMM generator ($EMMG_2$) for the second CA/DRM system may comprise a switch **800** (or some other determining means) for selecting a particular $SK_{2,j}$ (out of the signature keys: $SK_{2,1}$ and $SK_{2,2}$, associated with that CA/DRM system) to use when carrying out the signature process to generate CSLK-init EMMs.

It will be appreciated that any number of CA/DRM systems associated with the head-end system **4** may have a plurality of associated pairs ($SK_{i,j}$, $SVK_{i,j}$) of signature keys and corresponding signature verification keys. Thus, in general, if there are m ($m \geq 1$) CA/DRM systems associated with a head-end system **4**, and if the i-th ($i=1 \ldots m$) CA/DRM system has n_i ($n_i \geq 1$) associated pairs ($SK_{i,j}$, $SVK_{i,j}$) of signature keys and corresponding signature verification keys, then there are

$$n = \sum_{i=1}^{m} n_i$$

pairs ($SK_{i,j}$, $SVK_{i,j}$) of signature keys and corresponding signature verification keys. The H-module **720** receives the n signature verification keys $SVK_{i,j}$ from the CA/DRM systems as its input, along with the generated virtual control word CW*, and generates a control word CW as described above for FIG. **7**.

As each CA/DRM system of FIGS. **7** and **8** uses signature keys (and associated signature verification keys) specific to that CA/DRM system (i.e. two CA/DRM systems do not use the same signature key), a content provider/CA system operator can change the key pair of one CA/DRM system without a significant impact on the other CA/DRM systems (possibly operated by another content provider/CA system operator). More precisely, when a CA/DRM system updates a pair

($SK_{i,j}$, $SVK_{i,j}$) with a pair (SK, SVK), then: (a) the EMM generator of that CA/DRM system needs to generate and distribute new CSLK-init EMMs (containing CSLK values, and a signature based on the updated signature key SK) for the receivers **2** associated with this CA/DRM system; (b) the other CA/DRM systems should be made aware of the new signature verification key SVK; (c) all CA/DRM systems should distribute the new signature verification key SVK to all their associated receivers (because, as will be described below, the receivers will need access to the new signature verification key). In a broadcast network, this distribution is generally very bandwidth efficient, as the message containing the new signature verification key SVK can be identical for all receivers.

Hence, if one CA/DRM system updates/renews a key pair ($SK_{i,j}$, $SVK_{i,j}$) (e.g., after the signature key $SK_{i,j}$ is compromised) with an updated (SK, SVK) pair, then the impact on the other CA/DRM systems in the SimulCrypt operation is minimal. Moreover, if the signature key $SK_{i,j}$ is compromised, then the head-end security of the other CA/DRM systems is not compromised as their own signature keys are not the same as the compromised signature key. These other CA/DRM systems simply need to be made aware of the new updated signature verification key SVK and these other CA/DRM systems need to make the receivers **2** that they service also aware of the new updated signature verification key SVK, which is a straightforward operation for these other CA/DRM systems. If the signature key $SK_{i,j}$ is compromised, then receiver security is restored for all CA/DRM systems in the SimulCrypt operation as soon as the updated signature verification key SVK is used as input to the H-module (instead of using $SVK_{i,j}$), revoking the compromised signature key $SK_{i,j}$.

