One-Time Pad: Encryption

e=000	h=001	i=010	k=011	l=100	r=101	s=110	t=111

Encryption: Plaintext ⊕ Key = Ciphertext

	h	e	i	l	h	i	t	l	e	r
Plaintext:	001	000	010	100	001	010	111	100	000	101
Key:	111	101	110	101	111	100	000	101	110	000
Ciphertext:	110	101	100	001	110	110	111	001	110	101
	s	r	l	h	s	s	t	h	s	r

One-Time Pad: Decryption

e=000	h=001	i=010	k=011	l=100	r=101	s=110	t=111

Decryption: Ciphertext ⊕ Key = Plaintext

	s	r	l	h	s	s	t	h	s	r
Ciphertext:	110	101	100	001	110	110	111	001	110	101
Key:	111	101	110	101	111	100	000	101	110	000
Plaintext:	001	000	010	100	001	010	111	100	000	101
	h	e	i	l	h	i	t	l	e	r

One-Time Pad

Double agent claims sender used following "**key**"

	s	r	l	h	s	s	t	h	s	r
Ciphertext:	110	101	100	001	110	110	111	001	110	101
"**key**":	101	111	000	101	111	100	000	101	110	000
"Plaintext":	011	010	100	100	001	010	111	100	000	101
	k	i	l	l	h	i	t	l	e	r

e=000 h=001 i=010 k=011 l=100 r=101 s=110 t=111

One-Time Pad

Or sender is captured and claims the key is…

	s	r	l	h	s	s	t	h	s	r
Ciphertext:	110	101	100	001	110	110	111	001	110	101
"key":	111	101	000	011	101	110	001	011	101	101
"Plaintext":	001	000	100	010	011	000	110	010	011	000
	h	e	l	i	k	e	s	i	k	e

e=000 h=001 i=010 k=011 l=100 r=101 s=110 t=111

One-Time Pad Summary

- **Provably** secure…
  - Ciphertext provides **no** info about plaintext
  - All plaintexts are equally likely
- …but, only when be used correctly
  - Pad must be random, used only once
  - Pad is known only to sender and receiver
- Note: pad (key) is same size as message
- So, why not distribute msg instead of pad?

Real-World One-Time Pad

- Project VENONA
  - Encrypted spy messages from U.S. to Moscow in 30's, 40's, and 50's
  - Nuclear espionage, etc.
  - Thousands of messages
- Spy carried one-time pad into U.S.
- Spy used pad to encrypt secret messages
- Repeats within the "one-time" pads made cryptanalysis possible

VENONA Decrypt (1944)

[C% Ruth] learned that her husband [v] was called up by the army but he was not sent to the front. He is a mechanical engineer and is now working at the ENORMOUS [ENORMOZ] [vi] plant in SANTA FE, New Mexico. [45 groups unrecoverable]

detain VOLOK [vii] who is working in a plant on ENORMOUS. He is a FELLOWCOUNTRYMAN [ZEMLYaK] [viii]. Yesterday he learned that they had dismissed him from his work. His active work in progressive organizations in the past was cause of his dismissal. In the FELLOWCOUNTRYMAN line LIBERAL is in touch with CHESTER [ix]. They meet once a month for the payment of dues. CHESTER is interested in whether we are satisfied with the collaboration and whether there are not any misunderstandings. He does not inquire about specific items of work [KONKRETNAYa RABOTA]. In as much as CHESTER knows about the role of LIBERAL's group we beg consent to ask C. through LIBERAL about leads from among people who are working on ENOURMOUS and in other technical fields.

- "Ruth" == Ruth Greenglass
- "Liberal" == Julius Rosenberg
- "Enormous" == the atomic bomb

Stream ciphers

Attacks on OTP and stream ciphers

Review

- **OTP**:
  - $E(k,m) = m \oplus k$
  - $D(k,c) = c \oplus k$
- Making OTP practical using a PRG:
  - $G: K \longrightarrow \{0,1\}^n$
- **Stream cipher**:
  - $E(k,m) = m \oplus G(k)$
  - $D(k,c) = c \oplus G(k)$
- Security: PRG must be unpredictable

Attack 1: **two time** pad is insecure !!

