Encryption

The Problem

- Using HTTP, anyone with access to your packets can see everything you are doing online
  - This includes your passwords!
- Who has access to my packets?
  - Your ISP at home
  - UBIT on campus
  - Tier 1 Networks

  - .. and **everyone within wifi range of your device!**

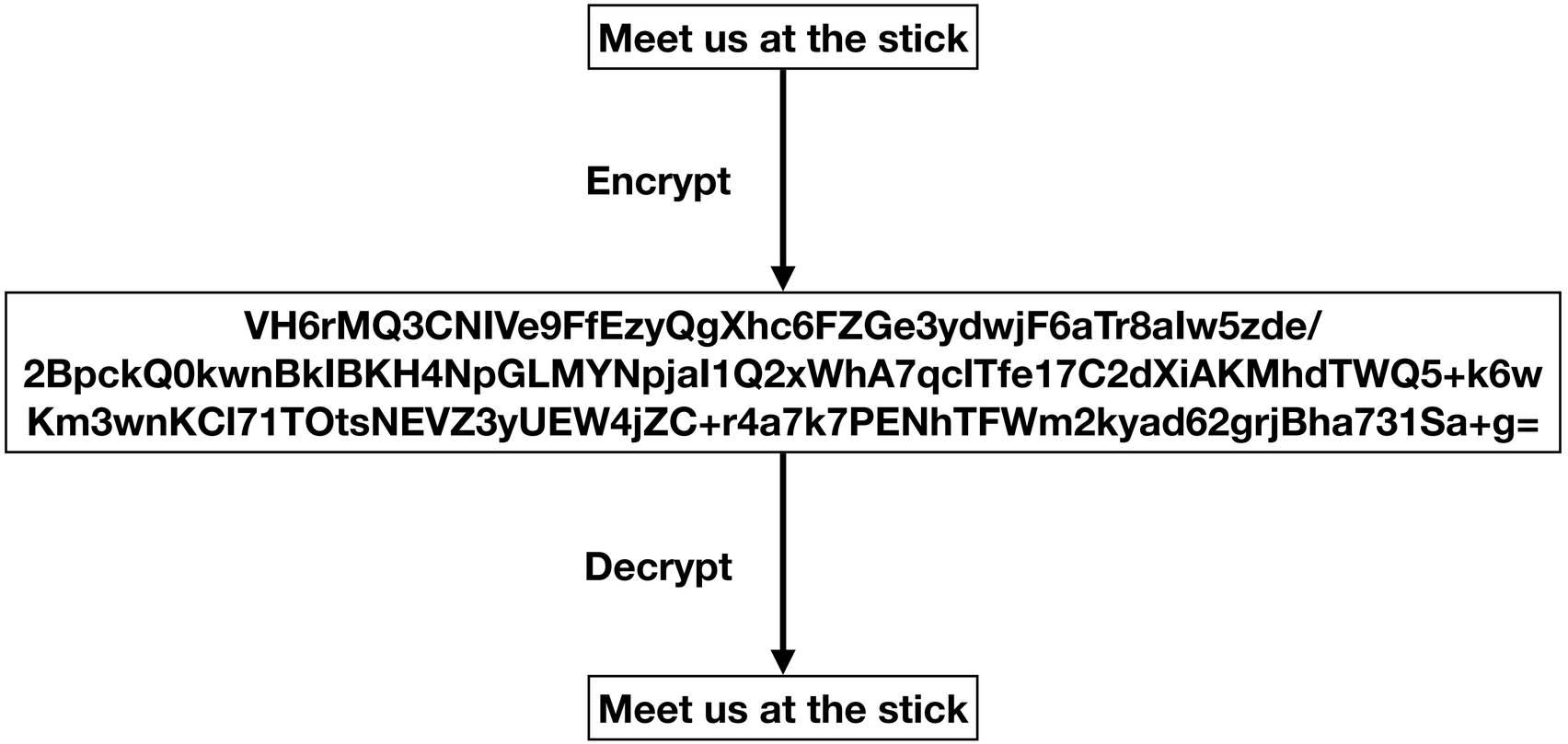
The Solution

- We'll just add an S to our protocol and call it HTTPS
  - HTTP over TLS

Encryption

- Hide communication from attackers/eavesdroppers
- Want to send a **plaintext** message
  - Could be HTML, JSON, JavaScript, text, an image, etc
  - Plaintext is a cryptographic term to mean unencrypted
  - We encrypt at the byte level
- Encrypting the **plaintext** outputs a random looking **cyphertext**
- No one should be able to read this cypher text except the intended recipient
- Only the intended recipient can decrypt the **cyphertext** and read the **plaintext** message

Encryption


Meet us at the stick
Encrypt
VH6rMQ3CNIVe9FfEzyQgXhc6FZGe3ydwjF6aTr8aIw5zde/
2BpckQ0kwnBkIBKH4NpGLMYNpjaI1Q2xWhA7qclTfe17C2dXiAKMhdTWQ5+k6w
Km3wnKCl71TOtsNEVZ3yUEW4jZC+r4a7k7PENhTFWm2kyad62grjBha731Sa+g=
Decrypt
Meet us at the stick