If a CA/DRM system operator wants to renew a key pair ($SK_{i,j}$, $SVK_{i,j}$) with a new key pair (SK, SVK), then switching to the new key pair happens simultaneously for all receivers **2** in a operator's population of receivers **2** (as the control words generated to scramble content will be based on the updated SVK, via the H-module **720**, at the point of switching over to the new key pair). From an operational point of view, there is a risk that not all these receivers **2** have received all required information (via EMMs) when the provider starts using the new key pair (more precisely: the new SVK, a receiver's unique CSLK-init pattern signed with the new SK, or a CSLK intended for the CA/DRM client might not have been transmitted to, or received at, a receiver **2** via an EMM when the new SVK is used to generate control words). This can potentially cause a number of receivers to "black-out" for a while as they will not be able to successfully descramble content (as they will not be able to use the updated CSLK messages or the updated SVK). However, CA/DRM systems that have a plurality of associated ($SK_{i,j}$, $SVK_{i,j}$) pairs have the following advantage. A first (current) key pair ($SK_{i,j}$, $SVK_{i,j}$) can be used to generate CSLK-init pattern messages, that is, the signature key $SK_{i,i}$, is used to sign CSLK-init patterns. The signature key $SK_{i,k}$ of a second key pair ($SK_{i,k}$, $SVK_{i,k}$) is reserved for future use (securely storing the key $SK_{i,k}$). The signature verification keys of both the first and second pair (that is, $SVK_{i,j}$ and $SVK_{i,k}$) are used by the H-module **720** to generate control words CW for scrambling content. Suppose that the operator wants to revoke the first key pair ($SK_{i,j}$, $SVK_{i,j}$) (e.g., in case the signature key $SK_{i,j}$ is compromised). First, the CA/DRM system retrieves $SK_{i,k}$ from secure storage. Next, the CA/DRM system generates new CSLK-init EMMs, using $SK_{i,k}$ as the signature key (if CSLK is also updated, then also EMMs containing the new CSLK values for the CA/DRM clients need to be generated). The CA/DRM system distributes the EMMs to the receivers **2**. The CA/DRM system also generates a third key pair ($SK_{i,w}$, $SVK_{i,w}$), and distributes the public signature verification key $SVK_{i,w}$ to all CA/DRM systems in the SimulCrypt operation. All CA/DRM systems distribute $SVK_{i,w}$ to their receivers (e.g., using an EMM). As long as the $SVK_{i,j}$ and $SVK_{i,k}$ are used by the H-module **720** to generate control words CW for scrambling content, the receivers **2** will accept (or continue to operate correctly and perform correct descrambling with) CSLK-init messages signed with the signature key $SK_{i,j}$ or $SK_{i,k}$. That is, during this time, the chip sets **402** can independently switch to using the new/updated CSLK-init message signed with $SK_{i,k}$, instead of forcing all chip sets **402** to switch at the same time. For instance, the CA/DRM system can request a group of CA/DRM clients **404** at a time to start using the new CSLK EMMs (the new CSLK-init pattern being signed with $SK_{i,k}$). This restricts the number of receivers **2** that can black-out simultaneously. After the CA/DRM system has requested all receivers **2** to use the new CSLK (EMMs), then receiver security can be restored by using as input to the H-module **720** instead of $SVK_{i,j}$. After this, the first key pair ($SK_{i,j}$, $SVK_{i,j}$) is renewed with the second key pair ($SK_{i,k}$, $SVK_{i,k}$), and receiver security is restored for the content encrypted with control words derived using $SVK_{i,w}$, in that the chip set will not accept CSLK-init messages signed with (the compromised) $SK_{i,j}$. Note that this process can be applied iteratively; the key pairs in the next iteration are ($SK_{i,k}$, $SVK_{i,k}$) and ($SK_{i,w}$, $SVK_{i,w}$).

FIG. **9** schematically illustrates an example method of using a chip set. This is the same as illustrated in FIG. **4** (and therefore only the differences between the two Figures shall be described below). The system and method shown in FIG. **9** is compatible with the systems illustrated in FIGS. **7** and **8**.

In particular, instead of the CA/DRM client **404** being provided with a single signature verification key SVK and providing this to the chip set **402**, the CA/DRM client **404** receives the set of n signature verification keys $SVK_1, \ldots, SVK_n$ and provides these n signature verification keys $SVK_1, \ldots, SVK_n$ to the chip set **402** (without loss of generality, a single subscript is used to distinguish the different signature verification keys; more than one key in this set may be associated with a single CA/DRM system). The CA/DRM client **404** may store each signature verification key SVK_i in a corresponding memory element **420**(*i*) of the CA/DRM client **404**; the chip set **402** may store each signature verification key SVK_i in a corresponding memory element **424**(*i*) of the chip set **402**.

The CA/DRM client **404** is informed of the set of signature verification keys $SVK_1, \ldots, SVK_n$ by the CA/DRM system (associated with the head-end system **4**) that is servicing the receiver **2** of the CA/DRM client **404** as has been set out above.

Additionally, the H-module **432** of FIG. **4** has been replaced in FIG. **9** with an H-module **900**. The H-module **900** operates in the same way as the H-module **720** of the systems illustrated in FIGS. **7** and **8**. Thus, provided that the chip set **402** has been provided with legitimate/current signature verification keys $SVK_1, \ldots, SVK_n$, and provided that it has managed to successfully obtain a correct virtual control word CW*, then the output of the H-module **900** will be the same control word CW as that output by the H-module **720** in the head-end system **4** and hence the chip set **402** will be able to successfully descramble the scrambled content stream.

Preferably, a security requirement for the chip set implementation is that a CW* and a set of signature verification keys $SVK_1, \ldots, SVK_n$ may only be provided to the H-module **900** to derive a CW (or such a derived CW may only be used

for content descrambling) if the authenticity of the CSLK-init message associated with the encrypted CW* is verified with one of the keys in the set of signature verification keys $SVK_1, \ldots, SVK_n$ and if the CSLK-init message is found to be authentic.

As the chip set **402** has a plurality of signature verification keys $SVK_1, \ldots, SVK_n$ available to it, the signature verification module **426** is arranged to select the signature verification key SVK_i corresponding to the CSLK-init pattern that it receives from the CA/DRM client **404**. For example, the head-end system **4** may assign a unique key identifier ID_i to SVK_i, and may append ID_i to SVK_i and to a CSLK-pattern signed with the corresponding signature key SK_i. This enables the signature verification module **426** to select the associated signature verification key SVK_i from the received set of signature verification keys $SVK_1, \ldots, SVK_n$. It will be appreciated that other mechanisms may be used to allow the signature verification module **426** to select the correct signature verification key SVK_i. For example, the signature verification module **426** may be arranged to try each of the signature verification keys $SVK_1, \ldots, SVK_n$ until one of them successfully verifies the signature of the CSLK-init pattern—if none of them successfully verify this signature, then the signature verification process has failed.

