EECS 388: Embedded Systems

11. Security (Part 2)

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Agenda

- Security attributes
- Threat model
- Software security
- **Information flow**
- **Encryption**
- **Digital signature and hashing**
- **SSL/TLS**

Information Flow

- Many security properties concern the FLOW of information between different principals in a system.
  - Confidentiality: preventing secret → attacker
  - Integrity: preventing attacker → system
- Information flow security is the study of how such flows affect the security and privacy properties of a system.

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Example 1: Illegal Information Flow?

```
int patient_id; // initialized to the
                // patient's unique identifier
void take_reading() {
   float reading = read_from_sensor();

   display(reading);

   send(network_socket, hospital_server,
        reading, patient_id);

   return;
}
```

Example 2: Illegal Information Flow?

```
int patient_id; // initialized to the
                // patient’s unique identifier
long cipher_text;

struct secret_key_s {
  long key_part1; long key_part2;
}; // struct type storing 128-bit AES key

struct secret_key_s secret_key; // shared key

void take_reading() {
  float reading = read_from_sensor();

  display(reading);

  enc_AES(&secret_key, reading, &cipher_text);

  send_enc(network_socket, hospital_server,
           cipher_text, patient_id);

  return;
}
```

Example 3: Illegal Information Flow?

```
int patient_id; // initialized to the
                // patient's unique identifier
int patient_pwd; // stored patient password

float stored_readings[100];

void show_readings() {
  int input_pwd = read_input(); // prompt user for
                                // password and read it
  if (input_pwd == patient_pwd) // check password
    display(&stored_readings);
  else
    display_error_mesg();

  return;
}
```

The fact that you failed to login
Leak some information about
Your password

Limiting Password Attempts

- To limit information leakage, most today's devices disable them after a few failed attempts.

Invasive Attack

```
int patient_id; // initialized to the
                // p
int patient_pwd;

float stored_readings[100];

void show_readings() {
  int input_pwd = read_input(); // prompt user for
                                // password and read it
  if (input_pwd == patient_pwd) // check password
    display(&stored_readings);
  else
    display_error_mesg();

  return;
}
```

What if the attacker is capable of directly reading from the memory?

Secure Storage and Hashing

```
int patient_id; // initialized to the
                // patient's unique identifier
int patient_pwd_hash = read_from_secure_storage(…)

float stored_readings[100];

void show_readings() {
  int input_pwd = read_input(); // prompt user for
                                // password and read it
  if (hash(input_pwd) == patient_pwd_hash) password
    display(&stored_readings);
  else
    display_error_mesg();

  return;
}
```

Invasive Attack

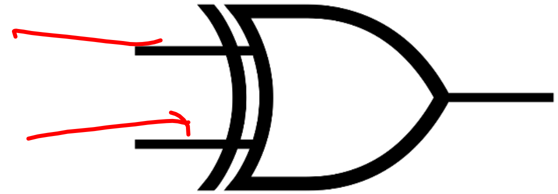
```c
int patient_id; // initialized to the
                // patient's unique identifier
long cipher_text;

struct secret_key_s {
  long key_part1; long key_part2;
}; // struct type storing 128-bit AES key

struct secret_key_s secret_key; // shared key

void take_reading() {
  float reading = read_from_sensor();

  display(reading);

  enc_AES(&secret_key, reading, &cipher_text);

  send_enc(network_socket, hospital_server,
           cipher_text, patient_id);

  return;
}
```

What if the attacker is capable of directly reading from the memory?

Basic Cryptography

- Symmetric (shared key) crypto
  - XOR encryption (one-time pad)
  - DES (56 bit key)
  - AES (up to 256bit key)
- Asymmetric (public-key) crypto
  - RSA
- Digital signature and secure hashing
  - SHA-256

XOR



NPUT		OUTPUT
A	B	A XOR B
0	0	0
0	1	1
1	0	1
1	1	0

XOR Encryption

Assume M (a message) and K (a key) are n-bit words. Let the cipher text be

$$C = M \oplus K.$$

To decode C,

$$C \oplus K = (M \oplus K) \oplus K = M \oplus (K \oplus K) = M \oplus 0 = M.$$

This uses the facts that exclusive OR ($\oplus$) is associative and commutative, that $B \oplus B = 0$ for any B, and that $B \oplus 0 = B$ for any B.

