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Aspects of Public Key Cryptosystems in Practice

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RSA or Elliptic Curves ?

The Current Status of Public Key Cryptography (I)

- **RSA**
  still the most popular public key system

  - Pro‘s:
    - easy to understand - even for non-experts
    - easy to implement
    - patent expired
    - underlying mathematical problem considered “old“ and hard
  - Contra‘s:
    - extra-long parameters
    - multiplicativity
    - vulnerable again side-channel-attacks

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The Current Status of Public Key Cryptography (II)

- **Elliptic Curves**
  the most attractive alternative to RSA
  - Pro‘s:
    - shorter parameters
    - shorter digital signatures
    - faster than RSA
    - cryptographic security grows exponentially with length of parameters
  - Often heared Contra‘s:
    - underlying mathematical problem considered “new“
    - confusing patent situation
    - confusing number of implementiation options
    - more difficult to explain and to implement

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Side Channel Attacks - SPA and Timing Attack

- **SPA: Simple Power Attack**
  - Attack: *Direct interpretation of power consumption measurement.*
  - *Defense:* *Avoid key dependent power profile by uniforming the computations*

- **Timing Attack:**
  - Attack: *Statistical evaluation of the correlation between key bits,plaintext and the running time of the cryptographic algorithm*
  - *Defense:* *Make running time independent of key bits by uniformization of the computations. Randomize input and/or keybits*

- **Methods to protect EC cryptosystems against SPA and timing attacks:**
  - Use Montgomery's method for point multiplication
  - Introduce dummy operation to "homogenize" the point operations
    - $P \rightarrow P + P$
    - $P, Q \rightarrow P + Q$

Side Channel Attacks - DFA and DPA

It seems that elliptic curve based cryptosystems are easier to protect against DFA and DPA than the RSA-system.

- DFA: Differential Fault Analysis
  - Attack: *Induce computational errors to the device and deduce key bits from the information leaked by the faulty result*
  - Defense: *Check the consistency of the result of computation*
    - RSA: Complicated protocols with additional consistency relations.
      - Shamir's protection against the Bellcore-attack
    - EC: Consistency relation is implicitely given.
      - Check if resulting point is on curve.

Side Channel Attacks - DFA and DPA (II)

- DPA *Differential Power Analysis*
  - Attack: Apply statistical tests to intermediate results in order to detect correlations between and plain-/ciphertext in the power consumption profile.
  - Defense: Decorrelation of intermediate results and key-bits, plain- and ciphertext by randomization.
    - RSA: Randomize exponent and/or basis of modular exponentiation.
    - EC: As in the case of RSA, and use randomized projective co-ordinates.

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Side Channel Attacks - Consequences

- It seems that elliptic curve based cryptosystems can be protected against DFA and DPA with less additional costs than RSA.
- Implementation of the RSA-system is getting more complicated
  - randomization
  - consistency checks
- One might expect that RSA is rapidely loosing its attractiveness.

Basic Constituents for Elliptic Curve Based Cryptosystems

- Cryptographic schemes
  - easily derived from the the classical DL-schemes in GF(p)*
    - EC-DH, EC-DSA, etc.
- Good curves
  - now in a sufficient way under control
    - CM-curves with large class number (Spallek, Morain, Lay)
    - SEA-algorithm (Schoof, Atkin, Elkies, Müller, Couveigne, Lercier)
- Random number generator
  - Crucial cryptographic operation for most schemes $k,P \rightarrow [k]\cdot P$

    (k is a random integer, P a point on an elliptic curve, k to be used only once)
- Arithmetic support
  - field arithmetic in the underlying finite field
  - ordinary modular arithmetic (modulo the group order of a point P)

Todays Options for Elliptic Curve Based Cryptosystems (I)

The current standards for elliptic curve based cryptosystems offer a (unnecessary ?) large number of implementation options:

- various schemes for the same cryptographic mechanism
- various choices for the underlying finite field
  - GF(p)
  - $GF(2^n)$
    - normal basis representation
    - polynomial basis representation
  - $GF(p^n)$ binary length of p ~ word length of chosen processor

consequence

We are loosing the common arithmetic basis of public key cryptography

Options for Elliptic Curve Based Cryptosystems (II)

Elliptic curves defined over prime fields GF(p)

Pro‘s:

- Based on ordinary modular arithmetic
- Dual mode with RSA possible
- Offers migration path for RSA-users
- One more “degree of freedom“

Often heared Contra‘s:

- Impossible on smart cards
- Area consumption too large
- Much slower than elliptic curves over GF(2^n)

Options for Elliptic Curve Based Cryptosystems (III)

Elliptic curves defined over prime fields GF(2^n)

Pro's:

- Arithmetic is easy to implement
- Can be run with very high clock frequency
- Area and power consumption smaller than in the case of GF(p)

Contra's:

- The use of ordinary modular arithmetic cannot be avoided
- High clocking rate cannot be used in smart cards
- Patent situation
  - The idea to implement arithmetic units for GF(2^n) and mod(N) on **one** IC might be covered by a patent.

