A NOVEL H.264 SVC ENCRYPTION SCHEME FOR SECURE BIT-RATE TRANSCODING

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ABSTRACT
This paper presents a novel architecture for the secure delivery of encrypted H.264 SVC bitstreams. It relies on a block cipher and stream cipher used in a novel way that would allow an intermediary transcoder to truncate the bitstream to the appropriate bit-rate without decrypting the data. The system, called SVC-sec, is compared to other architectures presented in the literature and it is shown that SVC-sec offers many benefits, particularly when used with FGS streams.

Index Terms — Video Coding, TV Broadcasting, Security, Cryptography

1. INTRODUCTION
The recent advances in mobile computing and multimedia processing has lead to a flourish in the variety of devices capable of handling digital video data. These devices however, vary in their processing power as well as the capacity of the channel that is used to transmit the data. The recent extension to the H.264 standard, H.264 SVC [1] gained significant interest in the research community. The main advantage of SVC (Scalable Video Coding) over its predecessor, AVC [2], is that it uses an embedded bitstream to encapsulate different quality levels within a single stream. The bitstream can therefore be scaled depending on the requirements of the destination. For most commercial systems, this would be a major advantage over existing codecs as the computationally expensive encoding process only needs to be carried out once to produce all the required bitstreams. The bitstream can then be scaled by intermediary nodes.

The business model of many commercial content providers relies on viewers paying a subscription premium in order to view content that is protected using some form of encryption. When an encryption algorithm is used with a bitstream that is transmitted directly to the destination, the system is simple. The receiver can decrypt the data using the secret key, obtained when the premium is paid. After decryption, the bitstream is decoded as normal. When using a scaling transcoder in the channel however, the transcoder would have to access the headers of the NAL units in order to be able to decide which packets to keep and which ones to discard. Allowing the transcoder to decrypt any of the bitstream would mean that the security of the entire system would depend on the ability of the transcoder to withstand attacks by potential hackers. While hardware tamper-proofing of the transcoder is an efficient solution, it can be expensive and is not often viable in commercial systems. This means that the transcoder is often not a trusted system and can therefore compromise the security of the entire network. In addition, the encryption algorithm must be able to cope with parts of the ciphertext being removed. Traditional block and stream ciphers used directly would not allow such scaling operations as the decryption operation would lose synchronization. Some work has been done on secure transcoders for H.264 AVC bitstreams in [3] that can be modified for use with SVC. There is also some work in the literature on secure transcoders for scalable bitstreams. Algorithms for other scalable codecs include SSLFE and SMLFE for MPEG-4 presented in [4], while [5] presents a selective encryption approach that encrypts only important parts of a quad-tree wavelet type encoder. Secure Scalable Streaming (SSS) [6] is an architecture that allows any scalable bitstream to be encrypted while keeping header information intact for transcoders to access. This system allows coded image bitstreams to be transmitted efficiently in a secure manner but has various issues when used with a video system. A generic encryption concept for use with scalable bitstreams is presented in [7]. This method also has some shortcomings when dealing with some of the scalability features of the SVC standard. This paper presents a novel architecture called SVC-sec that exploits the structure of an SVC bitstream in order to efficiently deliver the bitstream while providing end to end security for content providers. SVC-sec can be implemented using a combination of block and stream ciphers in a novel way, and the concepts can be extended to any scalable bitstream.

2. ENCRYPTING SCALABLE BITSTREAMS
The SSS architecture, presented in [6] is a generic architecture for any scalable bitstream that needs to be delivered in a secure manner. The system uses progressive encryption which relies on either a stream cipher or a block cipher in Cipher Block Chaining (CBC) mode of operation [8]. The...
two types of encryption are shown in Fig. 1. The SSS architecture reorders the packets according to priority before encrypting them. This ensures that the transcoder can truncate the bitstream at any point. The higher priority packets that have not been discarded can then be decrypted correctly as they do not rely on the lower priority packets. A similar approach was presented in [9] that provides better security by encrypting the NAL headers as well in a format compliant manner. These approaches lead to various issues due to the dependencies between packets as described in the following sections of this paper.