In some embodiments, the set of signature verification keys $SVK_1, \ldots, SVK_n$ and the CSLK-init message are provided to the chip set **402** with every encrypted CW*. In such embodiments, the set of signature verification keys does not need to be stored for future use inside the chip set **402**.

In practice, the CA/DRM client **404** and the chip set **402** will use the key CSLK to protect the transfer of multiple virtual control words CW* from the CA/DRM client **404** to the chip set **402**. To avoid time-consuming public-key operations for deriving every CW* (that is, the public-key decryption performed by the decryption module **428** using the CSSK of the chip set **402**, and the signature verification performed by the signature verification module **426** using SVK_i), in some embodiments the key CSLK is stored (and maintained) inside the chip set **402** after it has been obtained (e.g. in the memory module **430**). Thus, the public-key operations of the signature verification module **426** and the decryption module **428** only need to be performed when the chip set **402** receives a new CSLK-init pattern from the CA/DRM client **404**.

In some embodiments, the set of signature verification keys $SVK_1, \ldots, SVK_n$ to be used as input to H-module **900** is provided to the chip set **402** with every encrypted CW* from the CA/DRM client **404**. In such embodiments, the set of signature verification keys does not need to be stored for future use inside the chip set **402**. If the set $SVK_1, \ldots, SVK_n$ is provided with an encrypted CW* message from the CA/DRM client **404**, then before a stored CSLK is used to decrypt the encrypted CW*, some embodiments of the invention are arranged for the chip set **402** to verify whether CSLK (as stored in the memory module **430**) has been loaded/obtained using one of the keys in the received set $SVK_1, \ldots, SVK_n$ (i.e. whether the process to initially obtain and store CSLK involved the signature verification module **426** performing a signature verification process on a received CSLK-init pattern using one of the received signature verification keys $SVK_1, \ldots, SVK_n$). One way to achieve this is the following: after processing a CSLK-init message (received together with the associated signature verification key SVK_i), the chip set **402** computes a cryptographic hash value of the signature verification key SVK_i (that it used to verify the authenticity of the CSLK-init pattern), and the chip set **402** stores this hash value together with CSLK. For every signature verification key in the received set of signature verification keys (received together with the encrypted CW*), the chip set **402** can compute its hash value and can compare the computed hash value with the hash value stored with the CSLK required to decrypt the encrypted CW*—if this check reveals that the stored CSLK has been loaded using a valid signature verification key, then the stored CSLK may be used by the decryption module **434** to decrypt the encrypted CW*. Notice that in such embodiments a CSLK-init message only needs to be provided with the associated signature verification key SVK_i (instead of the set of signature verification keys). That is, in such embodiments the signature verification module **426** does not need to be arranged to select the signature verification key SVK_i from a set.

In some embodiments, the set of keys $SVK_1, \ldots, SVK_n$ (and their key identifiers $ID_1, \ldots, ID_n$) may be stored inside the chip set **402** for future use. That is, the stored set of keys (and their key identifiers) are used to process CSLK-init messages and encrypted CW* messages provided to the chip set **402** from the CA/DRM client **404**. In such an embodiment, one or more CSLK-init patterns and one or more encrypted CW* can be provided to the chip set **402**. The chip set **402** can derive CSLK from a CSLK-init message using the stored set of keys $SVK_1, \ldots, SVK_n$ and the stored set of key identifiers (used by signature verification module **426** to select the correct key from the stored set). The chip set **402** may store CSLK for future use. The chip set **402** uses the derived CSLK to obtain CW* from the encrypted CW*. Next, the chip set **402** can provide CW* and the stored set of keys $SVK_1, \ldots, SVK_n$ as input to the H-module **900** to produce the output CW. In this way, communication costs between the CA/DRM client **404** and the chip set **402** are reduced, and overall system performance may be improved.

In some embodiments, multiple CSLK keys are stored (and maintained) inside the chip set **402** after they have been obtained (as set out above). Storing multiple CSLK keys can avoid having to perform public-key operations when switching from a current stored CSLK to another stored CSLK. This is particularly useful if the chip set **402** supports the concurrent use of multiple CA/DRM clients **404**, each of which may use a different CSLK (and possibly a different set of signature verification keys), as the chip set **402** can then perform (fast) switching between CSLKs as and when desired/necessary.