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Elliptic Curve Cryptosystems - Patent Situation

- The general idea to use elliptic curves for public key cryptosystems is free of patents

- All the relevant public key based security services
  - digital signatures, key excange, authentication

  can be realized in a patent free way

BUT:

- Some elliptic curve analogues of cryptographic schemes are covered by patents
  - Menezes-Qu-Vanstone, Nyberg-Rueppel, Schnorr, etc.

- There is a large number of patents covering special implementation techniques

Unpleasant Experiences with Elliptic Curve based Cryptosystems

- Some ideas to make implementations of elliptic curve based cryptosystems faster or easier to implement turned out to be contra-productive.

  - Use of supersingular curves
    - Idea: Avoid determining the number of points
  - Use of anomalous curves
    - Idea: Double use of arithmetic
  - Use of curves over GF (2^{mn})
    - Idea: Store parts of the arithmetic

Avoid unnecessary fixings

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Hardware Supporting Elliptic Curve Cryptosystems

INFINEON:

- The Smart Card-ICs SLE66CxxP
  - A family of smart card ICs supporting public key algorithms based on ordinary modular arithmetic.

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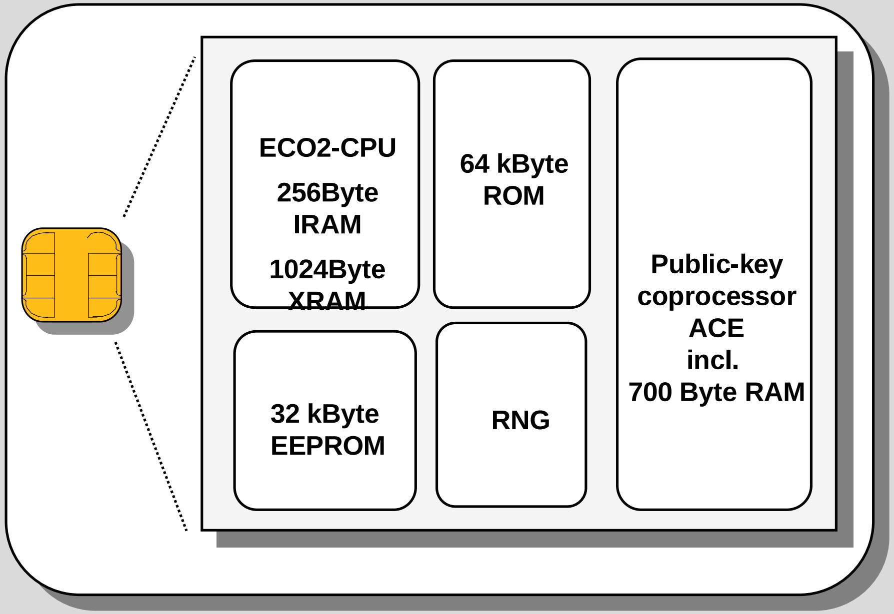
- The PLUTO-IC
  - A high-performance encryption IC. (encryption rate 2Gbit/sec)
  - Elliptic curve cryptosystem based on curves over GF(p), p of length 320 bit

- ELCRODAT-6-2
  - An encryption device for the ISDN-telecommunication network
  - Elliptic curve cryptosystem based on curves over GF(p), p of length 256 bit