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XOR Encryption

Assume M (a message) and K (a key) are n-bit words. Let the cipher text be

$$C = M \oplus K.$$

Note that without knowing K, C contains no information about M. This is because for any given M, we can generate any C by choosing the right K,

$$K = C \oplus M.$$

This is because

$$C = M \oplus K = M \oplus (C \oplus M) = C \oplus (M \oplus M) = C.$$

Slide source: Edward A. Lee and Prabal Dutta (UCB)

Example

- Encryption

```
        01010111 01101001 01101011 01101001 ← M: message (“Wiki”)
XOR     11110011 11110011 11110011 11110011 ← K: repeat key (11110011)
-------------------------------------------------
=       10100100 10011010 10011000 10011010 ← C: encrypted message
```

- Decryption

```
        10100100 10011010 10011000 10011010 ← C: encrypted message
XOR     11110011 11110011 11110011 11110011 ← K: repeat key
-------------------------------------------------
=       01010111 01101001 01101011 01101001 ← M: message (“Wiki”)
```

https://en.wikipedia.org/wiki/XOR_cipher

XOR Encryption

A key K should be used only once! Suppose

$$C_1 = M_1 \oplus K$$

and

$$C_2 = M_2 \oplus K.$$

Then

$$C_1 \oplus C_2 = M_1 \oplus M_2,$$

which reveals *some* information about M_1 and M_2. Specifically, if you determine one, you can determine the other.

How?

Slide source: Edward A. Lee and Prabal Dutta (UCB)

Example

- Recovering the key from M and C

```
        01010111 01101001 01101011 01101001 ← M: message (“Wiki”)
XOR     10100100 10011010 10011000 10011010 ← C: encrypted message
-----------------------------------------------
=       11110011 11110011 11110011 11110011 ← K: repeat key (11110011)
```

- Pros and Cons of XOR Encryption
  – Inexpensive
  – Insecure when key is used repeatedly and/or part of the message is known

Symmetric (Shared Key) Cryptography

- Block cipher uses more elaborate algorithms so that key size and message size don't need to be the same.
- Data Encryption Standard (DES) – mid 1970s.
- Advanced Encryption Standard (AES) – 2001 Based on a cryptographic scheme called Rijndael proposed by Joan Daemen and Vincent Rijmen, two researchers from Belgium. AES uses a message block length of 128 bits and three different key lengths of 128, 192, and 256 bits.

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Asymmetric (Public Key) Cryptography

- Each participant has two keys, a public and a private one.
- A message is encrypted with the public key.
- The message can only be decrypted with the private key.
- Public and private keys match via clever algorithms.
- Relies on a *one-way function,* easy to compute, hard to reverse without knowing a (private) key.

