Electronic payment systems

- overview of basic concepts
- credit-card based systems (MOTO, SSL, SET)
- electronic cash systems (DigiCash)
- micropayment schemes (PayWord, probabilistic schemes)

Overview of basic concepts

- brief history of money
- traditional forms of payment
  - cash
  - payment through bank
  - payment cards
- electronic payment systems
  - security requirements
  - basic classification

A brief history of money

- barter
  - most primitive form of payment
  - still used in primitive economies or under exceptional conditions
  - problem: "double coincidence of wants"
    - you want to change food for a bicycle
    - you need to find someone who is hungry AND has a spare bicycle
- commodity money
  - physical commodities which have recognized value
    e.g., salt, gold, corn, …
  - desirable properties
    - portability
    - divisibility

  → gold and silver coins became the most commonly used

A brief history of money (cont'd)

- commodity standard
  - ~ 19th century
  - use of tokens (e.g., paper notes) which are backed by deposits of gold and silver held by the note issuer
  - more comfortable and more SECURE !
- fiat money
  - tokens have value by virtue of the fact that a government declares it to be so AND this assertion is widely accepted
  - this works only if
    - the economy is stable
    - the government is trusted
- electronic money
  - ~ end of 20th century
  - paper tokens and metal coins are replaced by electronic representations of money
  - made possible by progress in computing and networking technology

Overview of basic concepts

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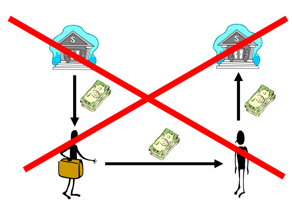
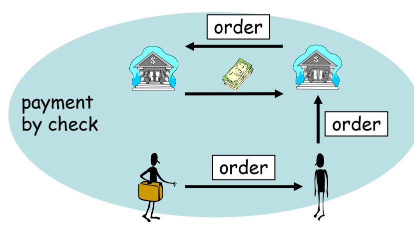
Cash

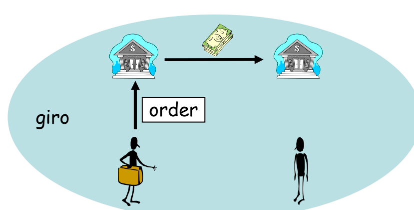
- most commonly used form of payment today
  - ~80% of all transactions
  - average transaction value is low
- advantages of cash
  - easy to transport and transfer
  - no transaction costs (no third party is involved directly)
  - no audit trail is left behind (that's why criminals like it)
- disadvantages of cash
  - in fact, cash is not free
    - banknotes and coins need to be printed and minted
    - old bank notes and coins need to be replaced
    - this cost is ultimately borne by the tax payers
  - needs extra physical security when
    - transported in large quantities (e.g., from the mint to banks)
    - stored in large quantities (e.g., in banks)
  - vaults must be built and heavy insurances must be paid
  - risk of forgery

Payment through banks

- if both parties have accounts in a bank, then it is unnecessary for one party to withdraw cash in order to make a payment to the other party who will just deposit it again in the bank







Payment by check

- advantages
  - no need for bank at the time of payment
- disadvantages
  - returned items
    - if funds are not available on the payer's bank account, then the check is returned to the payee's bank
    - if the payee has already been credited, then the bank loses money
    - otherwise the payee suffers
    - problem: no verification of solvency of the payer at the time of payment
  - processing paper checks is very expensive and time consuming
    - checks must be physically transferred between banks
    - authenticity of each individual check must be verified
- still popular in some countries
  - e.g., in the US, ~80% of non-cash payment transactions are check payments with an average value of ~1000$

