Multimedia Security

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Outline

- Introduction + Motivation
- Content Protection in Transit
  - Encryption
  - *Key Management*
- Content Copyright Protection
  - Watermarking
- *Content Copy Control*
  - *Digital Rights Management (DRM)*

Introduction

- Motivation:
  - Digital representation opens new digital service markets and distribution chains (VoD, superdist, etc);
  - Reproduction is easy and flawless - vast opportunities for wholesale theft;
  - Security is one approach to combat piracy.
- **Encryption** and **watermarking** are complimentary approaches to content protection.
- **DRM** models make use of encryption and watermarking to secure content.

Content Protection

Encryption

Encryption

Definitions ([32][33])

- Digital Content or Content
- Video Compression or *Coding*
  - Uncompressed bit rates for standard (European) television can be as high as 166Mbit/s [32].
  - Compression reduces effective size of sampled video by eliminating spatial and/or temporal redundancy at coder.
  - Greater compression ratios possible if algorithm is "lossy."

Encryption

Definitions ([33])

- Video Transcoding:
  - Aim: to convert coded content from a higher to a lower bit rate (in order to match content coding to channel or device capability);
  - Transcoding can be expensive: pixel domain approach requires full decode, process, and re-code.
  - "Rate Shaping" examples:
    - Spatial down-sampling (resolution change);
    - Frame rate reduction;
    - Change of compression formats or tools;

Encryption

Definitions ([33][34])

- Scalable Compression:
  - Aim: to make transcoding redundant;
  - Encode video once; truncate stream, layers or bits to achieve desired rate or quality.
  - MPEG-2/4 offer "scalability profiles"
    - Eg. MPEG-4 Fine Granular Scalability (FGS):
      - Base Layer encoded to min bit-rate R_b;
      - Progressive enhancement layer encoded to max bit-rate R_m.
      - All devices receive base layer;

Encryption

Definitions ([35][36])

- Motion Picture Experts Group (MPEG) Standards
  - MPEG-1: 1992 – Non-interlaced video up to 1.5 Mbit/s.
  - MPEG-2: 1994 – Interlaced and broadcast video up to 15 Mbit/s.
  - MPEG-4: 1999 – 2GBits/sec and representation of individual objects within frames.
  - Joint Picture Experts Group (JPEG)

Encryption
Approaches

- Secure Scalable Streaming (SSS)
  - Secure Scalable Video Streaming for Wireless Networks (Wee et al. [6])
  - Secure Scalable Video Streaming for Wireless Networks (Wee et al. [7])
- Selective Encryption
  - MPEG video encryption algorithms (Bharagava et al. [3])
- *Adaptive Rich Media Secure*
  - *Securing Media for Adaptive Streaming (Venkatramani et al. [9])*

Encryption

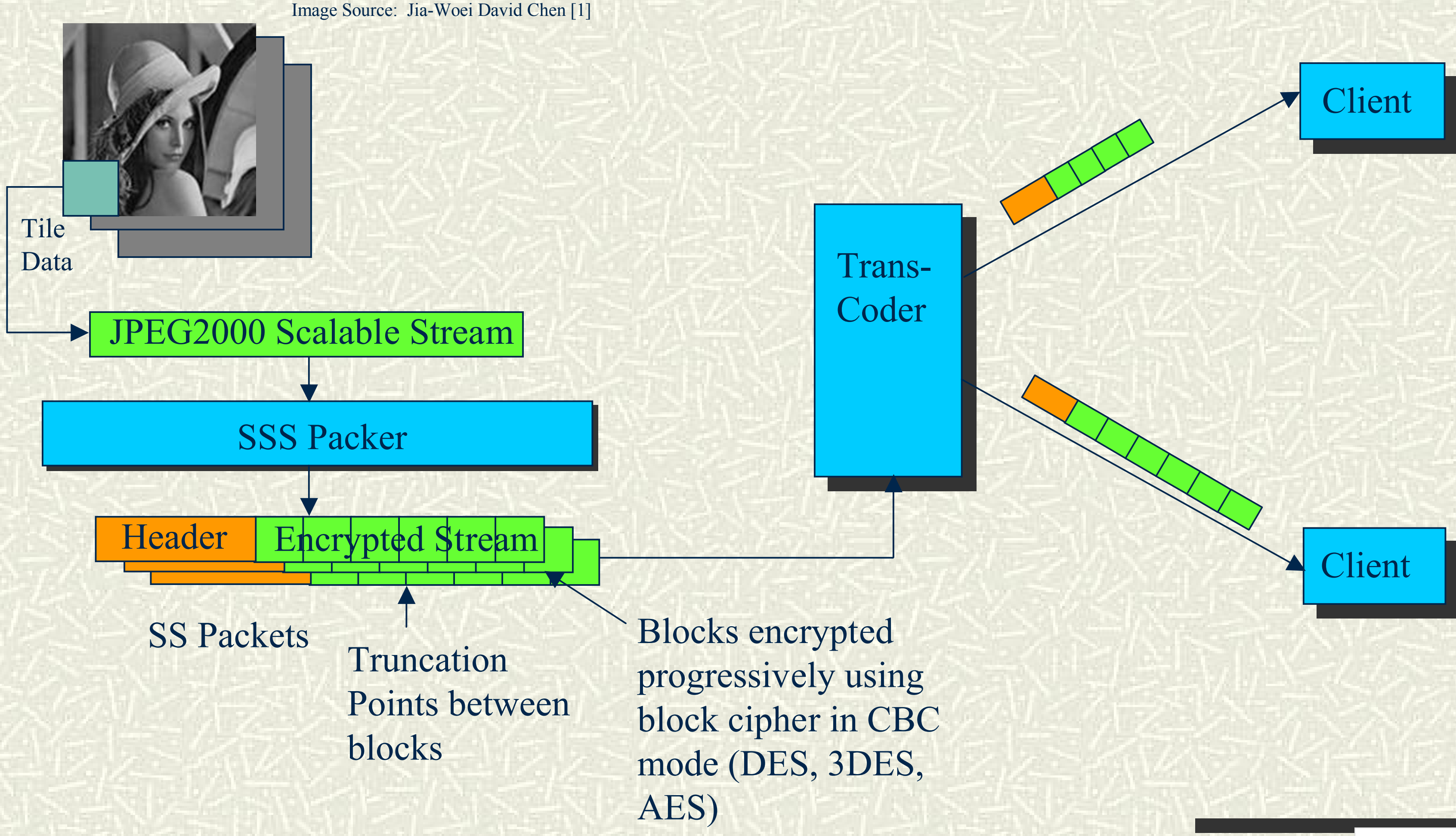
SSS ([6][7])

- "Traditional" transcoding is expensive especially if there are many streams.
- Transcoders need access to secret keys to perform transcoding operations – this introduces a security point-of-failure.
- SSS allows transcoding by intelligent stream truncation:
  - Assumes scalable coding (e.g. JPEG2000, MPEG-4 SNR FGS).

Encryption

SSS ([[6][7])

Image Source: Jia-Woei David Chen [1]



Encryption

Selective Encryption ([3])

- Aim:
  - Render multimedia content incomprehensible without using “heavyweight” encryption.
- Concept:
  - Encrypt small but significant portions of video stream.
  - Employ the (already resource heavy) compression phase to implement the encryption.