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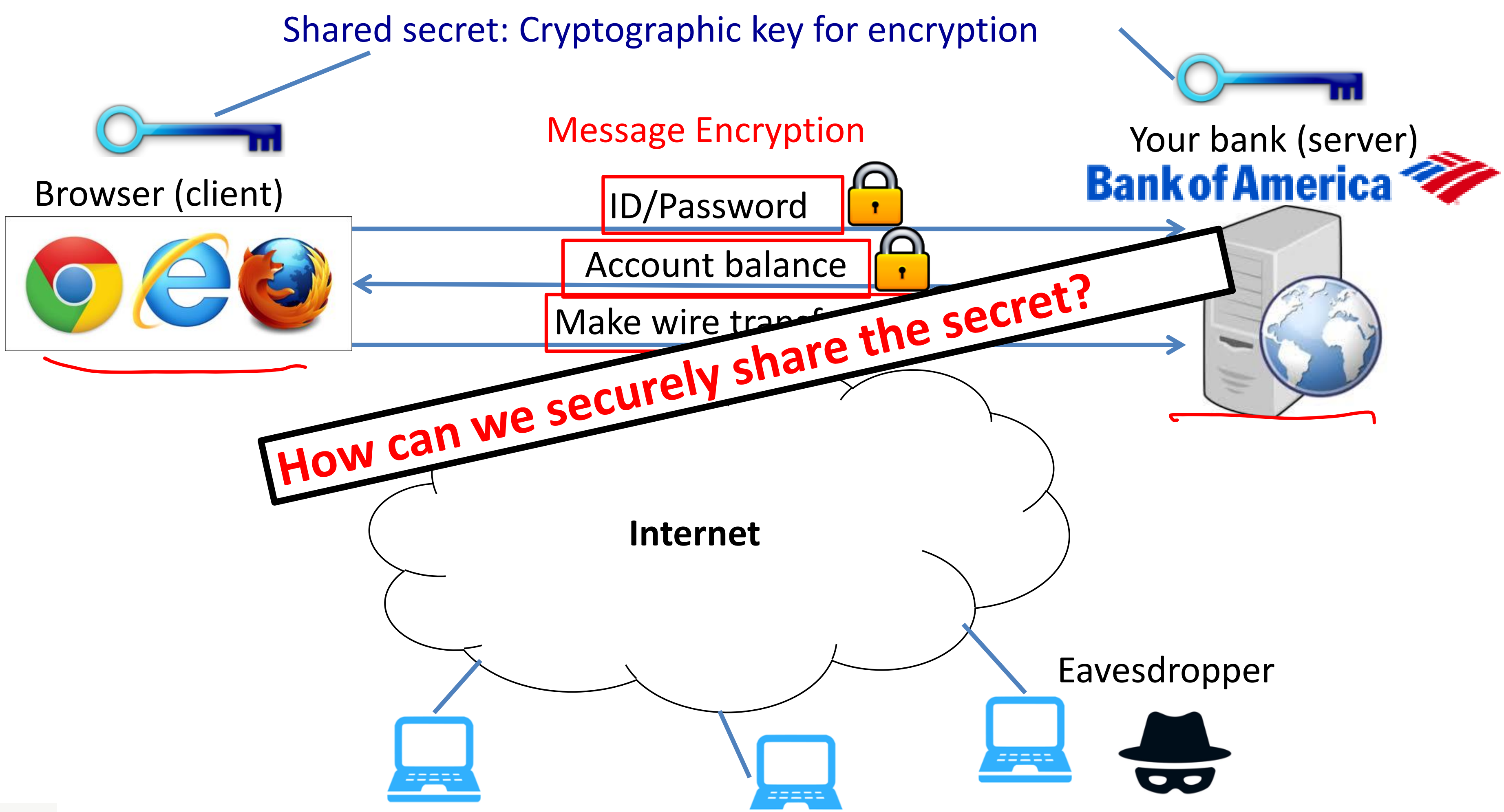
SSL/TLS

- Secure Socket Layer/Transport Layer Security
  - Widely used for web servers on the Internet
  - Provides:
    - Authentication
    - Confidentiality and integrity of communication

