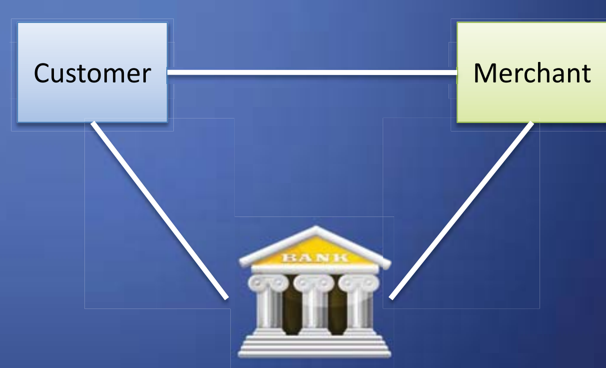
Payment Systems

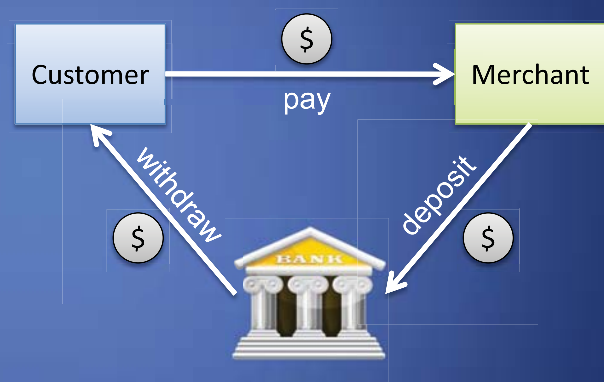
Electronic Payment Schemes

- Schemes for electronic payment are multi-party protocols
- Payment instrument modeled by electronic coin that has a fixed value and can be exchanged with a traditional monetary instrument
- Parties include:
  - Payer (customer)
  - Payee (merchant)
  - Bank



Transactions

- Transactions in an electronic payment scheme typically include:
  - Withdrawal of coins by customer from the bank
  - Payment of coins by customer to merchant
  - Deposit of coins by merchant into bank



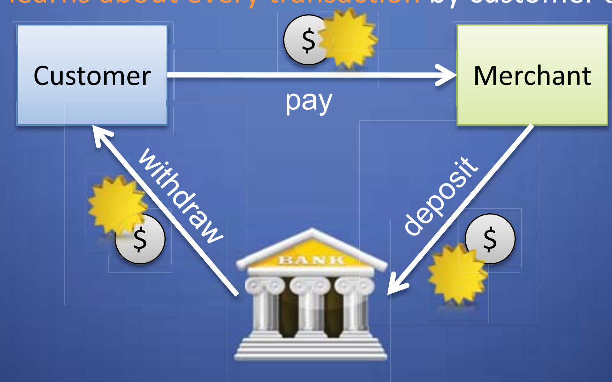
- Online scheme:
  - The bank participates in the payment transaction
- Offline scheme
  - The bank does not participate in the payment transaction

Goals

- Integrity
  - Coins cannot be forged
  - Legitimate transactions are honored
- Accountability
  - Transactions cannot be later denied
  - Disputes can be efficiently settled
- Privacy
  - The identity of some parties is not revealed to other parties
  - Coins cannot be traced to the payer and/or payee (digital cash)

Payment with Digital Signatures

- Coins are random identifiers digitally signed by the bank at the time of withdrawal
- The merchant verifies the signature by the bank
- The bank honors deposit of valid coins
- Security and privacy issues:
  - Customer can copy coin and double spend
  - The bank learns about every transaction by customer and merchant



Private Payment Scheme

- A blind signature allows the signed to sign a message without knowing the message itself
- Basic digital cash scheme:
  - The bank does a blind signature on the coins withdrawn by the customer
  - The merchant verifies the signature and deposits the coins
  - The bank cannot link the coins to the customer

Blind Signatures with RSA

- The RSA cryptosystem supports a simple and efficient blind signature scheme
- Consider an RSA signing scheme with
  - Public modulus N
  - Public encryption exponent e and public cryptographic hash function h
  - Secret decryption exponent d
- The bank can create a signature on any item without knowing it
- Bank must have assurance that it is signing a valid coin of the correct amount