If the set of keys $SVK_1, \ldots, SVK_n$ (and their key identifiers $ID_1, \ldots, ID_n$, or cryptographic hash values of the keys $SVK_1, \ldots, SVK_n$) are stored inside the chip set **402** for future use, and if a new set of signature verification keys is provided to the chip set **402** (to be stored inside the chip set **402** instead of the set of keys $SVK_1, \ldots, SVK_n$), then the chip set **402** may be arranged to determine whether one or more of the stored CSLK(s) was(were) loaded using a key that is not present in the set of newly received signature verification keys. For example, the key identifier ID_i (or cryptographic hash value) of the signature verification key SVK_i used to verify the authenticity of the CSLK-init message may be stored together with CSLK. The newly received set of signature verification keys, the stored set of signature verification keys $SVK_1, \ldots, SVK_n$ (and their key identifiers or their cryptographic hash values) and the key identifiers (or the cryptographic has values) stored with the CSLK(s) can be used to determine whether one or more of the stored CSLK(s) was(were) loaded using a key that is not present in the set of newly received signature verification keys. If there are any such CSLK(s), then the chip set **402** may be arranged to not use such a CSLK to derive a CW* (e.g., such CSLKs can be de-activated or simply deleted from the memory module **430**). Alternatively, all stored CSLKs may be deleted from the memory module **430** whenever a new set of verification keys is loaded and

stored inside the chip set **402**. Further, if stored CSLK(s) was(were) de-activated, then the chip set **402** may be arranged to (re-)activate the CSLK(s) if a new set of signature verification keys is provided to the chip set **402**, and if the associated CSLK-init pattern was verified using one of the keys in this new set. For instance, (re-)activation can be useful if the chip set **402** supports the concurrent use of multiple CA/DRM clients **404**, each of which may use a different CSLK and a different set of signature verification keys, as the chip set **402** can then perform (fast) switching between CSLKs as and when desired/necessary.

FIGS. **10-12** schematically illustrate modified versions of the systems and methods illustrated, respectively, in FIGS. **7-9**. The difference is that the head-end systems **4** and the chip sets **402** illustrated include an h-module **1000**. The h-module **1000** is arranged to receive, at its input, the set of signature verification keys $SVK_1, \ldots, SVK_n$ instead of this set of signature verification keys being provided to the respective H-module **720**, **900**. The h-module **1000** uses its input to produce an intermediate value Z (which the chip set **402** may store for future use in a memory module **1010** of the chip set **402**). The H modules **720**, **900** then receive, as their input, the intermediate value Z (i.e. the value derived from the set of signature verification keys $SVK_1, \ldots, SVK_n$) and the virtual control word CW* and output a control word CW accordingly—in this sense, they operate in a similar manner to the H-module **432** of FIG. **4** (which has two inputs, one being a CW* and the other being a second value). The h-module **1000** may operate in exactly the same way as the H-module **720**, **900** except that it does not receive a virtual control word CW* as its input. For example, the h-module **720** may merge the inputs $SVK_1, \ldots, SVK_n$ and may then apply a cryptographic hash function h to the merged inputs to produce the output Z. The function h may also be any other suitable cryptographic function (i.e. it need not necessarily be a hash function). Possible implementations of the function h preferably have the following property: given Z, it is hard (e.g., difficult, computationally difficult, infeasible or computationally infeasible) to find or calculate or determine a key pair (SK*, SVK*) and an input to h, such that the determined signature verification key SVK* is a signature verification key in the determined input to h, and such that Z is the output of h for this input (i.e. such that providing that input to function h, or as an input to the h-module **1000**, would result in outputting the value Z). In certain embodiments, "hard" may mean that an adversary may not be able to derive such an input in polynomial time or space. In other embodiments, "hard" may be defined by specifying a lower bound on the number of operations or on the size of the memory required to find such an input. As a third example, one may define "hard" by specifying an upper-bound on the probability that the property is not satisfied. Possible ways of implementing the function h include the various ways of implementing the function H (as set out above).

In general, though, for these embodiments (that make use of the h-module **1000**), the joint implementation of the function H and the function h preferably has the following property: given CW, it is hard (e.g., difficult, computationally difficult, infeasible or computationally infeasible) to find or calculate or determine a key pair (SK*, SVK*) and an input to the joint implementation of the function H and the function h, such that the determined signature verification key SVK* is a signature verification key in the determined input, and such that CW is the output of the joint implementation of the function H and the function h for this input. In certain embodiments, "hard" may mean that an adversary may not be able to derive such an input in polynomial time or space. In other embodiments, "hard" may be defined by specifying a lower bound on the number of operations or on the size of the memory required to find such an input. As a third example, one may define "hard" by specifying an upper-bound on the probability that the property is not satisfied.