HTTPS = HTTP over SSL/TLS

Intro to SSL/TLS Based on Certificates



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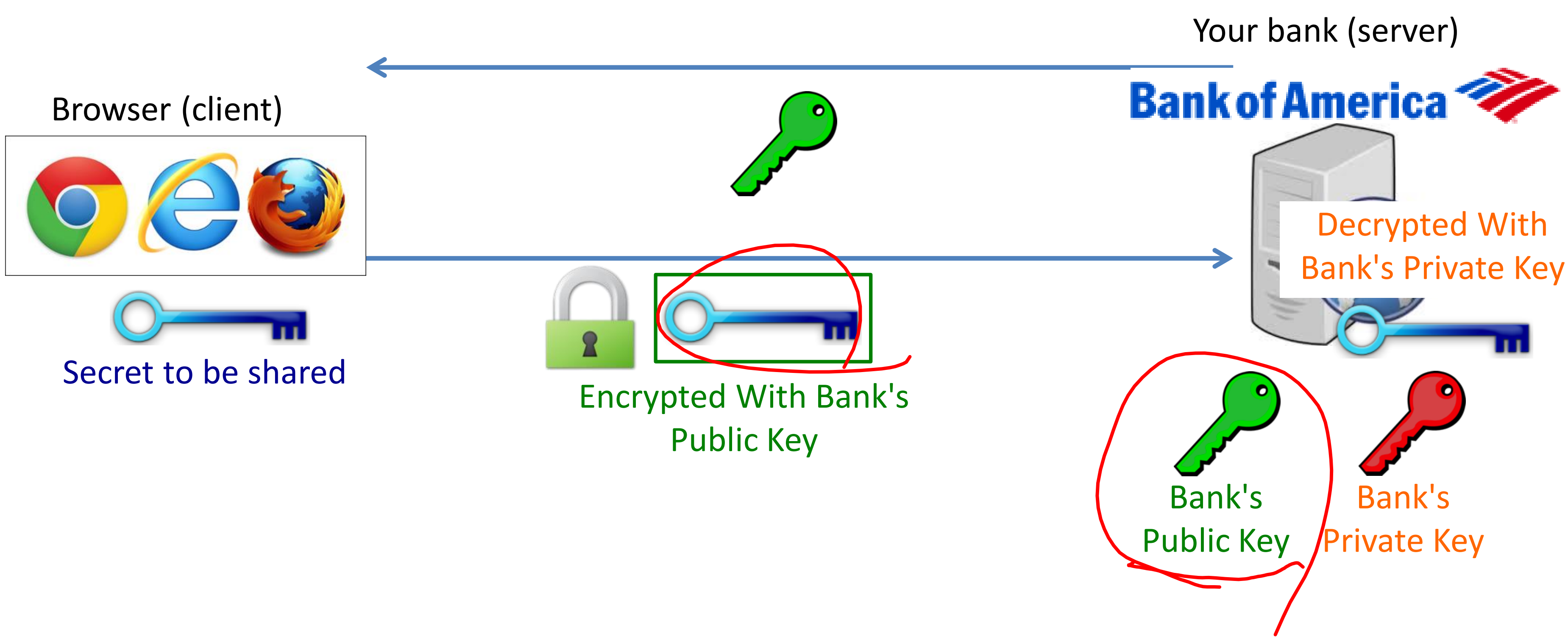
Intro to SSL/TLS Based on Certificates

