Το έργο χρηματοδοτήθηκε από το Πρόγραμμα Δικαιώματα, Ισότητα και Ιθαγένεια 2014-2020 της Ευρωπαϊκής Ένωσης

Asymmetric encryption

Facilitating GDPR compliance for SMEs and promoting Data Protection by Design in ICT products and services *(www.bydesign-project.eu)*

This presentation has been based on material provided by Dr. K. Limniotis (HDPA)

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Public-Key Cryptography

- Probably most significant advance in the 3000 year history of cryptography
- uses two keys – a public & a private key
- Asymmetric since parties are not equal
- uses clever application of mathematical (mainly number theoretic) concepts to function
- Note: complements rather than replaces symmetric key crypto

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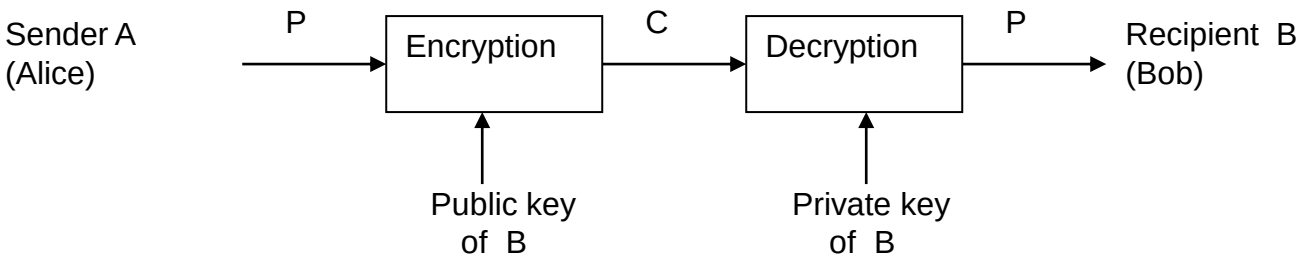
Public key encryption - operation

- Public-key (or asymmetric) encryption/decryption involves the use of two keys:
  - a public-key, which may be known by anybody (including adversaries), and can be used to encrypt messages,
  - a related private-key, known only to the recipient, used to decrypt messages,
  - infeasible to determine private key from public
- is asymmetric because
  - those who encrypt messages cannot decrypt these messages – only the legitimate recipient can



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Why Public-Key Cryptography?

- The sender may start encryption without any prior “secret” communication with the recipient
  - The secure key distribution problem is being solved
  - As it will be shown next, public-key crpytography also suffices to generate digital signatures – used to verify a message comes intact from the claimed sender
- Public invention due to Whitfield Diffie & Martin Hellman at Stanford University in 1976
  - Seems though to be known earlier in classified community
  - Diffie and Hellman, received the 2015 Turing award - http://awards.acm.org/about/2015-turing

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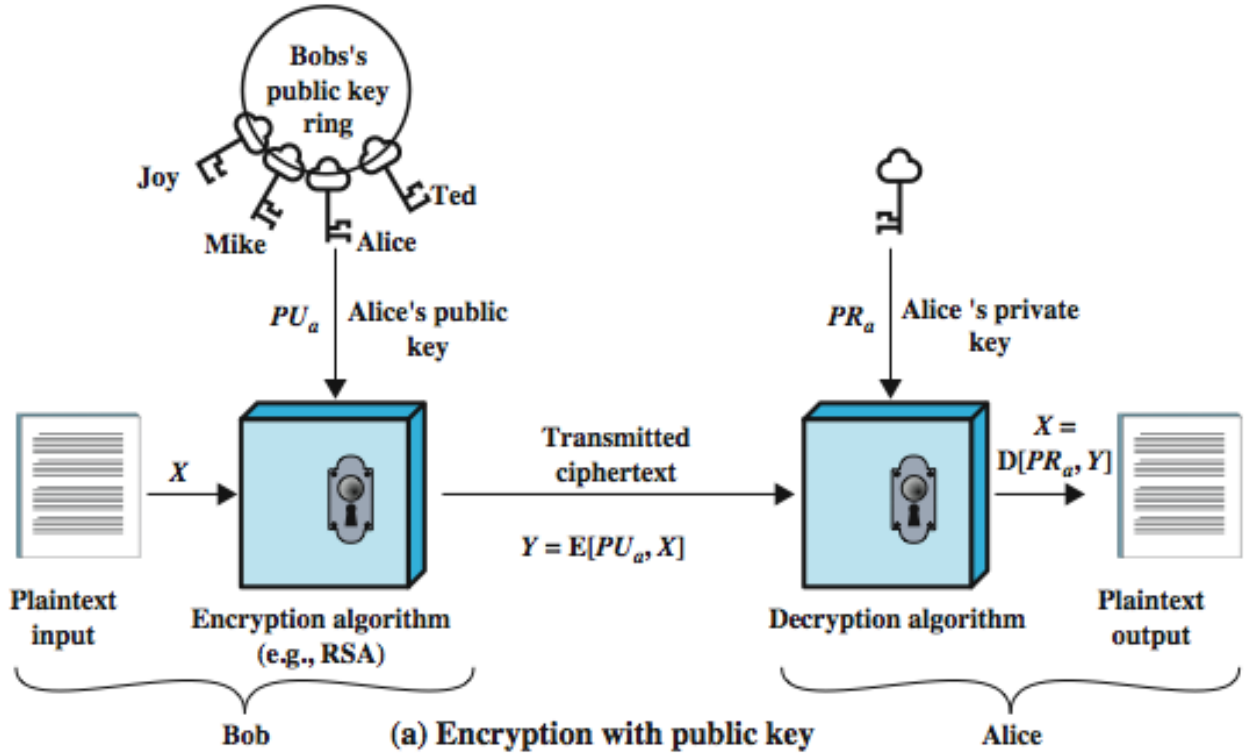
Public-Key Cryptography – a more generalized view