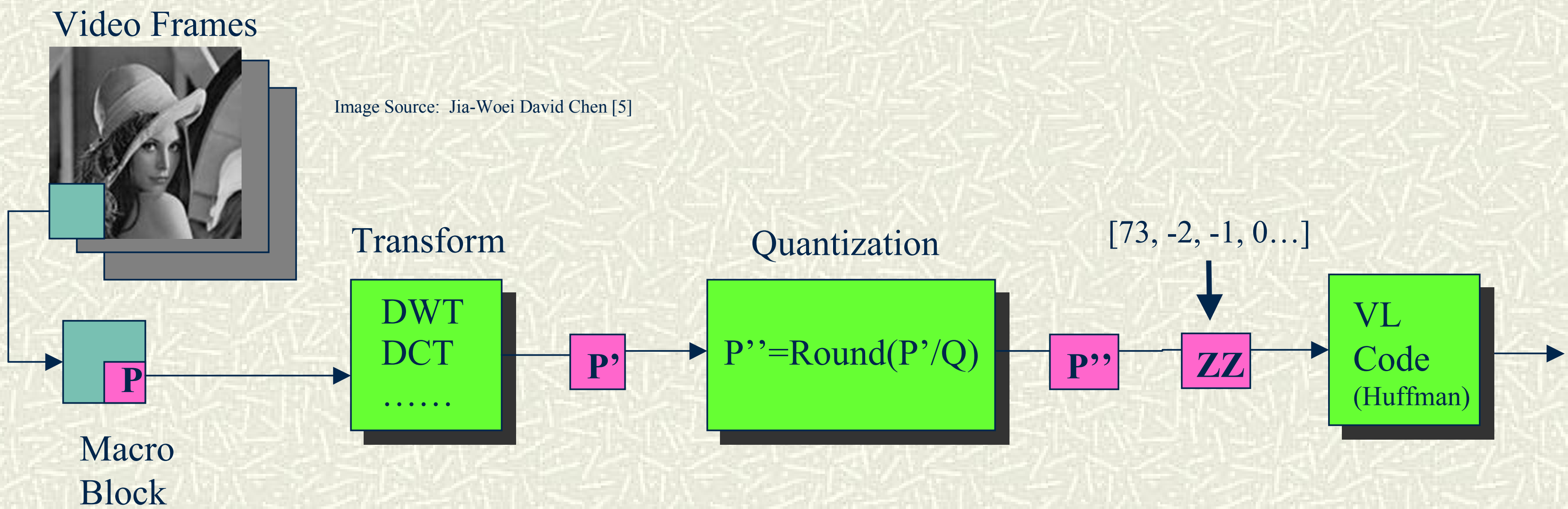
Encryption

Selective Encryption ([3])

- **MPEG Compression mini-tutorial ([3][4][37])**
- Video frames in MPEG are:
  - *Intra*-Frame (spatial) compressed (I-Frame).
  - *Inter*-Frame (temporal) compressed using Motion Compensated Prediction into:
    - P-Frames: Forward predicted MBs
    - B-Frames: Bi-directionally predicted MBs
- A video stream consists of a series of I, P, and/or B frames.

Encryption

Selective Encryption ([3]): *Intra*-Frame Compression



P

67	69	71	72	73	74	75	76
67	69	71	72	73	74	75	76
67	69	71	72	73	74	75	76
67	69	71	72	73	74	75	76
70	70	71	75	78	81	81	75
69	70	71	75	78	80	81	77
68	69	71	74	77	78	80	78
67	69	71	74	76	76	78	80

P'

587	-27	-5	1	-1	1	-1	0
-8	5	1	-3	0	-1	1	0
-2	-1	1	-3	1	-1	0	0
5	-1	-2	4	-1	1	-1	0
-1	0	0	0	0	0	0	0
-3	0	1	-2	0	0	0	0
0	0	0	0	0	0	0	0
2	0	-1	2	-1	1	0	0

Q (MPEG-1)

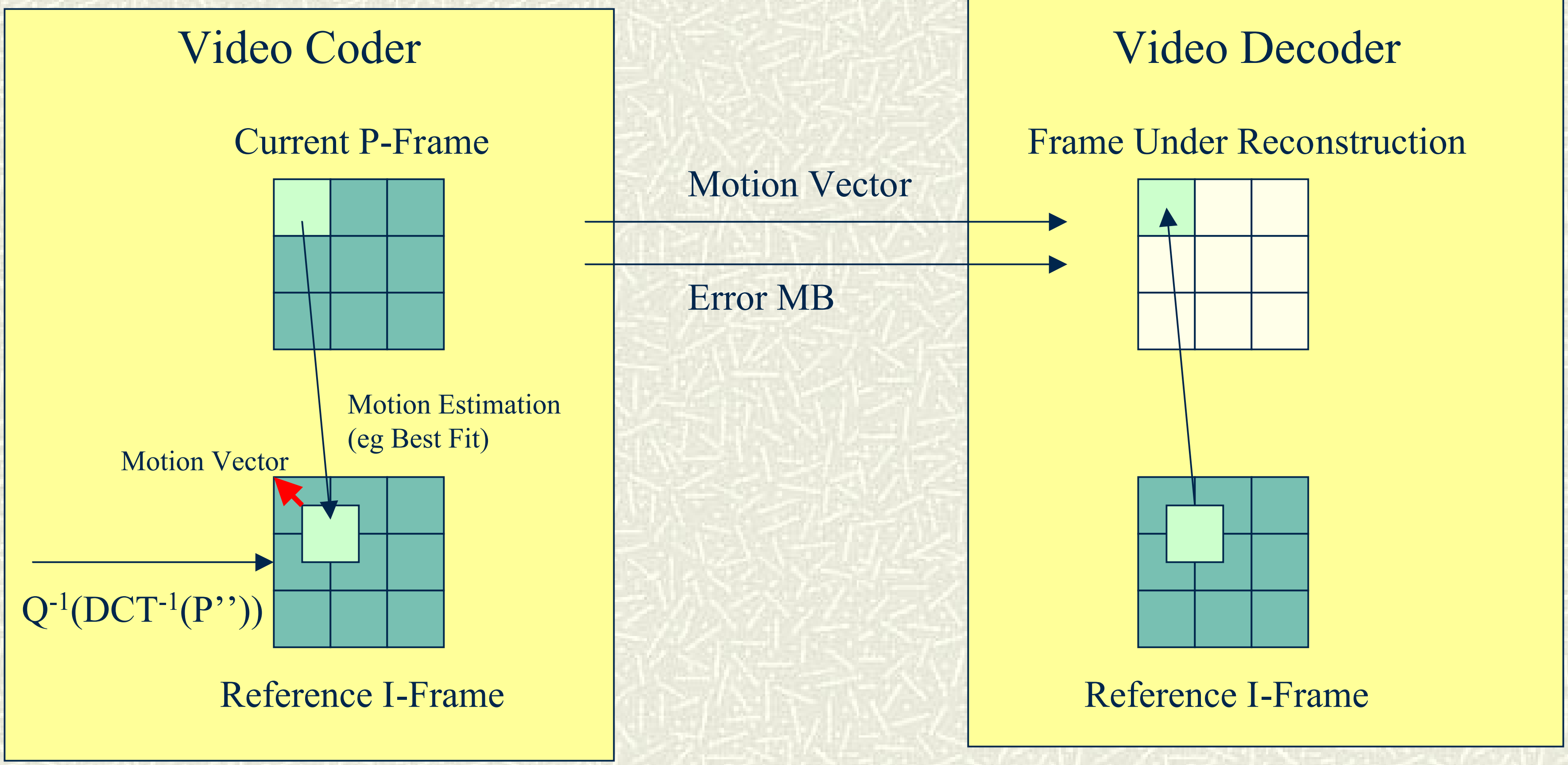
8	16	19	22	26	27	29	34
16	16	22	24	27	29	34	37
19	22	26	27	29	34	34	38
22	22	26	27	29	34	37	40
22	26	27	29	32	35	40	48
26	27	29	32	35	40	48	58
26	27	29	34	38	46	56	69
27	29	35	38	46	56	69	83