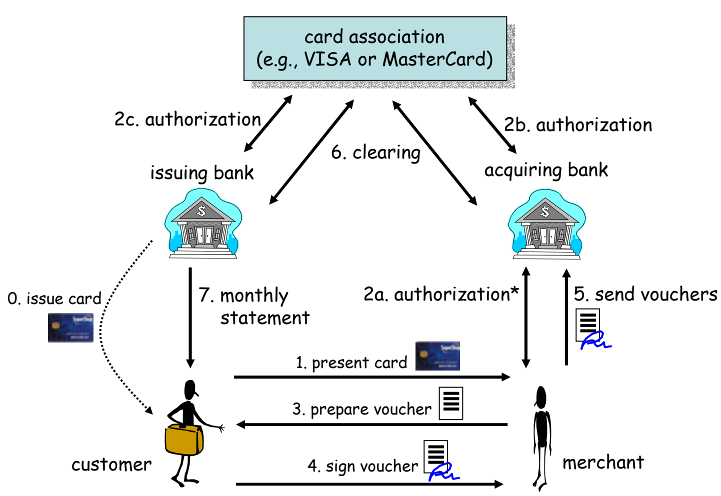
Giro payment

- advantages
  - the transaction cannot be initiated unless the payer has enough funds available
  - can be fully electronic (using the existing banking networks)
- disadvantage
  - the bank must be present at the time of payment
- quite popular in Hungary

Payments cards – brief history

- 1915: first card was issued in the US ("shoppers plates")
- 1950: Diners Club card (used for travel and entertainment)
- 1958: American Express card was born
- … : many card companies have started up and failed
- today: two major card companies dominate the world
  - VISA International
  - MasterCard

Payment by card



* authorization is optional, depends on policy

Payment cards – pros and cons

- advantages
  - flexibility of cash and checks (assuming infrastructure is in place)
  - security of checks (no need to carry cash in pocket)
  - solvency of the customer can be verified before payment is accepted
- disadvantages
  - needs infrastructure to be deployed at merchants
    - e.g., card reader, network connection, etc.
  - transaction cost
    - covered by merchants
    - paying with cards is not worth for very low value transactions (below 2$)

Payment card types

- debit card
  - the customer must have a bank account associated with the card
  - transaction is processed in real time: the customer's account is debited and the merchant's account is credited immediately
- charge card
  - the customer doesn't need to pay immediately but only at the end of the monthly period
  - if she has a bank account, it is debited automatically
  - otherwise, she needs to transfer money directly to the card association
- credit card
  - the customer doesn't need to pay immediately, not even at the end of the monthly period
  - the bank doesn't count interest until the end of the monthly period

Main security requirements for e-payment

- authorization
  - a payment must always be authorized by the payer
  - needs payer authentication (physical, PIN, or digital signature)
  - a payment may also need to be authorized by the bank
- data confidentiality and authenticity
  - transaction data should be authentic
  - external parties should not have access to data
  - some data need to be hidden even from participants of the transaction
    - the merchant does not need to know customer account information
    - the bank doesn't need to know what the customer bought
- availability and reliability
  - payment infrastructure should always be available
  - centralized systems should be designed with care
    - critical components need replication and higher level of protection

Main security requirements for e-payment (cont'd)

- atomicity of transactions
  - all or nothing principle: either the whole transaction is executed successfully or the state of the system doesn't change
    - in practice, transactions can be interrupted (e.g., due to communication failure)
    - it must be possible to detect and recover from interruptions (e.g., to undo already executed steps)
- privacy (anonymity and untraceability)
  - customers should be able to control how their personal data is used by the other parties
  - sometimes, the best way to ensure that personal data will not be misused is to hide it
    - anonymity means that the customer hides her identity from the merchant
    - untraceability means that not even the bank can keep track of which transactions the customer is engaged in

Basic classification of e-payment systems

- pre-paid, pay-now, or pay-later
  - pre-paid: customer pays before the transaction (e.g., she buys electronic tokens, tickets, coins, …)
  - pay-now: the customer's account is checked and debited at the same time when the transaction takes place
  - pay-later (credit-based): customer pays after the transaction
- on-line or off-line
  - on-line: a third party (the bank) is involved in the transaction (e.g., it checks solvency of the user, double spending of a coin, …) in real-time
  - off-line: the bank is not involved in real-time in the transactions