- The sender has a ring of public keys, (at least) one for each potential recipient
- Of course, the sender has also his own public-private key pair…



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Symmetric vs Public-Key

Conventional Encryption	Public-Key Encryption
Needed to Work: 1. The same algorithm with the same key is used for encryption and decryption. 2. The sender and receiver must share the algorithm and the key. *Needed for Security:* 1. The key must be kept secret. 2. It must be impossible or at least impractical to decipher a message if no other information is available. 3. Knowledge of the algorithm plus samples of ciphertext must be insufficient to determine the key.	*Needed to Work:* 1. One algorithm is used for encryption and decryption with a pair of keys, one for encryption and one for decryption. 2. The sender and receiver must each have one of the matched pair of keys (not the same one). *Needed for Security:* 1. One of the two keys must be kept secret. 2. It must be impossible or at least impractical to decipher a message if no other information is available. 3. Knowledge of the algorithm plus one of the keys plus samples of ciphertext must be insufficient to determine the other key.

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Some widely known public key cryptographic schemed

- Diffie-Hellman (protocol)
- RSA
- El Gamal
- Rabin
- McEliece
- Elliptic curve cryptography
- And others…

- Not all of them are being used for the same purposes

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Public-Key Applications

- can be classifies into 3 categories:
  - encryption/decryption (provide secrecy)
  - digital signatures (provide authentication)
  - key exchange (of session keys)
- some algorithms are suitable for all uses, others are specific to one

Algorithm	Encryption/Decryption	Digital Signature	Key Exchange
RSA	Yes	Yes	Yes
Elliptic Curve	Yes	Yes	Yes
Diffie-Hellman	No	No	Yes
DSS	No	Yes	No

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RSA

- by Rivest, Shamir & Adleman of MIT in 1977
- best known & widely used public-key scheme
- based on exponentiation in a finite field over integers modulo a prime
- uses large integers (eg. 2048 bits today)
- security due to cost of factoring large numbers

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Which is the difficult mathematical problem for RSA?

- Any positive integer n can be represented in exactly one way as a product of primes (Fundamental Theorem of Arithmetic)
  - e.g. $140 = 2 \cdot 2 \cdot 5 \cdot 7$
  - There is no other product of primes which gives rise to 140
- Finding out the unique such product of primes, for given number n, is being called factorization of n
- Factorization is known to be computationally hard
- The security of RSA is based on the difficulty of the factorization problem

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Length of an RSA modulus

- It is hard to compare the equivalent security parameters for symmetric key cipher systems and RSA, however it is roughly believed that factorising a 512 bit number is about as hard as searching for a 56 bit symmetric key.
- Today, 2048 bits provide security (NIST suggests 2048 bits for RSA modulus size) – corresponds to 112-bit key security