P''

73	-2	0	0	0	0	0	0
-1	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0

Encryption

Selective Encryption ([3]): *Inter*-Frame Compression



References: Figure 2 of [3] and slides 46-56 of [4]

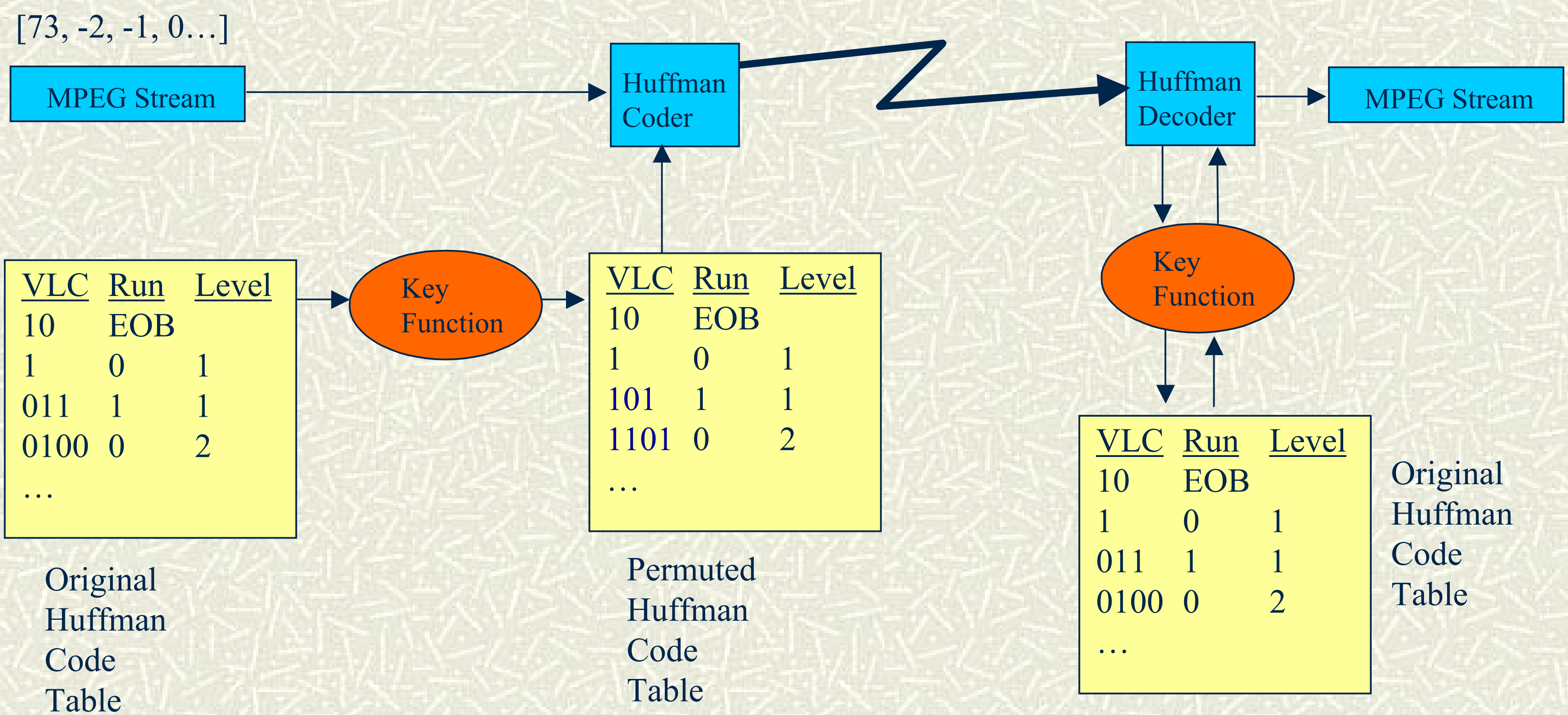
Encryption

Selective Encryption ([3])

- Review of selective encryption (Liu et al. [8]) includes the following approaches for Video stream encryption in frequency domain:
  - Encrypt I-frames, DCT coefficients, sign bits of motion vectors, every other bit of MPEG stream, every nth I-frame macroblock, etc.
  - Randomizing "zig-zag" pattern prior to VLC.
- Algorithms proposed in Bhargava et al.:
  - Huffman Permutation, VEA, MVEA, and RVEA

Encryption

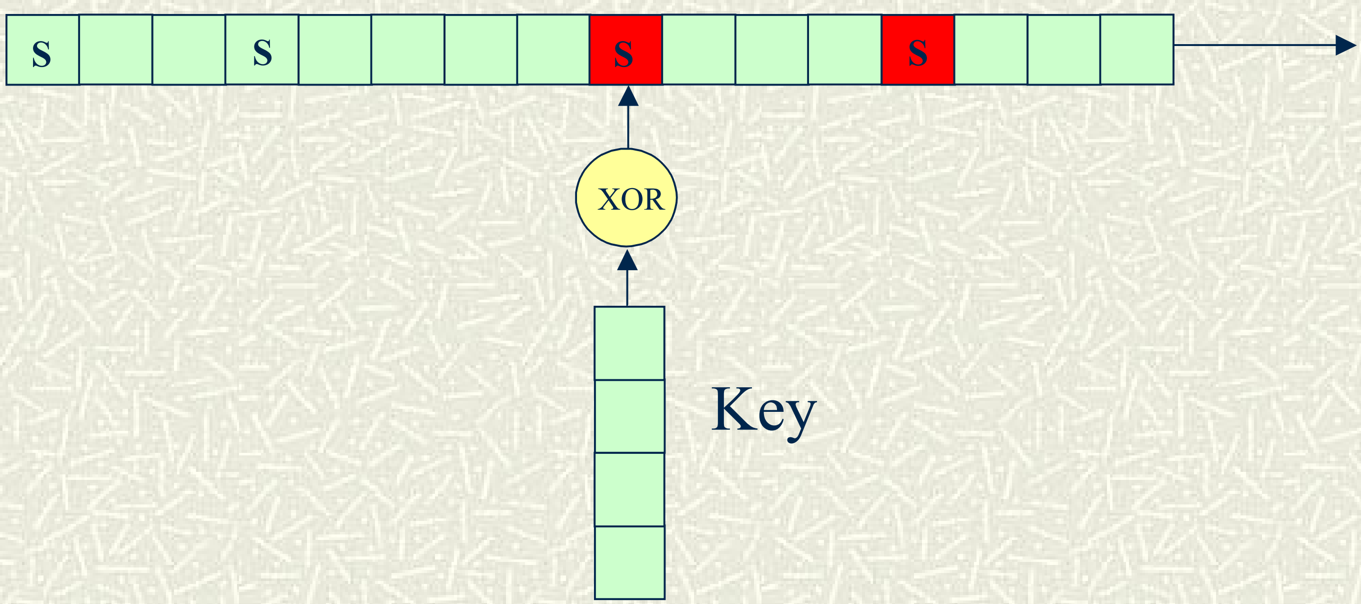
Selective Encryption: a.) Huffman Permutation [3]



Encryption

Selective Encryption: b.) Video Encryption Algorithm (VEA) [3]

- An m-bit key is randomly produced and XORed with the sign bits of DCT components in I-Frames.