Credit-card based systems

- motivation and concept:
  - credit cards are very popular today
  - use existing infrastructure deployed for handling credit-card payments as much as possible
  - enable secure transfer of credit-card numbers via the Internet
- examples:
  - MOTO (non-Internet based scheme)
  - First Virtual and CARI (non-cryptographic schemes)
  - SSL (general secure transport)
  - iKP (specific proposal from IBM)
  - SET (standard supported by industry including VISA, MasterCard, IBM, Microsoft, VeriSign, and many others)

MOTO – Mail Order / Telephone Order

- credit card number is sent via phone or post and then processed in the traditional way (using existing infrastructure)
- no cardholder signature !
  - → user is allowed not to agree to the purchase (limited liability)
  - → merchant must handle disputes (instead of banks)
  - → some special rules and precautions are applied:
    - additional information is requested from user (e.g., name, address)
    - goods are delivered to the address associated with the card
- fraud is still possible (but hopefully the benefits outweigh the disadvantages)
- still very popular (in the US and Western Europe)

Credit-card payment with SSL

- the user visits the merchant's web site and selects goods/services to buy
  - state information may be encoded in cookies or in specially constructed URLs
  - or state information may be stored at the merchant and referenced by cookies or specially constructed URLs
- the user fills out a form with his credit card details
- the form data is sent to the merchant's server via an SSL connection
  - the merchant's server is authenticated
  - transmitted data is encrypted
- the merchant checks the solvency of the user
- if satisfied, it ships the goods/services to the user
- clearing happens later using the existing infrastructure deployed for credit-card based payments

Pros and cons of SSL

- advantages:
  - SSL is already part of every browser and web server
    → no need to install any further software
    → users are used to it
    → this payment method can be used as of today
- disadvantages:
  - eavesdropping credit card numbers is not the only risk
  - another risk is that credit card numbers are stolen from the merchant's computer

SET – Secure Electronic Transactions

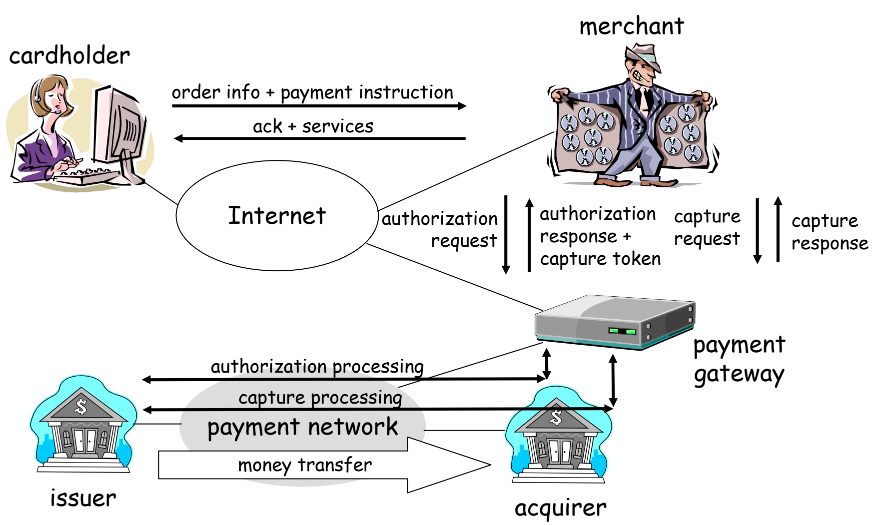
- a protocol designed to protect credit card transactions on the Internet
- initiated and promoted by MasterCard and Visa
  - MasterCard (and IBM) had SEPP (Secure E-Payment Protocol)
  - VISA (and Microsoft) had STT (Secure Transaction Technology)
  - the two proposals converged into SET
- many companies were involved in the development of the specifications (IBM, Microsoft, Netscape, RSA, VeriSign, …)
- the SET specification is available on the web (→ Google)
- it consists of three books:
  1. Business Description
  2. Programmer's Guide
  3. Formal Protocol Definition