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RSA Security

- Possible approaches to attacking RSA are:
  - brute force key search
    - infeasible given the large size of numbers
  - mathematical attacks
    - based on difficulty of computing φ(N), by factoring modulus N, or on not properly chosen parameters
  - timing attacks
    - on running of decryption
  - chosen ciphertext attacks
    - given properties of RSA

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Elliptic curve cryptography (ECC)

- A general class of public key algorithms that are based on a special mathematical structure, being called elliptic curve
  - Similarly to the DLP problem, there is a known difficult problem that is being called Elliptic Curve Discrete Logarithm Problem (ECDLP)
  - Any cipher whose security rests wit the difficulty of the ECDLP, is being called an elliptic curve cryptographic algorithm
  - ECC and RSA constitute the most common implementations of the public key algorithms
  - ECC will not be discussed in this course…

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The major advantage of the ECC

- Smaller key sizes to achieve the same level of security

ECC KEY SIZE (Bits)	RSA KEY SIZE (Bits)	KEY SIZE RATIO	AES KEY SIZE (Bits)
163	1024	1 : 6	
256	3072	1 : 12	128
384	7680	1 : 20	192
512	15 360	1 : 30	256

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General advantages of public key cryptographic algorithms

- No previous negotiation is needed
- The key pair can remain unchangeable for many years
  - In contrast to the symmetric key
- In a network, a much smaller number of keys is needed to be distributed with respect to the symmetric key
  - In symmetric encryption, we need a different key for each pair of users!
  - If we have N users, we actually need N(N-1)/2 symmetric keys

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General disadvantages of public key cryptographic algorithms

- Much smaller throughput
  - Actually, we cannot encrypt real time communication with public key encryption
- Keys of large sizes are difficulty to be handled
- Their security rests with difficult mathematical problems which are known to be difficult but they have not proved to be “unsolvable”.
  - What if we find a “solution” for such a problem?
- In a post-quantum world, most public key algorithms will be no secure any more!!

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Combining symmetric with public key algorithms (1/3)

First, a mutual authentication needs to be performed,

- Public key cryptographic structures are being used

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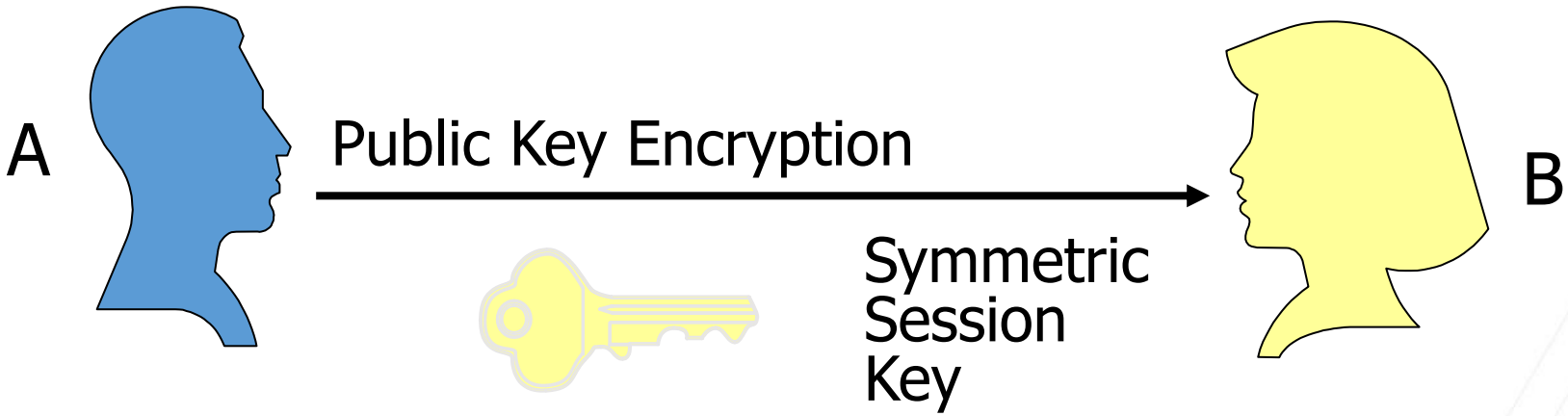
Combining symmetric with public key algorithms (2/3)

- Next, a user generates a symmetric key
- This key is being encrypted with the public key of the other user and is being transmitted to her
  - Hence, they both have the same secret key, being securely interchanged



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Combining symmetric with public key algorithms (3/3)

- Now they communicate securely, with symmetric key encryption