Encryption

Selective Encryption: b.) Video Encryption Algorithm (VEA) [3]

- Results in apparent "randomization" of sign bits.
- Increasing length of secret key does not increase complexity.
- Security relies on inverse-DCT process to "scramble" the video image.
- Weak against plaintext attacks.

Encryption

Selective Encryption: c.) Modified VEA (MVEA) [3]

- An m-bit key is produced as in VEA.
- Sign bits of DC components in I-Frames are encrypted.
- Sign bits of motion vectors in B and P Frames are encrypted – this has significant effect on reconstruction since changing motion vector sign changes direction.
- Also weak to plaintext attacks.

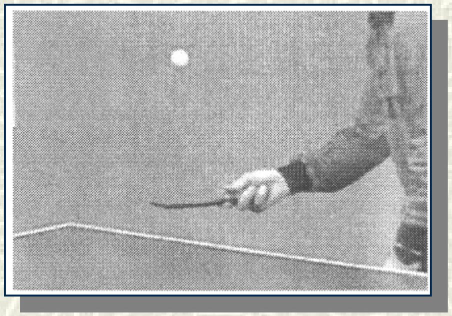
Encryption

Selective Encryption: d.) Robust VEA (RVEA) [3]

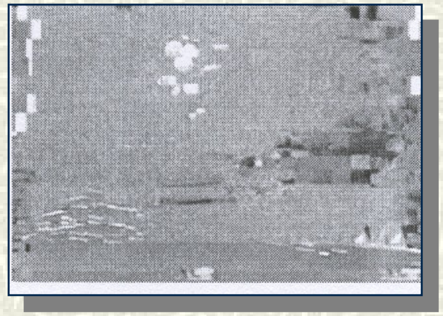
- Same as MVEA except that m-bit key and XOR is replaced by “heavyweight” symmetric encryption of sign bits.
- Since sign bits make up less than 10% of stream data, this use of “heavyweight” encryption is still more efficient than encrypting whole payload.

Encryption

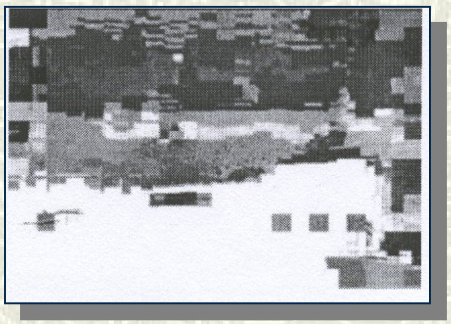
Selective Encryption: Sample Experimental Results from [3]



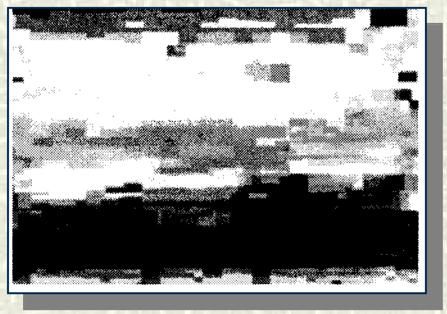
Original Video Frame
(Figure 9 of [3])



MVEA on B frame
Motion vectors only
(Figure 13 of [3])



VEA on I-Frames
(Figure 12 of [3])



RVEA
(Figure 14 of [3])

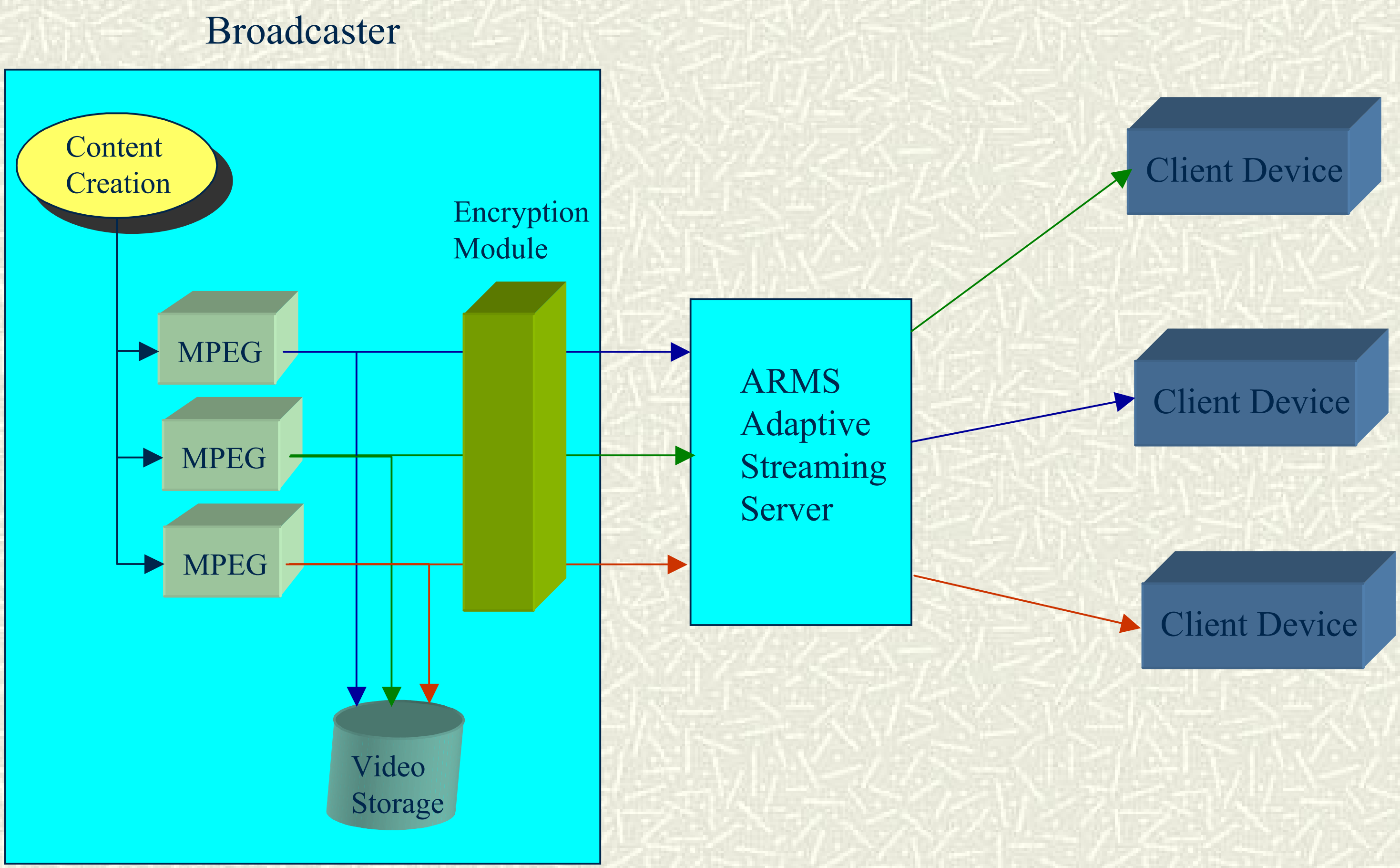
Encryption

Adaptive Rich Media Secure – ARMS ([9])