FIG. **13** schematically illustrates a variation of the chip set **402** of FIG. **12** in which the chip set **402** is not arranged to store the set of signature verification keys $SVK_1, \ldots, SVK_n$ for future use. Instead, the chip set **402** may simply store the output of the h-module **1000**, i.e. the intermediate value Z, and use this intermediate value Z as an input to the H-module **900**. In this way, the storage requirements of the chip set **402** can be reduced, as storing the intermediate value Z will generally require much less memory than storing the set of signature verification keys $SVK_1, \ldots, SVK_n$. In addition, performance for deriving CW from CW* and Z may be improved.

In some embodiments, after processing a CSLK-init message (received together with the associated signature verification key SVK_i), the chip set **402** computes a cryptographic hash value of the signature verification key SVK_i (that it used to verify the authenticity of the CSLK-init pattern), and the chip set **402** stores this hash value together with CSLK. If a set of signature verification keys is provided to the chip set **402** (used as input to the h-module **1000**, producing a value Z to be stored inside the chip set **402** for deriving control words), then the chip set **402** may compute the hash value of each signature verification key in the set, and use the computed hash values and the stored hash values (one stored hash value with every stored CSLK) to determine whether one or more of the stored CSLK(s) was(were) loaded using a key that is present in the set of received signature verification keys. As before, such a mechanism can be used to activate, deactivate or delete CSLK(s), based on the received set of signature verification keys.

In some embodiments, after the chip set **402** receives a set of signature verification keys $SVK_1, \ldots, SVK_n$, it computes a cryptographic hash value for each of these keys, and stores these values with the value of Z for future use. For example, if a CSLK-init message is received together with the associated signature verification key SVK_i, the chip set **402** can compute a cryptographic hash value of the signature verification key SVK_i. Next, the chip set compares the computed hash value with the stored hash values, and only processes the CSLK-init message if (at least) one of the stored hash values is equal to the computed hash value. In this way CSLK-init messages are only processed if SVK_i is an element of the set of signature verification keys $SVK_1, \ldots, SVK_n$ used to produce the stored Z.

In some embodiments, a set of cryptographic hash values (comprising, for each key in the set of signature verification keys $SVK_1, \ldots, SVK_n$, a corresponding cryptographic hash value derived from that signature verification key) is provided to the function H (or the function h if present) instead of the set of signature verification keys $SVK_1, \ldots, SVK_n$. In such embodiments, the chip set **402** does not need to receive (or store) the set of signature verification keys; the chip set **402** only needs to receive the set of cryptographic hash values and the signature verification key associated with a CSLK-init message. The chip set **402** can compute the cryptographic hash value of the received signature verification key (received with the CSLK-init message), and compare this hash value with the cryptographic hash values in the received (or stored) set of cryptographic hash values to determine if the signature verification key provided with the CSLK-init message is associated with one of the signature verification keys in the set $SVK_1, \ldots, SVK_n$. In one embodiment, the CA/DRM

(head-end) system can compute the set of cryptographic hash values. Next, the CA/DRM (head-end) system can send the set of cryptographic hash values to its CA/DRM clients. In such embodiments, the CA/DRM system only needs to provide the signature verification key(s) associated with that CA/DRM system to the CA/DRM clients associated with that CA/DRM system (to process CSLK-init messages associated with that CA/DRM system). Communication costs, storage costs and computation costs may be reduced in such embodiments. Alternatively, it may be the CA/DRM client that computes the set of cryptographic hash functions (having received the set of signature verification keys $SVK_1, \ldots, SVK_n$).

FIGS. **14-18** correspond to FIGS. **6**, **7**, **8**, **10** and **11** respectively. However, in the systems shown in FIGS. **14-18**, there is one or more legacy ECM generators **1500** and one or more legacy EMM generators **1550**. The legacy ECM generators **1500** and the legacy EMM generators **1550** correspond to one or more CA/DRM systems associated with the head-end system **4** that do not make use of the methods described above for protecting the confidentiality and authenticity of control words (that is, these CA/DRM systems do not make use of CW*). Thus, the legacy ECM generators **1500** are arranged to receive the CW generated by the H-module **900** and generate ECMs based on the CW—this is in contrast to the ECM generators **516** which generate ECMs based on the virtual control word CW*. In the systems shown in FIGS. **14-18**, the legacy ECM generators **1500** are arranged to receive the CW via the SimulCrypt synchronizer **530**, but it will be appreciated that this is not essential. Similarly, the legacy EMM generators **1550** generate EMMs and provide those EMMs to the multiplexer **524**—they do not provide an input to the H-module **900** or the h-module **1000**.