  (around 1000 pages all together)

SET participants

- cardholder
  - wants to buy something from a merchant on the Internet
  - authorized holder of payment card issued by an issuer (bank)
- merchant
  - sells goods/services via a Web site or by e-mail
  - has a relationship with an acquirer (bank)
- issuer
  - issues payment cards
  - responsible for the payment of the dept of the cardholders
- acquirer
  - maintains accounts for merchants
  - processes payment card authorizations and payments
  - transfers money to the merchant account, reimbursed by the issuer
- payment gateway
  - interface between the Internet and the existing credit-card payment network
- CAs

Overview of operation



Credit-card based systems / SET

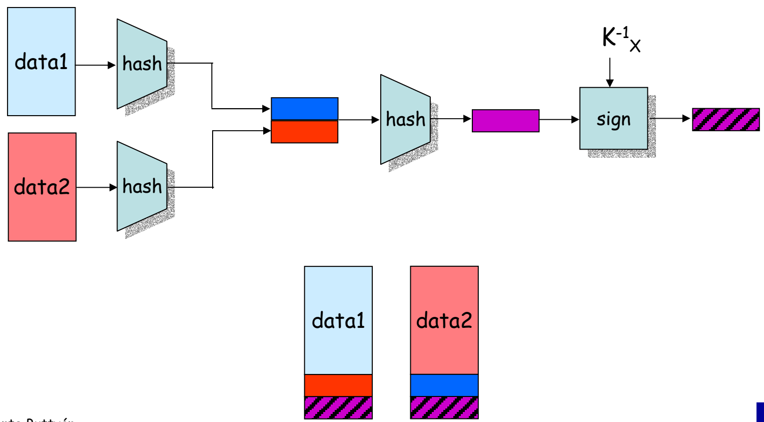
SET services

- cardholder account authentication
  - merchant can verify that the client is a legitimate user of the card
  - based on X.509 certificates
- merchant authentication
  - client can authenticate the merchant and check if it is authorized to accept payment cards
  - based on X.509 certificates
- confidentiality
  - cardholder account and payment information (i.e., her credit card number) is protected while it travels across the network
  - credit card number is hidden from the merchant too !
- integrity
  - messages cannot be altered in transit in an undetectable way
  - based on digital signatures

Credit-card based systems / SET

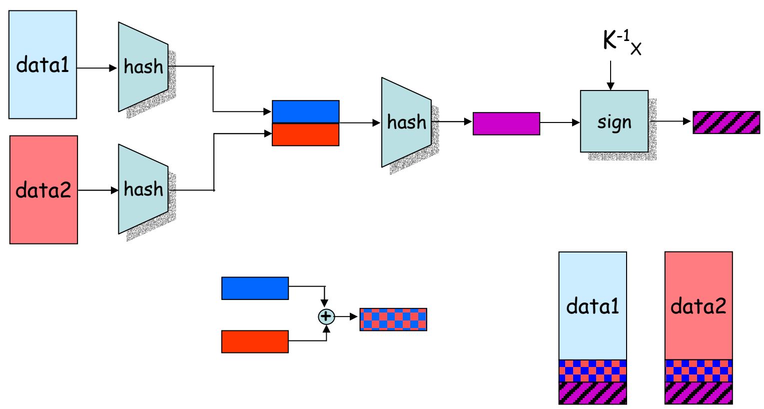
Dual signature – basic concept

- goal:
  - link two messages that are intended for two different recipients (e.g., order info and payment instructions in SET)
  - link may need to be proven in case of disputes