- Uses Internet Streaming Media Alliance (ISMA) standard for *secure content delivery (RTP over UDP)*.
- Uses stream cipher with encryption index to allow resync in event of packet loss (compare with SSS).
- Modifies ISMA to allow for multiple streams and stream switching.
- ARMS is basis of IBM VideoCharger system.

Encryption

Adaptive Rich Media Secure – ARMS ([9])



Ref: Figure 4 from [8]

Encryption

Summary of Video Encryption Approaches

	SSS	Selective Encryption	ARMS
Overhead	*Packet* overhead of 2-2.5% compared to end-to-end encryption.	No packet overhead. Software VEA *processing* time overhead of 1.8%. RVEA consumes 2.5% of time during compression.	ISMA meta data (unknown size) compared to end-to-end encryption..
Specialized streaming hardware required	Yes - SSS transcoder.	No	Streaming Server
Client modifications required	Yes - SSS aware client.	Yes.	Yes - ISMA aware client.

Copyright Protection

Digital Watermarking

Watermarking

- Digital Watermarking: Information is inserted directly into a multimedia object at the expense of a (hopefully) imperceptible degradation in the quality of that object.
- Has parallels with paper watermarking and steganography or data hiding.
- Complimentary to encryption and being invested in as a DRM solution.

Watermarking

Uses [11][16][17]

- Uses of Watermark schemes:
  - Identification of content origin (proof of ownership or authorship watermarks);
  - Tracing of illegally distributed copies of content (fingerprinting watermarks); and
  - *Disabling unauthorized access to content*.

Watermarking

Properties [11][18][19][20]

- Properties of Watermarks:
  - Robustness against both un-intentional attacks (standard data processing – compression, zooming, cropping, etc) and intentional attacks
  - Fragile
  - Imperceptible
  - Visible
  - Unambiguous

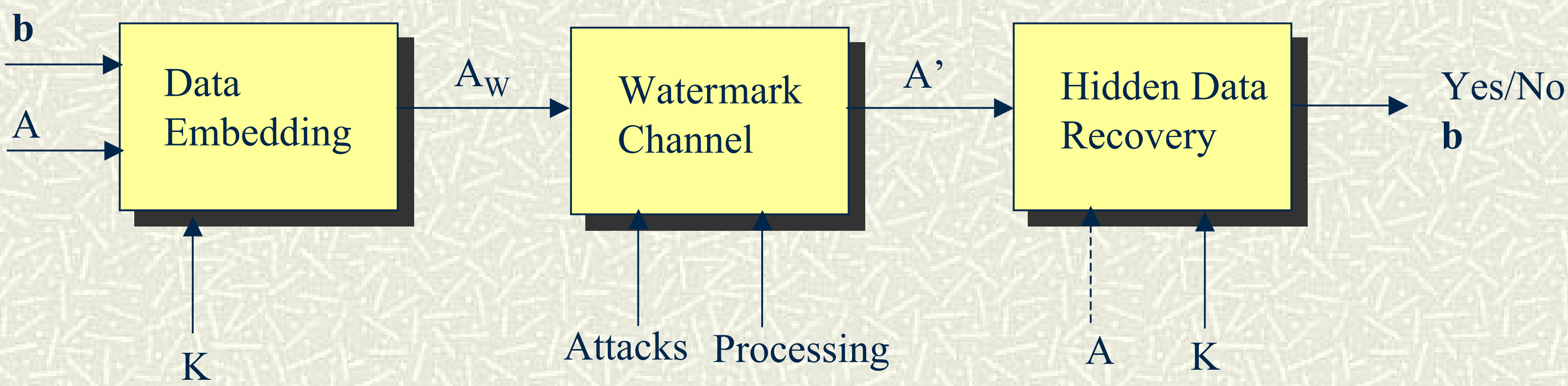
Watermarking

Blind vs Informed [19][21]

- Watermarking process can be:
  - Blind:
    - Watermark has no dependency on the "cover" object.
    - Original, unmarked object not needed to extract or detect watermark.
    - Typically blind watermarks use spread spectrum techniques where cover is considered to be "noise."
  - Informed:
    - Watermark signal depends on cover object.
    - For example, delta is added to higher frequency DCT coefficients to map them to detector decision regions.

Watermarking

System Model [16]



b=(b1, b2, b3, …)	The watermark information in the form of a binary string.
A	The original, unmarked media to be watermarked (also known as the cover media).
K	A cryptographic key which may be either symmetric or asymmetric.
Aw	A watermarked media.
A’	A watermarked media that has passed through the watermark channel.

Ref: Figure 1 of [16]

Watermarking

Watermark Attacks ([18][22][23])

- Watermark “attacks” drive research.
- Example attacks:
  - Protocol Attacks against Authorship Watermarks
  - *Attacks against FingerPrint Watermarks*
    - *Collusion Attacks*
    - *Protocol Attacks*

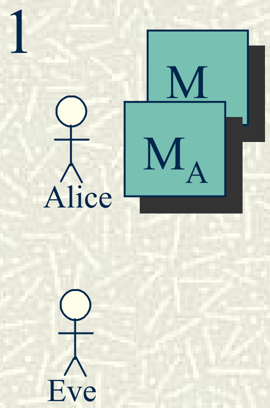
Watermarking

Protocol Attacks Against Ownership Watermarks ([23][24])

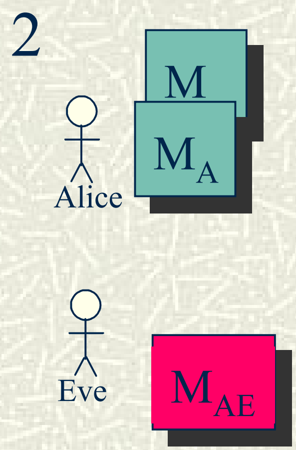
- Protocol attacks target the dispute resolution process rather than trying to remove the watermark.
- Protocol attacks introduce ambiguity and uncertainty in ownership.
- Types [24]:
  - Copy Attack – copy existing watermark from object A to B.
  - Ambiguity Attack – compute a watermark that was never inserted but can still be found in an object.