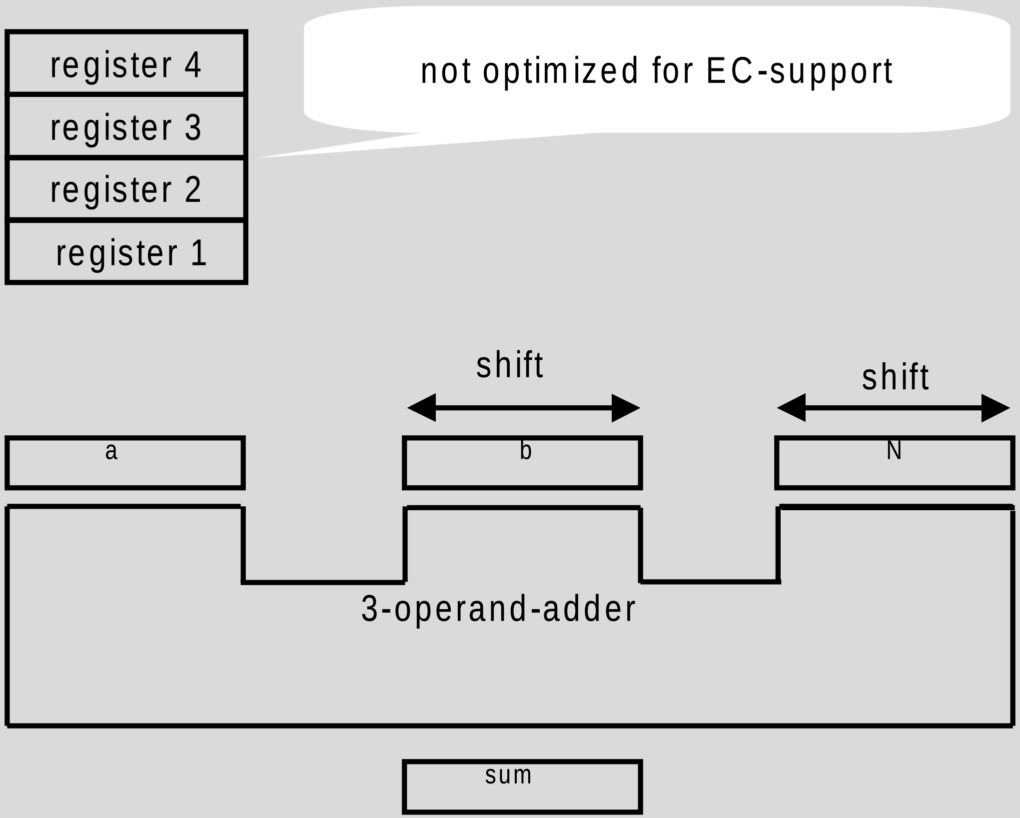
The Infinion Smart-Card-IC SLE66CX320P



- Public key coprocessor for modular arithmetic
- True physical random number generator
- Support of RSA and elliptic curves over GF(p)
  - RSA: up to 1024 Bit
  - Elliptic curves: up to 256 Bit
- Dedicated 700 Bytes of Crypto RAM
- Architecture optimized for minimum power consumption
- maximum clock frequency: 15 MHz
- Total area of public key coprocessor:

  << $1mm^2$ (0.25µ technology)

The Public Key Coprocessor of SLE66CxxP



- Characteristics:
  - 3-operand-parallel-adder
  - parallel/serial multiplication
  - Booth‘s algorithm to reduce the number of partial products
  - special modular reduction based on an comparing with (2/3)·N
  - 4 registers of length 560 bit
  - execution time for one modular multiplication of n-bit-integers:
    (1/2.8)·n clock cycles

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The Infinion Smart-Card-IC SLE66CX320P - Performance Data

Operation	[length of modulus]	execution time [@15 MHz]
[k]P on EC over GF(p)	160 bit	83 ms
[k]P on EC over GF(p)	256 bit	234 ms
a^b *mod N*	1024 bit	220 ms

Elliptic curves are faster than RSA, even on devices optimized for RSA-support

Elliptic curves on SLE66:

- All curves of type $y^2 = x^3 + ax + b$ over GF(p) are possible
- No restrictions concerning the parameters a, b and p
- Points P and [k]P in affine representation
- Calculation of [k]P using projective co-ordinates
- Patent-free implementation

The Infinion Smart-Card-IC SLE66CX320P - Possible Performance

Operation	[length of modulus]	execution time [@15 MHz]
[k]P on EC over GF(p)	160 bit	83 ms
[k]P on EC over GF(p)	256 bit	234 ms
a^b *mod N*	1024 bit	220 ms

← < 15 ms

← < 35 ms

Expected performance under the conditions

- Register organization optimized for EC-support
- Fast modular division available

The Encryption Device ELCRODAT 6-2

- ED 6-2S for the Euro-ISDN basic rate interface (S_0)
  - different line configurations:
    - point-to-point, e.g. interfacing of PBX
    - passive bus, up to eight subscribers (TE)
  - two independent B-channels
- ED 6-2M for the Euro-ISDN primary rate interface (S_{2M})
  - connection of PBX via S_{2M}-Interface
  - 30 independent B-channels
- Common Features of ED 6-2M and ED 6-2M
  - Tempest proof
  - Evaluated up to “TOP SECRET”
  - remote certificate update

