

About AES – Advanced Encryption Standard

A short introduction

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A short introduction to AES, the most common algorithm for current implementations of information encryption, including some relevant comments and observations on encryption in general as applicable to AES.

What is AES?

AES is short for Advanced Encryption Standard and is a United States encryption standard defined in Federal Information Processing Standard (FIPS) 192, published in November 2001. It was ratified as a federal standard in May 2002. AES is the most recent of the four current algorithms approved for federal use in the United States. One should not compare AES with RSA, another standard algorithm, as RSA is a different category of algorithm. Bulk encryption of information itself is seldom performed with RSA. RSA is used to transfer other encryption keys for use by AES for example, and for digital signatures.

AES is a *symmetric* encryption algorithm processing data in block of 128 bits. A bit can take the values zero and one, in effect a binary digit with two possible values as opposed to decimal digits, which can take one of 10 values. Under the influence of a *key*, a 128-bit *block* is encrypted by transforming it in a unique way into a new block of the same size. AES is symmetric since the same key is used for encryption and the reverse transformation, decryption. The only secret necessary to keep for security is the key. AES may be configured to use different key-lengths, the standard defines 3 lengths and the resulting algorithms are named AES-128, AES-192 and AES-256 respectively to indicate the length in bits of the key. Each additional bit in the key effectively doubles the strength of the algorithm, when defined as the time necessary for an attacker to stage a *brute force* attack, i.e. an exhaustive search of all possible key combinations in order to find the right one

Some background on AES

In 1997 the US National Institute of Standards and Technology put out a call for candidates for a replacement for the ageing Data Encryption Standard, DES. 15 candidates were accepted for further consideration, and after a fully public process and three open international conferences, the number of candidates was reduced to five. In February 2001, the final candidate was announced and comments were solicited. 21 organizations and individuals submitted comments. None had any reservations about the suggested algorithm.

AES is founded on solid and well-published mathematical ground, and appears to resist all known attacks well. There's a strong indication that in fact no back-door or known weakness exists since it has been published for a long time, has been the subject of intense scrutiny by researchers all over the world, and such enormous amounts of economic value and information is already successfully protected by AES. There are no unknown factors in its design, and it was developed by Dutch researchers in Holland therefore voiding the conspiracy theories sometimes voiced concerning an encryption standard developed by a United States government agency.

A strong encryption algorithm need only meet only single main criteria:

- There must be no way to find the unencrypted clear text if the key is unknown, except brute force, i.e. to try all possible keys until the right one is found.

A secondary criterion must also be met:

- The number of possible keys must be so large that it is computationally infeasible to actually stage a successful brute force attack in short enough a time.

The older standard, DES or Data Encryption Standard, meets the first criterion, but no longer the secondary one – computer speeds have caught up with it, or soon will.

AES meets both criteria in all of its variants: AES-128, AES-192 and AES-256.

Encryption must be done properly

AES may, as all algorithms, be used in different ways to perform encryption. Different methods are suitable for different situations. It is vital that the correct method is applied in the correct manner for each and every situation, or the result may well be insecure even if AES as such is secure. It is very easy to implement a system using AES as its encryption algorithm, but much more skill and experience is required to do it in the right way for a given situation. No more than a hammer and a saw will make anyone a good carpenter, will AES make a system secure by itself. To describe exactly how to apply AES for varying purposes is very much out of scope for this short introduction.

Strong keys

Encryption with AES is based on a secret key with 128, 192 or 256 bits. But if the key is easy to guess it doesn't matter if AES is secure, so it is as critically vital to use good and strong keys as it is to apply AES properly. Creating good and strong keys is a surprisingly difficult problem and requires careful design when done with a computer. The challenge is that computers are notoriously deterministic, but what is required of a good and strong key is the opposite – unpredictability and randomness.

Keys derived into a fixed length suitable for the encryption algorithm from passwords or pass phrases typed by a human will seldom correspond to 128 bits much less 256. To even approach 128-bit equivalence in a pass phrase, at least 10 typical passwords of the kind frequently used in day-to-day work are needed. Weak keys can be somewhat strengthened by special techniques by adding computationally intensive steps which increase the amount of computation necessary to break it.

The risks of incorrect usage, implementation and weak keys are in no way unique for AES; these are shared by all encryption algorithms. Provided that the implementation is correct, the security provided reduces to a relatively simple question about how many bits the chosen key, password or pass phrase really corresponds to. Unfortunately this estimate is somewhat difficult to calculate, when the key is not generated by a true random generator.

Security is relative

Security is not an absolute; it's a relation between time and cost. Any question about the security of encryption should be posed in terms of how long time, and how high cost will it take an attacker to find a key?

Currently, there are speculations that military intelligence services possibly have the technical and economic means to attack keys equivalent to about 90 bits, although no civilian researcher has actually seen or reported of such a capability. Actual and demonstrated systems today, within the bounds of a commercial budget of about 1 million dollars can handle key lengths of about 70 bits.

An aggressive estimate on the rate of technological progress is to assume that technology will double the speed of computing devices every year at an unchanged cost. If correct, 128-bit keys would be in theory be in range of a military budget within 30-40 years.

An illustration of the current status for AES is given by the following example, where we assume an attacker with the capability to build or purchase a system that tries keys at the rate of one billion keys per second. This is at least 1 000 times faster than the fastest personal computer in 2004. Under this assumption, the attacker will need about 10 000 000 000 000 000 000 000 years to try all possible keys for the weakest version, AES-128.

The key length should thus be chosen after deciding for how long security is required, and what the cost must be to brute force a secret key. In some military circumstances a few hours or days security is sufficient – after that the war or the mission is completed and the information uninteresting and without value. In other cases a lifetime may not be long enough.

Conclusion

There is currently no evidence that AES has any weaknesses making any attack other than exhaustive search, i.e. brute force, possible. Even AES-128 offers a sufficiently large number of possible keys, making an exhaustive search impractical for many decades, provided no technological breakthrough causes the computational power available to increase dramatically and that theoretical research does not find a short cut to bypass the need for exhaustive search.

There are many pitfalls to avoid when encryption is implemented, and keys are generated. It is necessary to ensure each and every implementations security, but hard since it requires careful examination by experts. An important aspect of an evaluation of any specific implementation is to determine that such an examination has been made, or can be conducted.

Correctly implemented AES-128 is likely to protect against a million dollar budget for at least 50 – 60 years and against individual budgets for at least another 10 years.