RSA Blind Signature Protocol

- The customer picks secret random values x and r
  - Coin identifier x
  - Number r in $\mathbf{Z}_N$ relatively prime to N
- The customer sends to the bank value

$$y = r^e\, h(x) \bmod N$$

- The bank creates signature $\sigma(y)$ on y

$$\sigma(y) = y^d \bmod N$$

- The customer derives from $\sigma(y)$ signature $\sigma(x)$ on x

$$\sigma(x) = \sigma(y) / r \bmod N$$

- Proof

$$\sigma(y) / r \bmod N = r^{ed-1}\, h(x)^d \bmod N = h(x)^d \bmod N = \sigma(x)$$

Blindly Signing a Valid Coin

- The customer generates k coins and submits to the bank commitments (cryptographic hashes) for all the coins
- The bank randomly selects $k-1$ coins
- The customer reveals to the bank the selected $k-1$ coins
- The bank verifies the commitments on the selected $k-1$ coins
- The bank creates a blind signature on the remaining coin
- The coin signed by the bank is valid with probability

$$1 - 1/k$$

Defenses Against Double Spending

- Online protocol
  - The bank is online during the payment transaction to revoke spent coins
- Offline protocol
  - Withdrawn coins embed encrypted customer identity
  - Deposited coins embed also encrypted merchant identity
  - Double spending caused the identity of the cheating party to be revealed

Secret Splitting into Shares

- A secret string x can be split into random values y and z as follows
  - Pick a random value y
  - Set $z = y \oplus x$
- String x can be reconstructed from y and z by setting
  - $x = y \oplus z$
- Both shares y and z are random values and are referred to as shares of x
- Neither share reveals any information about secret x

Coins

- Let h be a cryptographic hash function
- Given a secret string x, a commitment pair for x is a pair (a, b) such that
  - $a = h(y)$
  - $b = h(z)$
  - y and z are random shares of x
- Let ID be a string identifying the customer (e.g., name, address, etc.)
- The coin issued by the bank to the customer consists of
  - Coin identifier x
  - Vector of n commitments pairs $(a_1, b_1), \ldots, (a_n, b_n)$ for ID
- The coin does not reveal the identity of the customer

Withdrawal

- The customer generates and submits k coins to the bank
- The bank randomly selects $k-1$ coins
- The customer reveals to the bank the shares associated with the commitments pairs of the selected coins
- The bank creates a blind signature on the remaining coin
- The coin signed is valid with probability $1-1/k$

Payment

- The customer gives to the merchant a coin $\{ x ; [(a_1, b_1), \ldots , (a_n, b_n)] \}$
- The merchant verifies the signature on the coin
- The customer gives to the customer a random binary vector $s_1, \ldots , s_n$, called selector
- The customer reveals to the merchant the shares indicated by the selector, i.e., it sends to the merchant a vector of strings $P_1, \ldots , P_n$ such that

$$h(P_i) = a_i \text{ if } s_i = 0$$

$$h(P_i) = b_i \text{ if } s_i = 1$$

Deposit and Security Properties

- Deposit
  - The merchant deposits with the bank the coin and strings $P_1, \ldots, P_n$
  - The bank verifies the signature and keeps track of coins and associated strings
- Security properties
  - The probability that the selectors provided by two merchants are identical is $1/2^n$
  - Thus, if the customer double spends a coin, then the bank finds out the identity of the customer with probability $1 - 1/2^n$
  - A merchant can double spends a coin without being detected by the bank only if it can find a collision of the hash function
- The scheme does not prevent double spending but detects it and identifies the culprit with high probability

References

- The electronic cash scheme presented in this lecture is based on the work by David Chaum http://www.chaum.com/
- D. Chaum, A. Fiat, and M. Naor.
  Untraceable Electronic Cash, in
  Proc. CRYPTO 1988. http://citeseer.ist.psu.edu/421212.html
- S. Goldwasser and M. Bellare. *Lecture Notes on Cryptography* [Section 12.5]
  http://www-cse.ucsd.edu/users/mihir/papers/gb.html