Public Key Encryption

- How do we ensure that only the intended recipient can decrypt the message?
  - Public Key Encryption
- Generate a public and private encryption key
  - Private key is kept private
  - Public key is shared with anyone/everyone
- A message encrypted with the public key can only be decrypted by the corresponding private key
- If I want to send a message to someone, I can encrypt the message with their public key

Public Key Encryption

- The public and private key are inherently related

- An attacker must not be able to determine the private key given the public key [In any reasonable amount of time]
- An attacker must not be able to decrypt cyphertext without the private key [In any reasonable amount of time]

- Any public key encryption algorithm must have these property [And more]
  - Math and theory will help us

Public Key Encryption - RSA

- RSA - Rivest-Shamir-Adleman
  - A public key crypto system with the desired properties [we hope]

- Provides algorithms to:
  - Generate a public/private key pair
  - Encrypt with the public key
  - Decrypt with the private key

Public Key Encryption - RSA

Key Generation

- Choose two [large] prime numbers p and q
- n = p*q
- λ(n) = lcm(p-1, q-1)
- Choose e < λ(n) and gcd(e, λ(n)) = 1
- d = e^{-1} mod λ(n)

- Share e and n as the public key
- Keep d as the private key
- Discard p, q, and λ(n)

Public Key Encryption - RSA

Encryption

- To send a message m
- Compute c = m^e mod(n)
- Send c

Decryption

- Receive c
- Compute m = c^d mod(n)
- Read m

Public Key Encryption - RSA

- RSA key generation gives us: m = m^(e*d) mod(n)
- This means that we can also encrypt with the private key and decrypt with the public key
  - We call this a signature
  - Everyone can decrypt the message so there is no privacy
  - However, there is a guarantee that the author is legitimate (You know I'm the one who sent this message)
  - Useful to sign authentication tokens so the server know that it authorized this user

Public Key Encryption - RSA

- What about a brute force attack?
  - Attacker has the public key
  - Keep encrypting "guesses" of the plaintext until the cryptotext matches

Public Key Encryption - RSA

- What about a brute force attack?
- Solution: Use a padding algorithm
  - Add random bits to the end of each message
  - Attacker must guess these random bits
  - Adds security!
  - Unlike salting, this padding can be kept secret and adds entropy
    - We'll discuss salting when we hash user passwords
  - Makes encryption of even short messages secure

Public Key Encryption - RSA

Key Generation

- Choose two [large] prime numbers p and q
- n = p*q
- λ(n) = lcm(p-1, q-1)
- Choose e < λ(n) and gcd(e, λ(n)) = 1
- d = e^{-1} mod λ(n)

- Given p, q, and e an attacker can easily compute d (private key)
- Everyone already has e and n (the public key)
- So just factor n to get p and q, then compute the private key

Public Key Encryption - RSA

Factoring is hard [We hope]

- There is no publicly know algorithm that can efficiently factor a number
- Worst case is factoring the multiplication of two large primes
  - Exactly what RSA relies on for security
- It has not been proven that factoring is a "hard" problem
  - Quantum computers can factor efficiently
- We call the factoring problem a cryptographic primitive

Public Key Encryption - RSA

Encryption

- To send a message m
- Compute c = m^e mod(n)
- Send c

- Everyone knows e and n (The public key)
- An attacker can read c if they are within wifi range
- Just have to compute the discrete log_e of c mod n

Public Key Encryption - RSA

Computing a Discrete Log is hard [We hope]

- There is no publicly know algorithm that can efficiently compute discrete logarithms
- This problem is another cryptographic primitive

Public Key Encryption

Demo

HTTPS

Man-in-the-middle attack

- The first step in an HTTPS connection:
  - Client requests the server's public key
- An attacker controlling a router in one of the networks handling your packets can intercept this request and replace it with their own public key
- Attacker then intercepts all subsequent requests, decrypts them and responds with their responses
- It looks like you're talking to the server..
- Certificate Authorities (CA) can fix that

Certificate Authority (CA)

- A CA is a trusted source with a known public key
  - Public key is pre-installed in your browser (Called a root CA)
  - Assume no man-in-the-middle attack during your browser download and installation
- The CA issues certificates for domains and subdomains
  - You verify that you control the domain
  - Send them your public key
  - They send you a certificate

Certificate Authority (CA)

- Certificate includes
  - Your public key
  - Domain name and CA name
  - A **cryptographic signature** of a **hash** of the **certificate** body
  - The signature uses the CA's private key so you can verify it with their pre-installed public key that this was in fact issued by the CA
    - Man-in-the-middle cannot fake this without the CA's private key!

Certificate Authority (CA)

- Key chain
  - Not all CA public keys are pre-installed in your browser
  - A CA can have their public key certified by a root CA
  - A domain must provide a key chain that leads to a root CA
- Example key chain
  - Let's Encrypt certificate is signed by DST Root CA
  - Let's Encrypt will sign your certificate
  - Your key chain contains your public key signed by Let's Encrypt and Let's Encrypt's certificate signed by DST
  - Your browser starts with it's installed DST cert to verify the chain
- If a cert cannot be verified by a root CA it is called Self-signed and should not be trusted

Certificates

Example