ELCRODAT 6-2 -Cryptographic Features

- Public Key System, based on elliptic curves over GF(p)
  - Size of p: 256 Bits
  - digital signatures, authentication, key exchange
  - Certificates, based on X.509
- Hash function RIPE MD-160
- Access protection with smart card
- Physical random number generator
- Symmetric encryption algorithm
- Each ED 6-2 supports up to 1024 closed user groups
  - 32 different Management Groups (separate certificates and separate cryptographic parameters),
    each consists of up to 32 separate compartments

Practical Use of ELCRODAT 6-2

Germany:

- **IVBB** Governmental ISDN-Network (already in service)

  (IVBB = Informations**v**erbund **B**onn **- B**erlin**)**

European Union:

- **PrimeNet** Network connecting the prime ministers (planned)
- **DiploNet** Network connecting the foreign offices (planned)

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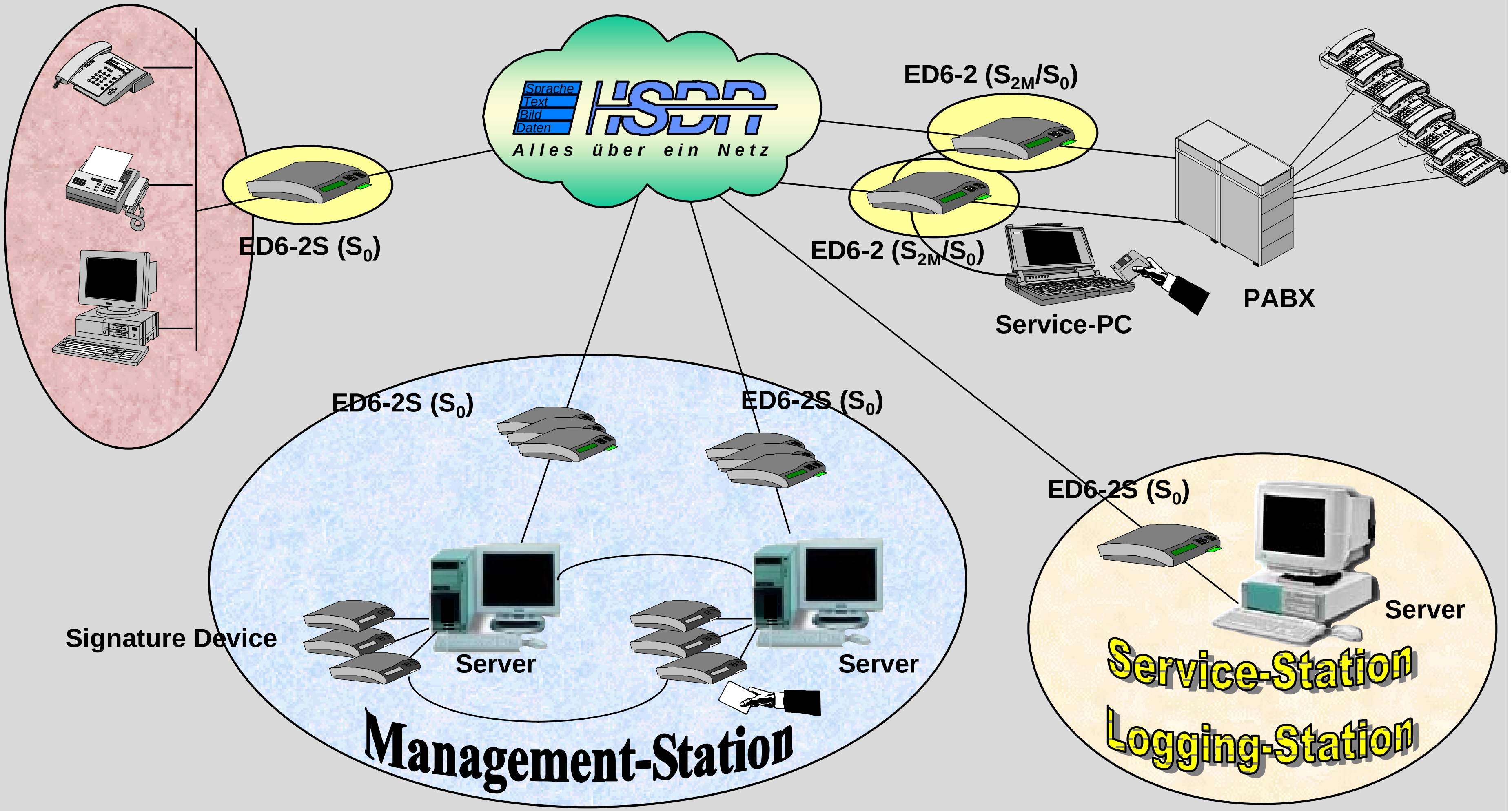
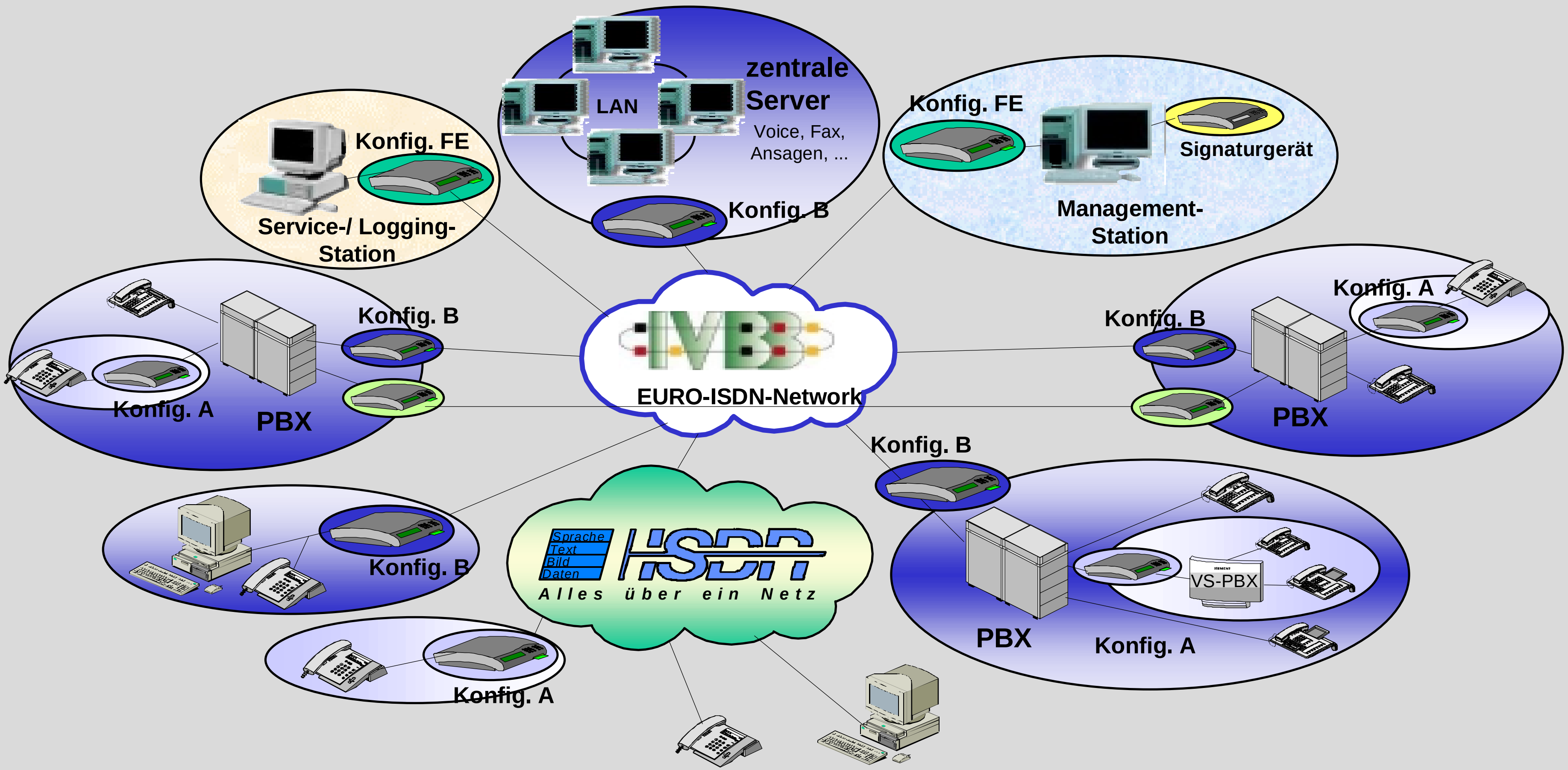
ELCRODAT 6-2 - Overview



Use of ELCRODAT 6-2 in the German Government Network IVBB



Conclusion

Elliptic curve cryptography is a mature technology

- All the necessary components are available
- Systems are already in practical use
- Patent free approach is possible

Why do you still hesitate to move towards elliptic curve cryptography?