Watermarking

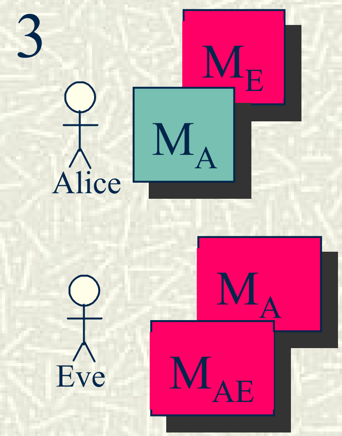
Single Watermarked Image Counterfeit Original (SWICO) ([23])



Alice creates watermarked object M_A from original M.



Eve examines M_A and finds a set of arbitrary features to call her watermark (E). She designs a detector to find this watermark.. This results in M_{AE}. Note that Alice's M also contains E.



Eve removes arbitrary features from MA to get her "original" M. Eve's M contains A and Alice's M contains E. So who owns M?

Watermarking

Protocol Attack Defences

- Approaches to eliminate protocol attacks:
  - Restrict degrees of freedom in selecting or designing watermark components [25]
  - Eliminate or limiting some attacks through cryptographic signatures and third party validation of watermarks [24].
  - Trusted time stamps.

Conclusions

- Encryption and Watermarking are at the forefront of research into content protection.
- Personal Learning Goals:
  - Technical details of MPEG.
  - Scoping a wide arc of research.
  - Research resources/techniques.

Questions?

Supplementary Material

- Key Management in Conditional access sytems;
- Digital Rights Management;

Content Protection

Key Management

Key Management

- Encryption techniques usually "assume" key management infrastructure.
- Key management for conditional access (CA) systems.
- CA systems are most prevalent form of broadcast encryption [10] and include:
  - Video on Demand
  - Subscription channels and Pay-Per-View [12]

Key Management

Characteristics ([2][11][13])

- Key management must:
  - Deal efficiently with end-user turnover:
    - Joins must not be able to access material already *casted; and
    - Leaves must not be able to access material that will be *casted
  - Have minimal impact on end-user processing;
  - Be scalable; and
  - Be resilient to key compromise (us).

Key Management

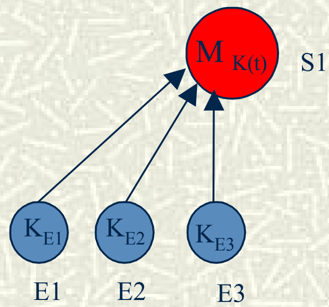
Approaches

- Flat or Star topology
  - Secure Group Communications using Key Graphs (Wong et al. [1]).
  - Key Management and Distribution for Secure Multimedia Multicast (Trappe et al. [2])
- Key Graph Model
  - Secure Group Communications using Key Graphs (Wong et al. [1]).
- Secret Sharing with Key Graphs
  - Multicast Security using Key Graphs and Secret Sharing (Eskicioglu et al. [13])
  - A Key Transport Protocol Based on Secret Sharing Applications to Information Security (Eskicioglu et al. [14])

Key Management

Flat or Star (Reference) Topology ([1][2])

- Flat or "Star" topology is most intuitive;



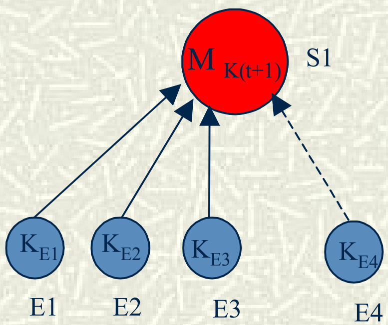
Ref: Figure 1 of [1]

- Characterized by server S1, end-users E_n.
- Multimedia data encrypted with Media key $M_{K(t)}$.
- End users have $M_{K(t)}$ and K_{En} used for key update operations.

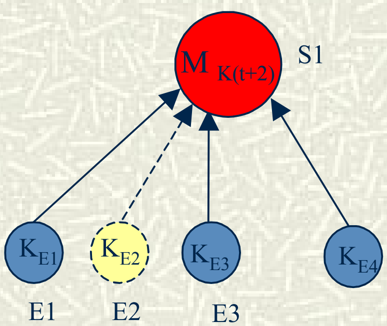
Key Management

Flat or Star (Reference) Topology ([1][2])

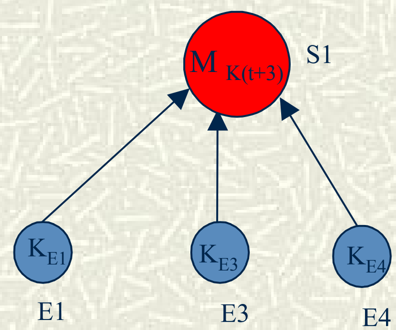
User Joins, Leaves and Key Update operations for Star Topology



CASE 1
E4 Joins:
1. $\{M_{K(t+1)}\}M_{K(t)}$
2. S1<->E4: K_{E4}
3. $\{M_{K(t+1)}\}K_{E4}$



CASE 2
E2 Leaves:
1. $\{M_{K(t+2)}\}K_{E1}, K_{E3}, K_{E4}$



CASE 3
Key Update:
1. $\{M_{K(t+3)}\}K_{E1}, K_{E3}, K_{E4}$

Refs: Figures 2 and 3 of [1]

Key Management

Flat or Star (Reference) Topology ([1][2])

- Obvious limitations of flat topology:
  - Leave operations and key updates require:
    - (n-1) encryptions by server;
    - (n-1) unicasts.
  - Star topology is un-scalable: complexity of server computation, communication, and storage requirements is linear.

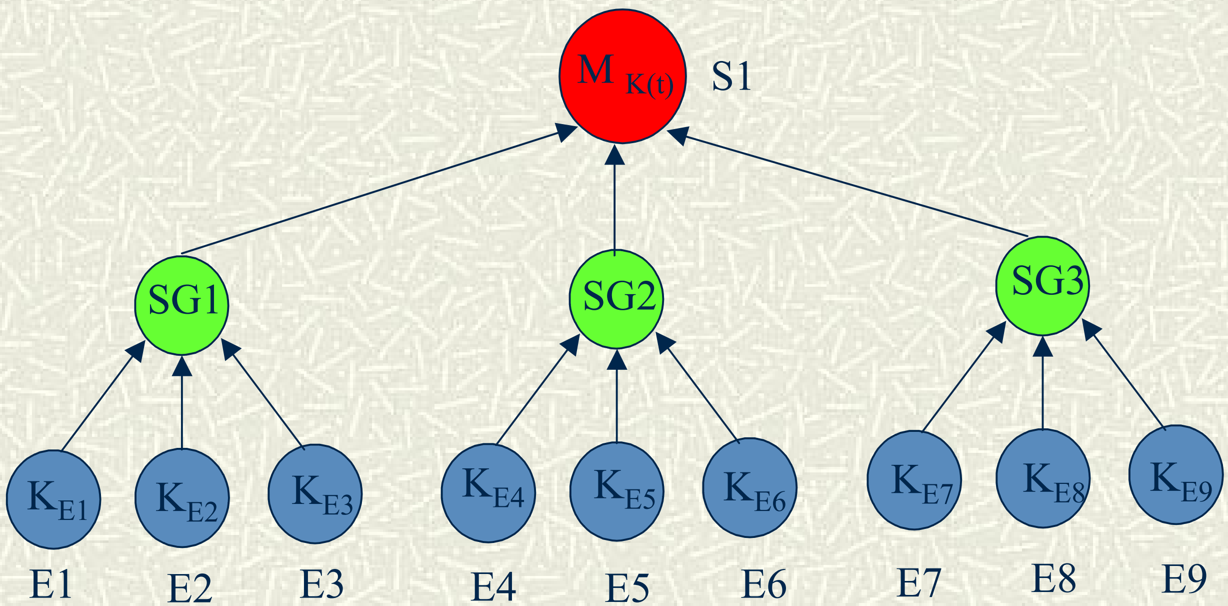
Key Management

Key Graph Model ([1])

- Wong's key graph model seeks to address scalability of star topology by introducing "subgroups"
- Server creates a key graph with n-leaves and a symmetric key at each node.
- K-nodes have keys only. M-nodes are end-users who retain a subset Q of Server's keys.
- Subset Q includes all keys in directed path to root node.