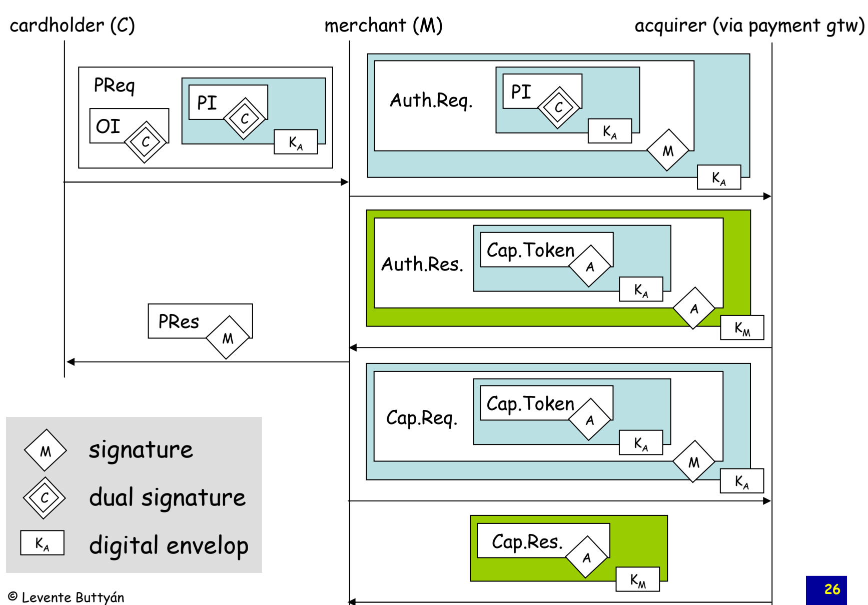


Dual signatures in SET

- goal:
  - same as in the basic case, but …
  - the two messages have the same signature



Overview of message protection mechanisms



Why did SET fail?

- less benefits than expected
  - merchants like to collect credit card numbers (they use it as indexes in marketing databases)
  - optionally, SET allows the merchant to get the credit card number from the acquirer → security improvements of SET are negated
- too high costs
  - SET requires a PKI
- no advantages for the customer !
  - the idea was that SET transactions would be handled as "cardholder present" transactions (due to the digital signature)
  - customers prefer MOTO-like systems where they can freely reverse a transaction if they are unhappy (not only in case of fraud) → customers were much worse off
  - SET requires the download and installation of a special software, and obtaining a public-key certificate

Electronic cash

- motivation and concept:
  - people like cash (75-95% of all transactions in the world are paid in cash)
  - design electronic payment systems that have cash-like characteristics
  - it is possible to ensure untraceability of transactions (an important property of real-world cash)
- examples:
  - DigiCash (on-line)
  - CAFE (off-line)

E-cash – a naïve approach

- electronic coins:

  (serial_number, value, Sig_{bank} (serial_number, value))

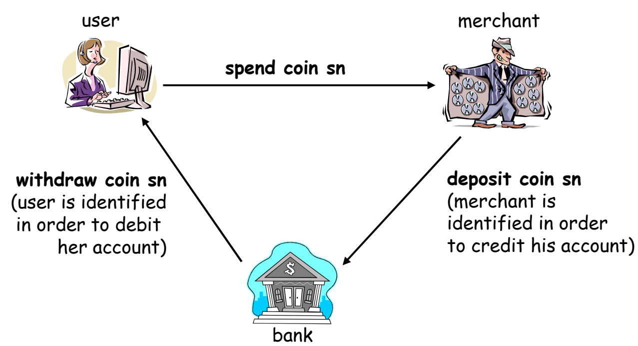
- problem 1: double spending
- a solution to problem 1:
  - merchants deposit received coins before providing any service or goods
  - the bank maintains a database of spent serial numbers
  - only coins that have never been deposited before are accepted by the bank