Reordering the packets according to priority instead of frame number would mean that almost the entire bitstream would have to be received at the decoder before the first frame can be decoded. This means that the lag on the decoder would be far too high for use with real-time streaming applications. The obvious solution to this problem would be to carry out the reordering locally within a GOP. While this would ensure that the maximum lag would be just one GOP, it also requires the cipher to be reset at the end of each GOP. This is because the nature of the progressive encryption means that the data from one packet relies on the data from the previous one to be encrypted and decrypted correctly. If the transcoder removes a packet at the end of one GOP, the first packet in the following GOP cannot be decrypted unless the cipher is reset. This approach however suffers from another problem. The GOP IDs are stored in the slice headers. Since the slice headers are encrypted before transmission, the decoder would not know where a new GOP starts until the slice headers are decrypted. In order to decrypt the slice headers, however, the decoder would need to calculate the GOP ID of the packet. The SVC-sec architecture presented in this paper overcomes these issues by ensuring that the packets are not reordered before encryption and that the packet dependencies during encryption are the same as the packet dependencies during coding.

The authors of [7] proposed a system whereby the encryption of the bitstream takes place in multiple dimensions. This system was proposed for an arbitrary bitstream with no consideration for the underlying standard or the types of scalability that need to be supported. While this approach has some benefits in offering format independent transcoding at network nodes, the type of cipher that is used to carry out the encryption has to be chosen depending on the requirements of the system. For instance, the base layer data contains the most important data that needs to be protected using the highest level of security. A block cipher used in a secure mode such as CBC would be ideal as the base layer is not transcoded. FGS packets however, are often truncated at the bit level. The use of a block cipher would not allow such a fine granular transcoding to be carried out. Since the FGS layer carries less important data, the use of a stream cipher would be adequate and indeed preferable in order to exploit the full benefits of FGS scalability. The other drawback of this approach is that it would not be effective in a system that uses more that one type of scalability. For instance, if an FGS and CGS layer is employed, the FGS layer may be dependent on the CGS layer or vice versa for correct decryption. This means that if one layer is dropped, the other may become undecipherable. The system proposed in this paper takes such factors into consideration in order to support the full array of scalability options supported by the emerging H.264 SVC standard.

3. SVC-SEC

Any encoded video bitstream has a dependency structure between the packets. The structure of the dependencies depends on the types of scalabilities that are supported by the standard. The SVC standard offers support for Medium Grain Scalability and Coarse Grain Scalability. In addition, work is being carried out on incorporating Fine Grain Scalability as an amendment to the standard in the future. A typical structure of dependencies in SVC is shown in Fig. 2.

An encryption scheme that follows a similar dependency structure would allow the packet order to be preserved during encryption and therefore allow maximum transcoding flexibility. Cipher independence would allow ciphers that have proven security to be used. The system has to cope with layers of CGS packets and individual MGS packets being dropped. The FGS packets may be dropped or truncated at the bit level. The two additional factors that need to be considered when designing this encryption scheme are Initialization Vector (IV) generation and the padding scheme used.

If the plaintext is not an exact multiple of the cipher block size, the last block is usually padded prior to encryption. This leads to an increase in the bit-rate of the encrypted bitstream. To avoid having to use padding, a technique called residual block termination (RBT) can be used. This technique encrypts the last full ciphertext block again using Electronic
Code Book (ECB) mode encryption [8]. Each bit of the \( n \)
bit residual block of plaintext is then XORed with the first \( n \)
bits of the result of the second encryption. This technique is
shown in Fig. 3. A block cipher in CBC mode that uses resid-
ual block termination will be referred to as CBC-RBT from
here on.

It was shown in [10] that the re-use of IVs with a fixed
key could create weaknesses in the cipher. When creating
more than one CBC chain, it is therefore important to ensure
that the same value of IV is never used in more than one chain.
Generating random IV values for each chain would require all
the IVs to be distributed prior to transmission of the encrypted
data. A similar problem is caused when using stream ciphers
as a different key is required for each encryption. A look up
table of IVs and keys could provide a solution.

![Fig. 3. CBC encryption with RBT (left) and CBC decryption
with RBT (right)](image)

The SVC-sec architecture [11], shown in Fig. 4, provides
an efficient and novel mechanism for the generation of all the
IVs and stream cipher keys that are required to carry out en-
cryption on a scalable bitstream. This scheme generates en-
cryption dependencies between the packets that match the de-
pendencies created during encoding. Any standard block or
stream cipher can be incorporated with the architecture.

For each packet, the NAL headers are left unencrypted to
allow the transcoder to carry out scaling on the bitstream. As
shown in Fig. 4, the base layer packets are encrypted first.
As these packets would not be dropped by the transcoder,
encryption dependencies are allowable amongst them. The
last ciphertext block of the first base layer packet is encrypted
again to form the IV for the following packet. The IV for
base layer packet \( n \), \( IV_{Bn} \) is therefore the encryption of
the last block of ciphertext from packet \( n - 1 \).