Key Management

Key Graph Model ([1])

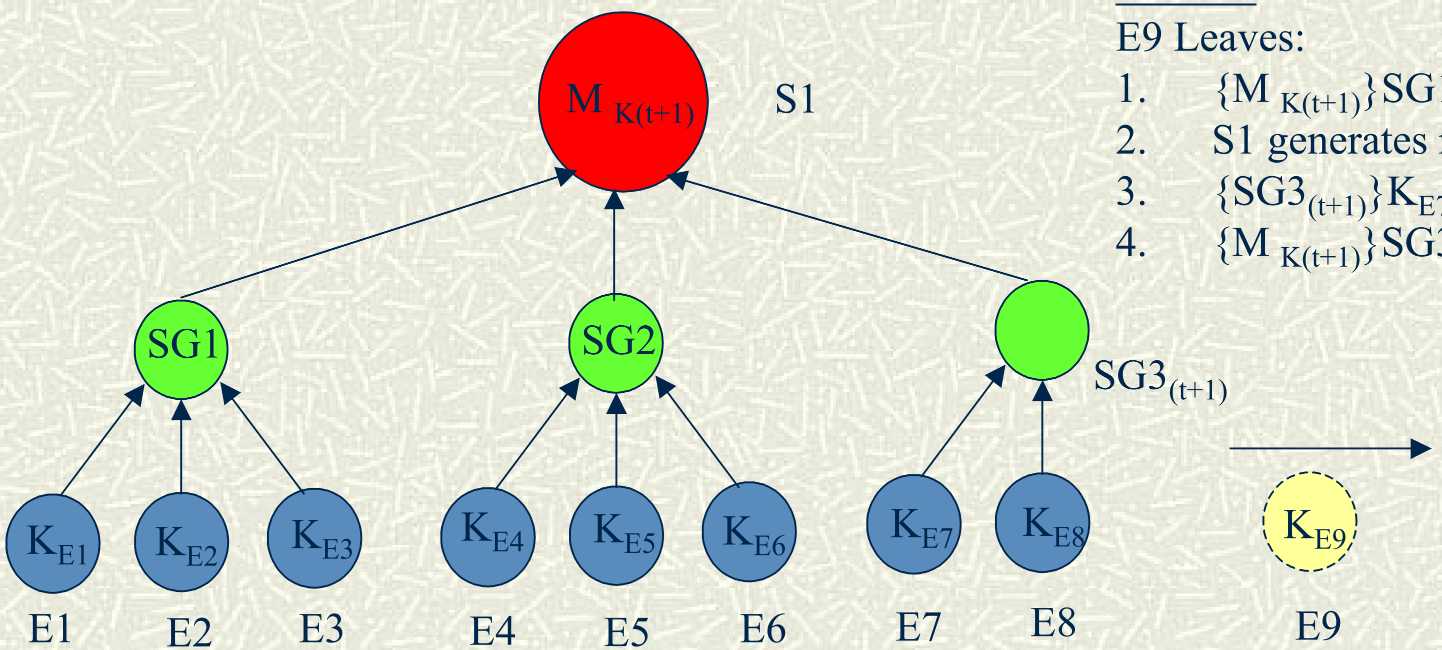


Each user E_n has $\{ M_{K(t)}\ SG_n\ K_{en} \}$

Ref: Figure 5 of [1]

Key Management

Key Graph Model ([1])



CASE 2

E9 Leaves:

1. $\{M_{K(t+1)}\}$SG1, SG2
2. S1 generates new key $SG3_{(t+1)}$
3. $\{SG3_{(t+1)}\}K_{E7}, K_{E8}$
4. $\{M_{K(t+1)}\}SG3_{(t+1)}$

Each user E_n has $\{ M_{K(t+1)}\ SG_n\ K_{en} \}$

Ref: Figure 5 of [1]

Key Management

Key Graph Model ([1])

- A user "leave" operation in the example involves five encryptions instead of eight.
- Key-update in the example involves three encryptions instead of nine.
- In a balanced tree with many users, the savings can be substantial.

Key Management

Secret Sharing With Key Graphs ([13][14])

- "Secret Sharing" for key distribution:
  - Uses threshold scheme where secret **S** is composed of **n** shares. User needs **t** of **n** shares to determine **S**.
  - Threshold scheme used by authors is based on A. Shamir's (t,n) thresholding scheme ([15]).

Key Management

Secret Sharing With Key Graphs ([13][14])

- Secret sharing example:
  - Pre-position (t-1) points [(x_1,y_1), (x_2,y_2)…] with end-user;
  - Choose secret S as point on Y axis (0,S);
  - Determine (t-1) degree polynomial f(x) that fits points [(x_1,y_1), (x_2,y_2)…] and (0,S).
  - Choose "activating share" point (x_n, y_n) s.t. $y_n=f(x_n)$ and (x_n, y_n) is not equal to any of [(x_1,y_1), (x_2,y_2)…] .
- To pass the secret, pass (x_n,y_n) to end-user (who now has t points on a (t-1) degree polynomial).
- Solve system of equations to determine a_0=(0,S).
- Secret can be changed without changing the pre-positioned information.

Key Management

Secret Sharing With Key Graphs ([13][14])

- CKMSS combines key graph model with secret sharing.
- In the key graph, wherever a key is found, a set of shares is distributed instead.
- Media, group, and client keys are generated at the end-user by sending an activating share (in the clear).

Key Management

Secret Sharing With Key Graphs ([13][14])

- Chief advantages of Secret Sharing with Key Graphs:
  - Periodic re-keys require multicast of fixed length "activating share" that does not need to be encrypted.
  - Simulation shows that increasing number of shares per node (degree of the polynomial) is "mildly non-linear."

Content Copy Control

Digital Rights Management (DRM)

DRM

- DRM: “a collection of technologies that enable technically enforced licensing of digital information” [26]
- DRM promises finer-grained control of content usage but:
  - Challenges currently accepted models of “fair use”; and
  - Invokes privacy concerns.