- problem 2: ever increasing database at the bank
- a solution to problem 2:
  - coins have an expiration time: (sn, val, exp, Sig_{bank}(sn, val, exp))
  - bank needs to store deposited coins until their expiration time only

Electronic cash

E-cash – a naïve approach (cont'd)

- problem 3: traceability



bank can link the withdrawal (identity of the user) and the deposit (identity of the merchant) via the serial number sn

- a solution to problem 3: DigiCash

Electronic cash

The main idea of DigiCash

- blind RSA signatures
  - the bank's public RSA key is (e, m), its private RSA key is d
  - user U generates a serial number s, and a random number r (blinding factor)
  - U computes $s \cdot r^e$ and sends it to her bank
  - the bank signs the blinded serial number by computing $(s \cdot r^e)^d = s^d \cdot r$
  - when U receives the blindly signed serial number, it removes the blinding: $s^d \cdot r \cdot r^{-1} = s^d$
  - U obtained a digital signature of the bank on the serial number
  - the bank cannot link $s^d \cdot r$ and s^d together (r is random)

- notes
  - the user must authenticate herself to the bank when withdrawing money, so that the bank can charge her account
  - the merchant must authenticate himself to the bank when depositing money, so that the bank can credit his account
  - messages should be encrypted in order to prevent theft of money

Electronic cash / DigiCash

Further precautions

- the serial number s shouldn't be random
  - a forger generates a random number c and computes $s = c^e$
  - since $c = s^d$, c looks like a serial number signed by the bank (i.e., a coin)

- two solutions:
  1. s should have a well defined structure (e.g., its second half is a known function of its first half)
  2. s shouldn't be a simple serial number, but s = h(coin_data), where coin_data = serial_number, value, expiration_time, …

Electronic cash / DigiCash

Different denominations

- the bank signs the blinded coin → it does not know the value of the coin
  - how much should the user be charged?
- one can allow a single denomination only in the system, but that wouldn't be practical
- in DigiCash, the bank uses different signing keys for different denominations

Micropayment schemes

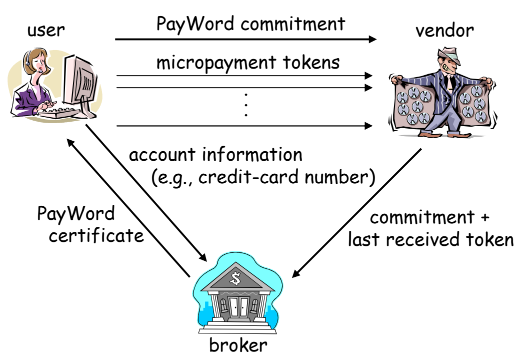
- motivation and concept:
  - many transactions have a very low value (e.g., paying for one second of a phone call, for one article in a newspaper, for one song from a CD, for 10 minutes of a TV program, etc.)
  - transaction costs of credit-card, check, and cash based payments may be higher than the value of the transaction
  - need solutions optimized for very low value transactions (perhaps by sacrificing some security)
- examples:
  - PayWord
  - probabilistic micro-payment schemes
- the truth: micropayment schemes are not very successful so far
  - people are used to get these kind of things for free
  - if they have to pay, they prefer the subscription model

PayWord

- designed by Rivest and Shamir in 1996
- representative member of the big family of **hash-chain based** micropayment schemes
- check-like, credit based (pay later) system
  - payment tokens are redeemed off-line
- uses public key crypto, but very efficiently (in case of many consecutive payments to the same vendor)
  - the user signs a single message at the beginning
  - this authenticates all the micropayments to the same vendor that will follow

PayWord model

- players:
  - user (U)
  - vendor (V)
  - broker (B)
- phases:
  - registration (done only once)
  - payment
  - redemption



Registration phase

- U provides B with
  - account information in a real bank (e.g., her credit card number)
  - shipping address
  - public key
- B issues a certificate for U

$$Cert_U = \{ B, U, addr_U, K_U, exp, more\_info \}_{K_B^{-1}}$$

more_info: serial number, credit limit, contact information of B, broker terms and conditions, …