In some embodiments, the output of the function H may include more than one value to be used in the content (de-) scrambling mechanism. For instance, the output of the H-module can consist of the virtual control word CW* and a second key derived from CW* and the set of keys $SVK_1, \ldots, SVK_n$ (or the value Z if h-module **1000** is used). These two derived keys can then be used in a super-scrambling solution where one key is used in a first scrambling step and the other key is used in a second scrambling step at the head-end system **4**. The chip set **402** may be modified to perform two corresponding descrambling steps instead of one. In general, the output of the H-module may include multiple content (de-)scrambling keys that can be used in a super-scrambling solution consisting of multiple content (de-)scrambling steps. The output of the function H may also include more than one control word. Each of these control words can be used for (de-)scrambling an associated piece of content. For instance, the output of the H-module can consist of two control words. The first control word can be used for (de-)scrambling a first piece of content, and the second control word can be used for (de-scrambling) a second piece of content. In embodiments in which the output of the function H includes more than one value to be used in the content (de-)scrambling mechanism, possible implementations of the function H preferably have the following property: given an output Y, it is hard (e.g., difficult, computationally difficult, infeasible or computationally infeasible) to find or calculate or determine a key pair (SK*, SVK*) and an input to H, such that the determined signature verification key SVK* is a signature verification key in the determined input to H, and such that Y is the output of H for this input. (If the h-module **1000** is used, then the preferred property can be adapted as mentioned before). In addition, one may require that the preferred property of the function H holds independently for parts of the output, e.g., for all keys associated with one piece of content. Notice that this is a stronger property which is useful, but not strictly necessary, as the weaker property (i.e., the property described above on the output Y) already implies that the descrambling of at least one of the pieces of content associated with the output of H will fail.

In some embodiments, a first subset of the set of signature verification keys $SVK_1, \ldots, SVK_n$ (or hash values thereof) is provided to the function h, and the input of the function H comprises both the output of the function h and a second subset of the set of signature verification keys $SVK_1, \ldots, SVK_n$ (or hash values thereof). These two subsets may each comprise one or more (or all) of the signature verification keys $SVK_1, \ldots, SVK_n$. The union of these two subsets is the entire set of signature verification keys $SVK_1, \ldots, SVK_n$. These two subsets may or may not overlap.

In some embodiments, the (bit-)length of a virtual CW* may be larger than the (bit-)length of a CW, e.g. if the output of the H-module includes more than one control word.

In some embodiments, the function H and/or the function h may receive one or more additional inputs and generate their respective outputs based on those one or more additional inputs.

While generic public-key cryptography modules have been described and used in the above-mentioned embodiments of the invention, it will be appreciated that any other suitable cryptographic operations and infrastructure may be used as long as the authenticity and confidentiality of a CW loading message are provided. As an example, the authenticity mechanism may use a symmetric scheme in which both SK and SVK are secret keys. A well known example of such a system is RSA with a randomly selected encryption (or decryption) exponent, both of which are kept secret. If an authenticity mechanism is used in which SVK is a secret key, then preferably the SVK is transmitted in encrypted form to the chip set **402**, e.g., using the chip set secret key CSSK of the associated chip set **402** as an encryption key. However, note that some of the advantages described in this disclosure do not apply if a symmetric authenticity mechanism is used. It may also be possible to insert additional key layers to the methods and systems described above, or to remove a key layer in the methods and systems described above.

The various symmetric and asymmetric encryption/decryption modules and schemes mentioned above may make use of any symmetric or asymmetric encryption/decryption algorithms currently known or devised in the future. Similarly, the various signature generation and verification modules and schemes mentioned above may make use of any signature generation and verification algorithms currently known or devised in the future.

It will be appreciated that embodiments of the invention may be implemented using a variety of different information processing systems. In particular, although the Figures and the discussions thereof provide exemplary architectures, these are presented merely to provide a useful reference in discussing various aspects of the invention. Of course, the description of the architecture has been simplified for purposes of discussion, and it is just one of many different types of architecture that may be used for embodiments of the invention. It will be appreciated that the boundaries between logic blocks are merely illustrative and that alternative embodiments may merge logic blocks or elements, or may impose an alternate decomposition of functionality upon various logic blocks or elements.

It will be appreciated that, insofar as embodiments of the invention are implemented by a computer program, then a storage medium and a transmission medium carrying the computer program form aspects of the invention. The com-

puter program may have one or more program instructions, or program code, which, when executed by a computer carries out an embodiment of the invention. The term "program," as used herein, may be a sequence of instructions designed for execution on a computer system, and may include a subroutine, a function, a procedure, an object method, an object implementation, an executable application, an applet, a servlet, source code, object code, a shared library, a dynamic linked library, and/or other sequences of instructions designed for execution on a computer system. The storage medium may be a magnetic disc (such as a hard drive or a floppy disc), an optical disc (such as a CD-ROM, a DVD-ROM or a BluRay disc), or a memory (such as a ROM, a RAM, EEPROM, EPROM, Flash memory or a portable/removable memory device), etc. The transmission medium may be a communications signal, a data broadcast, a communications link between two or more computers, etc.