Once a packet from the base layer is encrypted, the IV
generated for the following base layer packet is re-encrypted
in ECB mode. This block forms the stream cipher key for
the FGS packet as shown in the figure. The key used for the
FGS packets is changed for every frame to ensure the encoder
dependency structure is preserved during encryption. The key
for the \( n^{th} \) FGS packet, \( K_{Fn} \) is the encryption of \( IV_{Bn+1} \).

The last FGS key is re-encrypted again to generate the IV
for the enhancement layers. The enhancement layer packets
are then encrypted in the same way as the base layer packets
with the last block of every packet being encrypted a second
time to form the IV for the following block.

![Fig. 4. SVC-sec encryption on bitstream with 2 base layer,
FGS, MGS and CGS packets](image)

4. RESULTS

The criteria used to evaluate SVC-sec are as follows:

- Security
- Transcoding Flexibility
- Transcoder Latency
- Bit-rate Overhead

4.1. Security

To ensure that content transmitted using the SVC-sec system
cannot be viewed by unauthorized individuals, it is important
to ensure that the system is secure against possible attacks.
Since the architecture is independent of the cipher used for
encryption, the cipher can be chosen to match the require-
ments of the application. As the IVs used to encrypt the MGS
and CGS packets are always different, the system can be con-
sidered as a series of CBC chains. Using a secure cipher, each
chain would be secure against attacks. The stream cipher also
uses a different key for each packet. The system inherits its
security from the cipher, just like the SSS architecture.

4.2. Transcoding Flexibility

The transcoder performance would not be degraded by the
SVC-sec scheme. When using plaintext bitstreams, the main
feature of FGS packets if supported by SVC is that the pack-
ets can be truncated at arbitrary points along the bitstream as
long as the headers remain intact [12]. When using a block
encrypted bitstream, the smallest block that can be removed
is equal to the block size of the cipher. Removing a block
smaller than this would render the remainder of the encryp-
tion block undecipherable. When using a 128 bit block cipher,
the smallest block that can be dropped would be 128 bits.

When using SSS, the highest priority packets are base
layer packets, followed by MGS and FGS. The CGS pack-
ets would be ordered to the end of the bitstream. Since the
CGS packets rely on FGS packets in order to be decrypted correctly; it would not be possible to drop FGS packets until all the CGS layer packets have been dropped. FGS packets can only be dropped from the end of the bitstream. Truncating or dropping a packet from the middle of the bitstream would mean that the header of the following packet would be decrypted incorrectly, thereby corrupting the entire packet. SVC-sec provides greater transcoding flexibility. Using the stream cipher, the minimum block size that can be dropped from any FGS packet in the bitstream is 1 bit. Since there is no encryption dependency between any two FGS packets, this would still allow the rest of the bitstream to be decrypted. The CGS packets are also unaffected as they are not dependent on FGS packets. This flexibility would be beneficial when used in commercial systems as the ability to modify the bit-rate at a fine grain level could be desirable.

4.3. Transcoder Latency

The SSS approach introduces significant transcoding latency when dealing with encrypted bitstreams. Since the transcoder cannot drop packets from the middle of the bitstream, it has to wait until the entire stream has been received before dropping packets from the end. This also adds overhead in terms of storage requirements as the entire bitstream needs to be stored before it is re-transmitted. The SVC-sec approach has minimal latency as the packets can be dropped from almost any point in the bitstream. There is no additional latency when compared to a normal transcoder operating on plaintext data.

4.4. Bit-rate Overhead

In systems where the channel capacity is limited, any overhead introduced by the encryption process may be extremely undesirable. The overhead introduced depends on the type of padding that is used during encryption. Since the SSS architecture does not specify the type of padding that has to be used, the residual block termination technique can be easily integrated with it. When using this type of padding, both architectures produce no overhead as the size of the encrypted bitstream is the same as the size of the plaintext version.

5. CONCLUSIONS AND FURTHER WORK

This paper presented a novel architecture for scalable H.264 SVC encryption called SVC-sec that allows secure scaling of bitstreams at intermediary nodes. This technique was compared to the alternative techniques. It was shown that SVC-sec offers many benefits, particularly when used with FGS packets. The features of FGS could be exploited with SVC-sec while preserving the security offered by strong ciphers. Application level encryption schemes such as the one presented in this paper have several benefits over traditional network level encryption. However, much of the network level data is left unencrypted, allowing addition of potentially desirable header data to the packets before transmission.

6. REFERENCES