- the certificate is a statement by B to any vendor that B will redeem authentic paywords (micropayment tokens) produced by U turned in before the expiration date

Micropayment schemes / PayWord

Payment phase – generating the commitment

- when U is about to contact a new vendor, she computes a fresh payword chain

$$w_n,\ w_{n-1} = h(w_n),\ w_{n-2} = h(w_{n-1}) = h^{(2)}(w_n),\ \dots,\ w_0 = h^{(n)}(w_n)$$

where
  - n is chosen by the user
  - w_n is picked at random
- U computes a commitment

$$M = \{ V, Cert_U, w_0, date, more\_info \}_{K_U^{-1}}$$

- the commitment authorizes B to pay V for any of the paywords $w_1, \dots, w_n$ that V redeems with B before the given date
- paywords are vendor specific, they have no value to another vendor

Micropayment schemes / PayWord

Payment phase – sending micropayment tokens

- the i-th micropayment from U to V consists of the i-th payword and its index: (w_i, i)
- when V receives w_i, it can verify it by checking that it hashes into w_{i-1} (received earlier, or in the commitment in case of i = 1)
- since the hash function is one-way (preimage resistant) the next payment w_{i+1} cannot be computed from w_i
- V needs to store only the last received payword and its index
- variable size payments can be supported by skipping the appropriate number of paywords
  - let's assume that the value of each payword is 1 cent
  - and the last payword that U sent is (w_k, k)
  - if U wants to perform a payment of 10 cents, then she sends $(w_{k+10}, k+10)$

Redemption phase

- at the end of each day, the vendor redeems the paywords for real money at the broker
- V sends B a redemption message that contains (for each user that contacted V) the commitment and the last received payword w_k with its index k
- B verifies the commitment and checks that iteratively hashing w_k k times results in w_0
- if satisfied, B pays V k units and charges the account of U with the same amount

Efficiency

- user U
  - needs to generate one signature per "session"
  - needs to perform as many hash computation as the number of paywords needed (pre-computation of hash chains is possible)
  - needs to store the hash chain and her current position in the chain (time-memory trade-off is possible)
- vendor V
  - needs to verify one signature per "session"
  - needs to perform one hash computation per micropayment received
  - needs to store only the last received payword with its index, and the commitment
- broker B
  - needs to verify signatures and compute lot of hashes but all these are done off-line

Probabilistic micropayment schemes

- motivation:
  - in traditional micropayment schemes, the vendor cannot aggregate micropayments of different users
  - if the user spent only a few cents, then the cost of redeeming the micropayment tokens may exceed the value of the payment
  - example: typical value of a payword is 1 cent, whereas processing a credit-card transaction costs about 25 cents
- main idea:
  - suppose that U wants to pay 1 cent to V
  - U sends to V a lottery ticket that is worth 10$ if it wins, and it wins with probability 0.001
  - the expected value of U's payment is exactly 1 cent
  - if V conducts business with many users, then he approximately earns the value of the services/goods provided
  - advantage: only winning lottery tickets are redeemed at the bank
    - → number of vendor-bank transactions is greatly reduced
    - → value of lottery tickets surely exceeds the transaction cost

Micali-Rivest scheme

- check based, the user simply signs the transaction
- notation
  - T – encoding of the transaction (IDs of user, merchant, bank, transaction time, value, etc.)
  - F – fixed public function that maps an arbitrary bit string to a number between 0 and 1
  - s – fixed selection rate of payable checks
- setup
  - everyone establishes his own public key and corresponding private key for a digital signature scheme
  - the merchants signature scheme must be deterministic
    - $Sig_M(x) = Sig_M(x')$ if $x = x'$

Micropayment schemes / Probabilistic schemes

Micali-Rivest scheme (cont'd)