The invention claimed is:

1. A method for securely obtaining a control word in a chip set of a receiver, said control word for descrambling scrambled content received by the receiver, the method comprising, at the chip set:

receiving a secured version of a chip set load key, the chip set load key being secured to protect the confidentiality of the chip set load key and being secured using a signature key to protect the authenticity of the chip set load key;

obtaining the chip set load key from the secured version of the chip set load key, wherein said obtaining comprises using a signature verification key corresponding to the signature key to verify the authenticity of the chip set load key;

receiving a secured version of a virtual control word from a conditional access/digital rights management client communicably connected to the chip set;

using the chip set load key to obtain the virtual control word from the secured version of the virtual control word; and

using a first cryptographic function to produce a given output from an input;

wherein the input comprises:

the virtual control word and

either a plurality of signature verification keys or one or more values derived from a plurality of signature verification keys, wherein each signature verification key is associated with a conditional access/digital rights management system,

wherein the given output comprises at least one control word;

wherein said signature verification key corresponding to the signature key used to verify the authenticity of the chip set load key is one of said plurality of signature verification keys;

wherein the first cryptographic function has the property that it is infeasible to determine (i) a key pair, the key pair including a signature key and a signature verification key, and (ii) an input for the first cryptographic function comprising the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input.

2. The method according to claim **1**, comprising receiving and storing the signature verification keys of the plurality of signature verification keys, wherein said first cryptographic function is arranged to use said stored signature verification keys as a part of the input to the first cryptographic function.

3. The method according to claim **1**, comprising:

receiving the plurality of signature verification keys;

generating a derived value from the received plurality of signature verification keys; and

storing the generated derived value;

wherein said first cryptographic function is arranged to use said stored derived value as a part of the input to the first cryptographic function.

4. The method according to claim **1**,

wherein the secured version of the virtual control word is a virtual control word encrypted using the chip set load key; and

wherein obtaining the virtual control word from the secured version of the virtual control word comprises using the chip set load key to decrypt the secured version of the virtual control word.

5. The method according to claim **1**, wherein the secured version of the chip set load key comprises the chip set load key encrypted using a public key associated with the chip set and a signature based on the chip set load key using the signature key, wherein obtaining the chip set load key from the secured version of the chip set load key comprises:

decrypting the encrypted chip set load key using a secret key associated with the chip set, the secret key corresponding to the public key associated with the chip set, and wherein said verifying the authenticity of the chip set load key comprises verifying the signature using the signature verification key corresponding to the signature key.

6. The method according to claim **5**, comprising the chip set storing the chip set load key obtained from the secured version of the chip set load key so that the stored chip set load key can be used to decrypt secured versions of virtual control words received by the chip set.

7. The method according to claim **6**, comprising:

receiving the plurality of signature verification keys along with the secured version of the virtual control word; and

determining whether the signature based on the stored chip set load key was verified using one of the received signature verification keys and, if it is determined that the signature based on the stored chip set load key was not verified using one of the received signature verification keys, not using the stored chip set load key to decrypt the secured version of the virtual control word received by the chip set.

8. The method according to claim **5**, in which the receiver is one receiver in a plurality of receivers, each receiver in the plurality of receivers having a corresponding chip set that has an associated secret key, wherein the secret keys associated with the chip sets of the receivers in the plurality of receivers are different from each other.

9. A method for providing a control word to a chip set of a receiver, the control word to enable the receiver to descramble scrambled content transmitted to the receiver, the method comprising:

generating a virtual control word at a head-end system;

transmitting the virtual control word from the head-end system to a conditional access/digital rights management client via the receiver, wherein the conditional access/digital rights management client is communicably connected to the chip set;

transmitting to the chip set a secured version of a chip set load key, the chip set load key being secured to protect the confidentiality of the chip set load key, the chip set load key being secured using a signature key associated with a conditional access/digital rights management

system to protect the authenticity of the chip set load key, the chip set load key to enable the receiver to access the virtual control word;

using a first cryptographic function to produce a given output from an input;

wherein the input comprises:

the virtual control word and

either a plurality of signature verification keys or one or more values derived from a plurality of signature verification keys, wherein each signature verification key is associated with a conditional access/digital rights management system,

wherein the given output comprises at least one control word;

wherein the signature key used to secure the chip set load key thereby protecting the authenticity of the chip set load key corresponds to one of the plurality of signature verification keys;

wherein the first cryptographic function has the property that it is infeasible to determine (i) a key pair, the key pair including a signature key and a signature verification key, and (ii) an input for the first cryptographic function comprising the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input;

scrambling content using the control word to produce scrambled content; and

transmitting the scrambled content to the chip set.

10. The method according to claim **9**, wherein the secured version of the chip set load key comprises the chip set load key encrypted using a public key associated with the chip set and a signature based on the chip set load key using the signature key.

11. The method according to claim **9**, comprising transmitting the control word from the head-end system to a second conditional access/digital rights management client via a second receiver, wherein the second conditional access/digital rights management client is communicably connected to a second chip set of the second receiver.

12. The method according to claim **9**, wherein at least two of the signature verification keys in the plurality of signature verification keys are associated with the same conditional access/digital rights management system.