DRM

- Elements of a DRM system;
- Approaches to DRM:
    - Top down (MPEG-21)
    - Bottom up (OMA MDRM)
    - Legal approaches

DRM

Elements of DRM ([27])

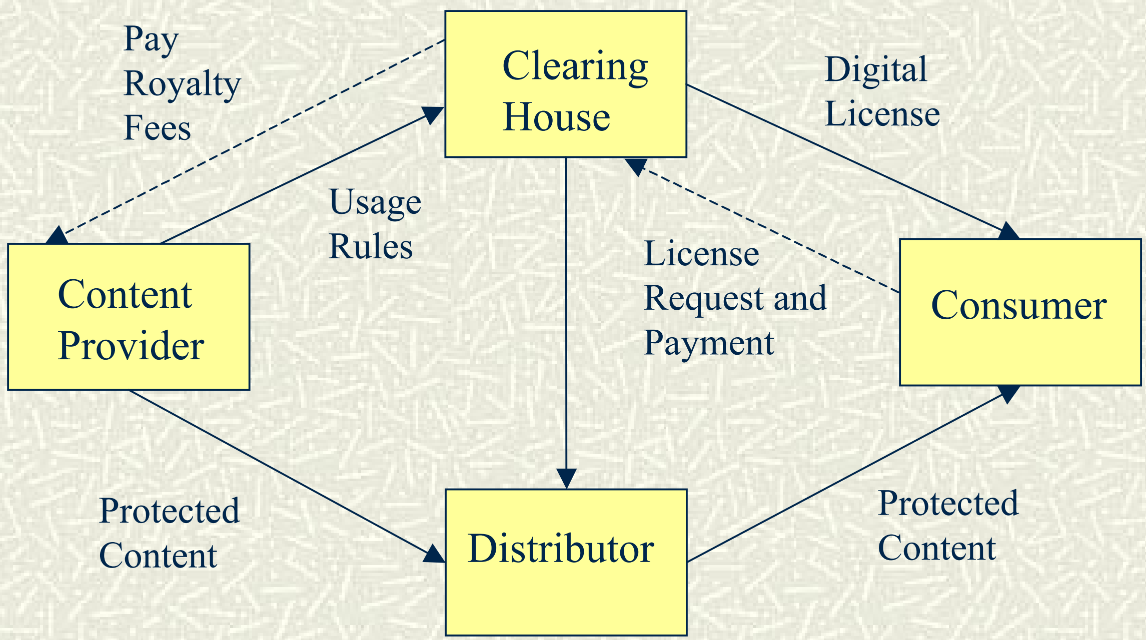


Figure 2.1 of [27]

DRM

Model Requirements

- Examination of the model reveals:
  - Need for a comprehensive REL;
  - Critical requirement for "trusted" clients to enforce licenses against content;
  - Privacy is an issue – licenses are issued to "entities."
  - Standardization is essential to avoid "stove-pipes."

DRM

Trusted Computing ([28])

- Trusted Computing is the “lynch-pin” of all DRM systems. The client must ensure that:
  - The client cannot remove the encryption from the file and send it to a peer;
  - The client obeys the rules set out in the DRM license; and
  - The client cannot separate the rules from the payload

DRM
Trusted Computing

- No sufficient general purpose trusted computing platform exists (yet).
- Work is under way:
  - Trusted Computing Group (not targeted towards DRM [29]);
  - Microsoft Next Generation Secure Computing Base (NGSCB) (formerly Palladium).([30][31])

DRM

Top Down Approach: MPEG-21

- Top-down approach: MPEG-21
- MPEG-21 seeks to
  - understand, integrate, and standardize all of the disparate elements that exist *now* for DRM
  - to perform a gap analysis; and
  - to fill in where standards appear to be lacking
- MPEG-21 is attempting to build the "big picture" of digital rights management

DRM

Top Down Approach: MPEG-21

- MPEG-21 Parts:
  - Vision, technologies, and strategies (introduction);
  - Digital Item Declaration (DID);
  - Digital Item Identification (DII);
  - Intellectual Property Management and Protection (IPMP) (continues MPEG-4 hooks to proprietary systems)
  - Rights Expression Language (REL);
  - Rights Data Dictionary (RDD); and
  - Digital Item Adaptation (DIA);

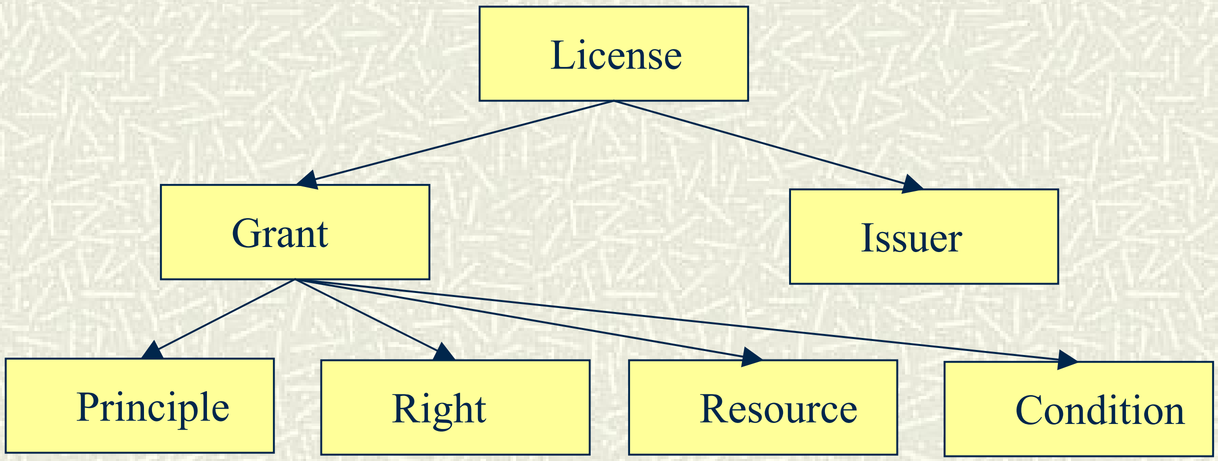
DRM

Top Down Approach: MPEG-21

- MPEG-21 REL
  - Based on ContentGuard’s XrML
  - Achieved standard status in early 2004.
  - *License* is most important concept in REL.

DRM

Top Down Approach: MPEG-21



MPEG-21 "License"

Ref: figure 3 wang

DRM

Bottom-Up Approach: OMA MDRM

- Bottom-up approach: OMA Mobile DRM
  - Open Mobile Alliance founded 2002.
  - Goal: introduce open DRM standards for mobile devices.
  - OMA scoped initial effort to devices with limited processing and memory (cell phones).
  - This approach lead to fast development of OMA MDRM 1.0 and *rapid* market adoption across resource limited devices.

DRM

Bottom-Up Approach: OMA MDRM

- OMA standard for REL is based on Open Digital Rights Language (ODRL).
- OMA MDRM 2.0 released in 2004:
  - Targets devices with more processing/memory;
  - Adds new security features (public key enc);
  - Expands business models.
- At some point, MDRM will meet MPEG-21.

DRM

Bottom-Up Approach: OMA MDRM

- Legal Approaches: DMCA
- DMCA is U.S. copyright law passed in 1998.
- Specifically bans:
  - Acts that circumvent access control/copy prevention mechanisms; and
  - Distribution of tools/technologies/information that allow circumvention.

DRM

Bottom-Up Approach: OMA MDRM

- Unintentional side effects of DMCA:
  - Stifles academic research (Felton vs Secure Digital Music Initiative);
  - Allows censorship of 2600 Magazine's web site and publication (DeCss) contrary to U.S. 1st Amendment Free Press.
  - Used by Lexmark as a business weapon against after-market toner makers.

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