- payment
  - user U pays by sending $C = (T, Sig_U(T))$ to merchant M
  - M verifies if C is payable by checking if $F(Sig_M(C)) < s$
- selective deposit
  - M sends only payable checks to the bank for deposit
  - after verification, B credits M's account with 1/s cents and debits U's account with the same amount

Micropayment schemes / Probabilistic schemes

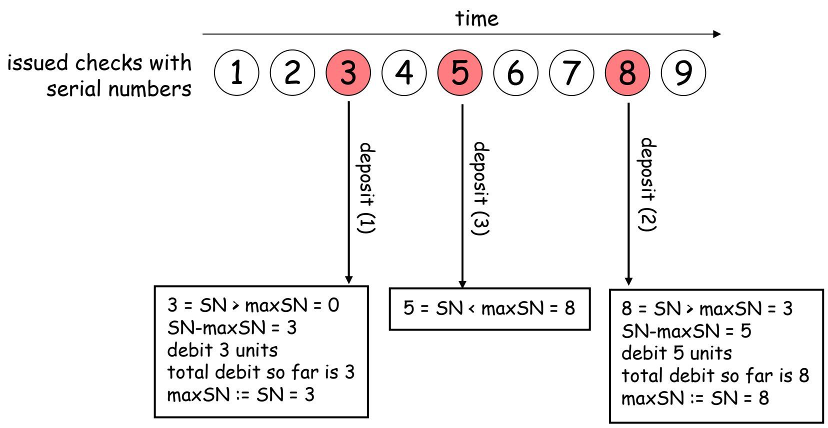
Some properties of the Micali-Rivest scheme

- $Sig_M(C)$ is unpredictable for both U and M
  - practically, $F(Sig_M(C))$ is a random number with close to uniform distribution over [0, 1]
  - the probability that $F(Sig_M(C)) < s$ is s
  - expected value of a check is 1 cent
- the bank essentially processes macropayments of value 1/s
  - e.g., if s = 1/1000, then the value is 10$
- potential "psychological" problem
  - possibility of user's excessive payments (in the short term)
  - e.g., it has a positive probability that the first 10 checks sent by the user are all payable
    - value of the goods/services received by the user is 10 cent
    - but her account is debited 100$
  - in the long run it will work, but users may not tolerate the risk of short term overpaying

Modified Micali-Rivest scheme

- notation and setup
  - same as for the basic Micali-Rivest scheme
- payment
  - U pays by sending $C = (T, Sig_U(T))$ to M
  - T contains a serial number SN (assigned sequentially to transactions by U)
  - M verifies if C is payable by checking if $F(Sig_M(C)) < s$
- selective deposit
  - M sends only payable checks to the bank for deposit
  - $maxSN_U$ denotes the highest serial number corresponding to U processed by B so far
  - if B receives a new payable check, then
    - B credits M's account with 1/s
    - if $SN > maxSN_U$, then it debits U's account with $SN-maxSN_U$ and sets $maxSN_U$ to SN

Illustration of the modified MR scheme



note: total debit of the user is always less than or equal to the highest serial number signed by the user so far

Some properties of the modified MR scheme

- cheating is possible
  - the same serial number may be used with different merchants
  - if only one of the two checks is payable than the cheating will not be detected
- however, large scale cheating can be detected with statistical auditing
  - example:
    - assume the user uses every serial number twice
    - number of payments made by the user is N
    - highest serial number used is N/2, user is charged at most N/2 cents
    - the joint credit of the merchants is approximately N
    - this can be detected by the bank !
    - in addition, the more the user cheats the higher the probability of two merchants depositing checks with the same serial number

Summary

- credit-card based
  - MOTO: non-cryptographic
  - SSL: most used today
  - SET: dual signature
- e-cash
  - DigiCash: untraceable, on-line
- micropayments
  - PayWord: hash chains
  - probabilistic: lottery tickets