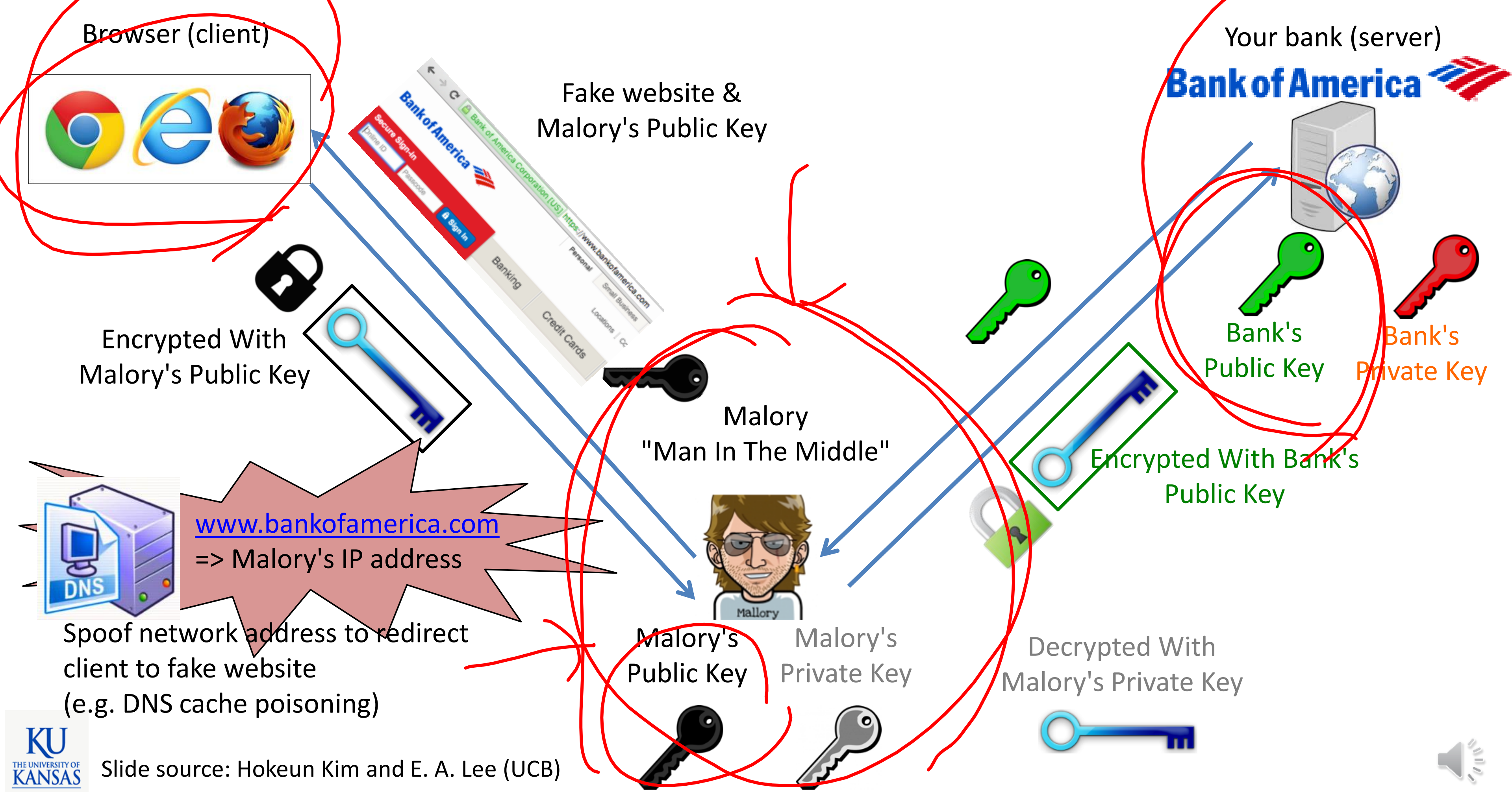
- Public key cryptography (e.g., RSA)



Slide source: Hokeun Kim and E. A. Lee (UCB)

Intro to SSL/TLS Based on Certificates

- However, even with public key cryptography…



Signing a Message

- Each participant has two keys, a public and a private one.
- A message is encrypted with the *private* key and both the message and its encryption are sent.
- The encrypted part can be decrypted with the *public* key. If it matches the plaintext message, the signature is valid.

Intro to SSL/TLS Based on Certificates

A (Digital) Certificate (Proof of Public Key's Authenticity)

- Name of certificate authority (CA)

  Symantec. digicert

- **www.bankofamerica.com**

  Bank of America

- Bank's **public key**

```
00:d6:  e:3c:c3:b7:b0:0e:c2:a3:0b:a8:7e:d6:
72:7  .e4:29:d0:2b:9b:30:ec:cc:d2:05:c1:0e:17:
41:e0:e3:58:42:98:95:73:06:13:8a:41:99:fb:69:
79:70:95:3e:77:69:c0:70:31:01:6f:fa:22:02:8e:
```

- Additional Information: validity period, etc.

Signed (encrypted)* with issuer (CA)'s Private key

- Digital Signature

```
7c:29:18:b4:57:8e:f5:bf:ec:bc:14:ea:ac:b9:3e:ad:13:dc:
3a:77:e7:7a:ab:3b:23:46:46:4a:2d:ee:7a:d0:
43:d6:17:d1:c6:86:ff:a0:b5:33:c4:de:ec:d8:
a6:cb:0f:02:a8:22:c7:fb:98:b1:75:61:b1:9d:
```

Can only be decrypted (verified) with issuer (CA)'s matching public key!