13. The method according to claim **9**, wherein at least two of the signature verification keys in the plurality of signature verification keys are associated with different conditional access/digital rights management systems.

14. The method according to claim **9**, in which a derived value is produced by providing the plurality of signature verification keys to a second cryptographic function, wherein the second cryptographic function has the property that it is infeasible to generate a key pair including a signature key and a signature verification key and an input for the second cryptographic function comprising the generated signature verification key such that the second cryptographic function produces that derived value from the generated input.

15. The method according to claim **9**, in which the one or more derived values comprise, for each signature verification key in the plurality of signature verification keys, a corresponding cryptographic hash value of that signature verification key.

16. A chip set, for a receiver, for securely obtaining a control word, said control word for descrambling scrambled content received by the receiver, the chip set arranged to carry out a method comprising:

receiving a secured version of a chip set load key, the chip set load key being secured to protect the confidentiality of the chip set load key and being secured using a signature key to protect the authenticity of the chip set load key;

obtaining the chip set load key from the secured version of the chip set load key, wherein said obtaining comprises using a signature verification key corresponding to the signature key to verify the authenticity of the chip set load key;

receiving a secured version of a virtual control word from a conditional access/digital rights management client communicably connected to the chip set;

using the chip set load key to obtain the virtual control word from the secured version of the virtual control word; and

using a first cryptographic function to produce a given output from an input;

wherein the input comprises:

the virtual control word and

either a plurality of signature verification keys or one or more values derived from a plurality of signature verification keys, wherein each signature verification key is associated with a conditional access/digital rights management system,

wherein the given output comprises at least one control word;

wherein said signature verification key corresponding to the signature key used to verify the authenticity of the chip set load key is one of said plurality of signature verification keys;

wherein the first cryptographic function has the property that it is infeasible to determine (i) a key pair, the key pair including a signature key and a signature verification key, and (ii) an input for the first cryptographic function comprising

the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input.

17. A system for providing a control word to a chip set of a receiver, the control word to enable the receiver to descramble scrambled content transmitted to the receiver, the system comprising:

at least one processor; and

at least one memory coupled to the at least one processor and storing instructions, which when executed by the at least one processor cause the at least one processor to:

generate a virtual control word at a head-end system;

transmit the virtual control word from the head-end system to a conditional access/digital rights management client via the receiver, wherein the conditional access/digital rights management client is communicably connected to the chip set;

transmit to the chip set a secured version of a chip set load key, the chip set load key being secured to protect the confidentiality of the chip set load key, the chip set load key being secured using a signature key associated with a conditional access/digital rights management system to protect the authenticity of the chip set load key, the chip set load key to enable the receiver to access the virtual control word;

use a first cryptographic function to produce a given output from an input;

wherein the input comprises:

the virtual control word and

either a plurality of signature verification keys or one or more values derived from a plurality of signature verifi-

cation keys, wherein each signature verification key is associated with a conditional access/digital rights management system,

wherein the given output comprises at least one control word;

wherein the signature key used to secure the chip set load key thereby protecting the authenticity of the chip set load key corresponds to one of the plurality of signature verification keys;

wherein the first cryptographic function has the property that it is infeasible to determine (i) a key pair, the key pair including a signature key and a signature verification key, and (ii) an input for the first cryptographic function comprising the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input;

scrambling content using the control word to produce scrambled content; and

transmitting the scrambled content to the chip set.

18. A receiver comprising the chip set according to claim **16**.

19. A non-transitory computer readable medium having stored thereon instructions that, when executed by a chip set of a receiver, cause the chip set to carry out a method for securely obtaining a control word, said control word for descrambling scrambled content received by the receiver, the method comprising:

receiving a secured version of a chip set load key, the chip set load key being secured to protect the confidentiality of the chip set load key and being secured using a signature key to protect the authenticity of the chip set load key;

obtaining the chip set load key from the secured version of the chip set load key, wherein said obtaining comprises using a signature verification key corresponding to the signature key to verify the authenticity of the chip set load key;

receiving a secured version of a virtual control word from a conditional access/digital rights management client communicably connected to the chip set;

using the chip set load key to obtain the virtual control word from the secured version of the virtual control word; and

using a first cryptographic function to produce a given output from an input;

wherein the input comprises:

the virtual control word and

either a plurality of signature verification keys or one or more values derived from a plurality of signature verification keys, wherein each signature verification key is associated with a conditional access/digital rights management system,

wherein the given output comprises at least one control word;

wherein said signature verification key corresponding to the signature key used to verify the authenticity of the chip set load key is one of said plurality of signature verification keys;

wherein the first cryptographic function has the property that it is infeasible to determine (i) a key pair, the key pair including a signature key and a signature verification key, and (ii) an input for the first cryptographic function comprising

the determined signature verification key or one or more values derived, at least in part, from the determined signature verification key, such that the first cryptographic function produces the given output from the determined input.

20. A system comprising one or more chip sets according to claim **16**.

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