Actually the hash of data is encrypted (signed), and the result of decryption is also hash

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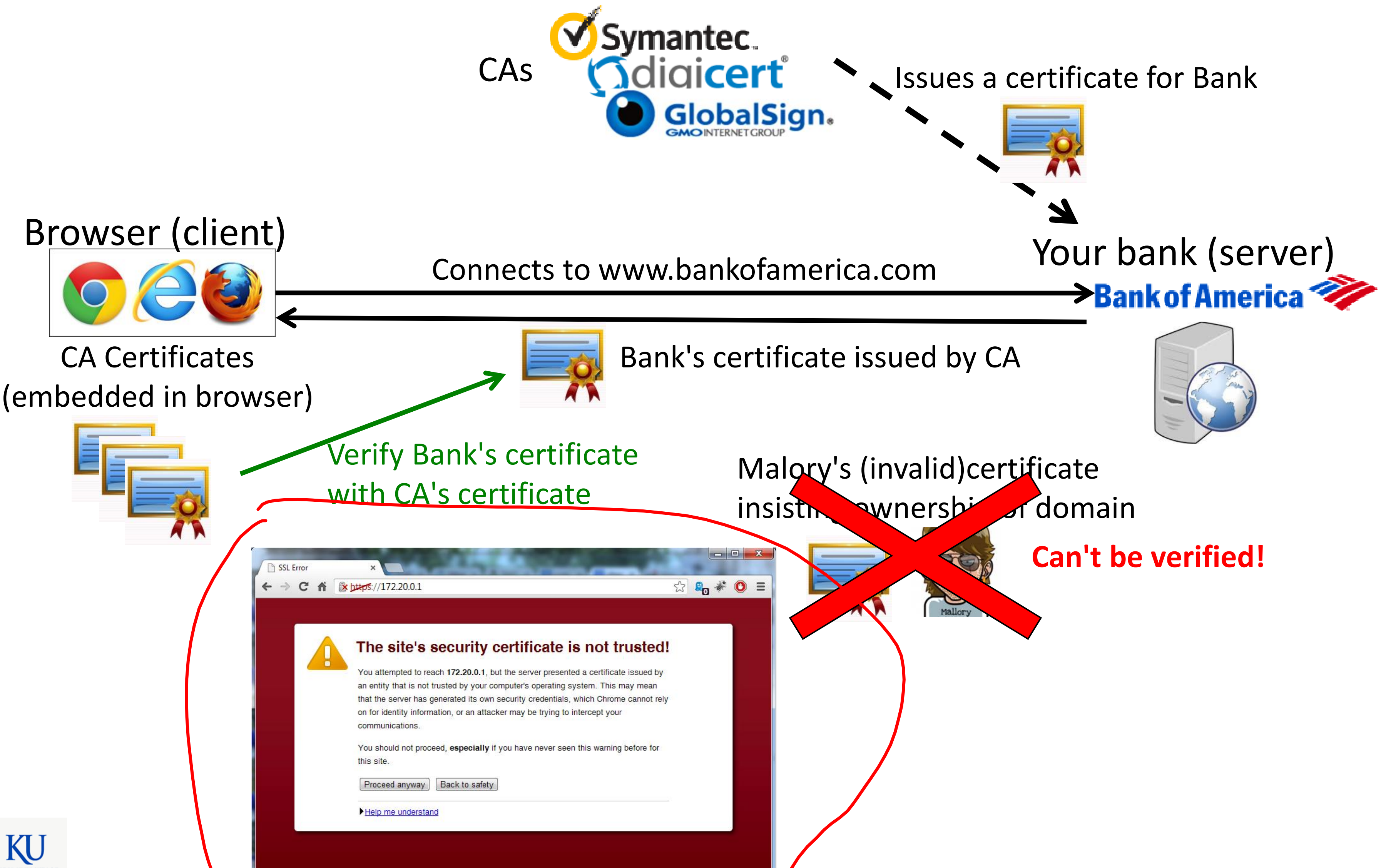
Intro to SSL/TLS Based on Certificates



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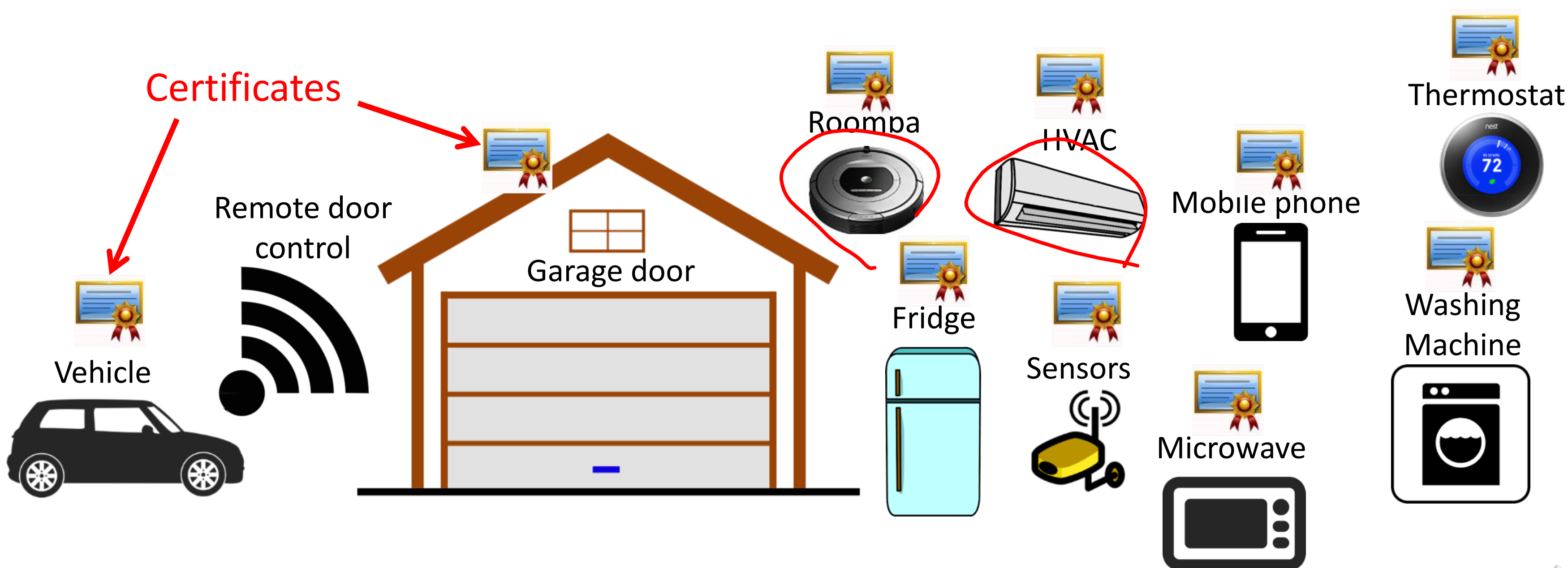
Issues with Using SSL/TLS for IoT

- Overhead for **resource-constrained devices**
  - Energy/computation overhead for public key crypto, communication bandwidth, memory, etc.
- Limited support **one-to-many communication**
  - Connections are 1-to-1 (server/client model)



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Issues with Using SSL/TLS for IoT

- Management overhead of certificates
  - If you use commercial certificate authorities (CAs)

GlobalSign GMO INTERNET GROUP

DomainSSL	1 Year	2 Years	3 Years	
Add-on Options:	only $249	only $448	only $613	Buy Now

digicert

3 Years	$139 per year	(Best Value - You Save $108)	BUY OR RENEW
2 Years	$157 per year	(You Save $36)	BUY OR RENEW
1 Year	$175		BUY OR RENEW

Quotes from www.digicert.com

- Company Validation
  … First, we will verify that the company requesting a certificate is in good standing …
- Domain Validation
  … can include emails or phone calls to the contact listed in a domain's whois record …

  - Alternative: free & automated CA   Let's Encrypt
    - Overhead for managing domains to get certificates

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Summary

- Security used to be an after thought (if any)
- In networked embedded systems (a.k.a. IoT) security is a first-class concern
- Embedded systems security are even harder than desktop/server security because of:
  - Diversity (no standard os, hardware, runtime, …)
  - Resource constraints (performance, energy, memory space, …)
  - The prevalent use of C (insecure language)
- Read chapter 17, take security courses…

Acknowledgements

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