- Never use stream cipher key more than once !!
  - $C_1 \leftarrow m_1 \oplus PRG(k)$
  - $C_2 \leftarrow m_2 \oplus PRG(k)$

- Eavesdropper does:
  - $C_1 \oplus C_2 \rightarrow m_1 \oplus m_2$
  - Enough redundancy in English and ASCII encoding that:
  - $m_1 \oplus m_2 \rightarrow m_1 , m_2$

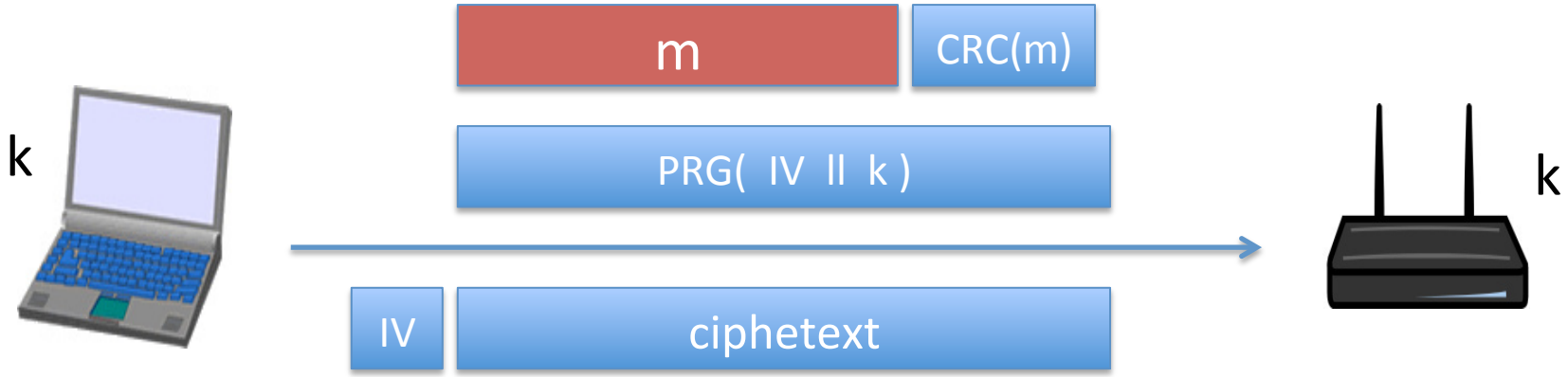
Crib Dragging

- Works if the plaintext is in natural language

1. Guess a part of plaintext and position in m1
2. Recover the other plaintext in m2
3. expand the recovered plaintext in m2
4. Recover a part of m1 using expanded part of m2

Real world examples

802.11b WEP:

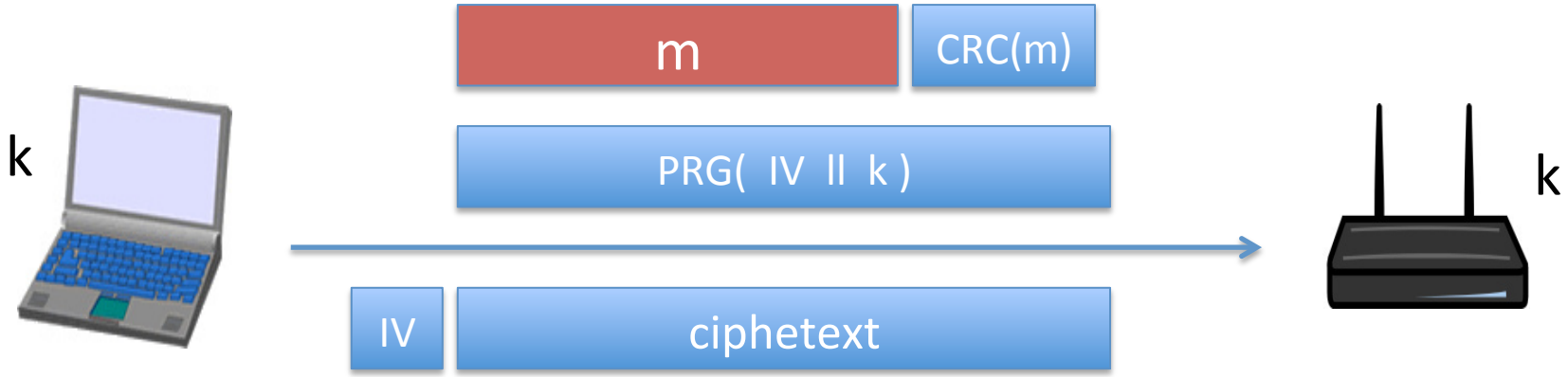


Length of IV: 24 bits

- Repeated IV after $2^{24} \approx 16M$ frames
- On some 802.11 cards: IV resets to 0 after power cycle

Avoid related keys

802.11b WEP:

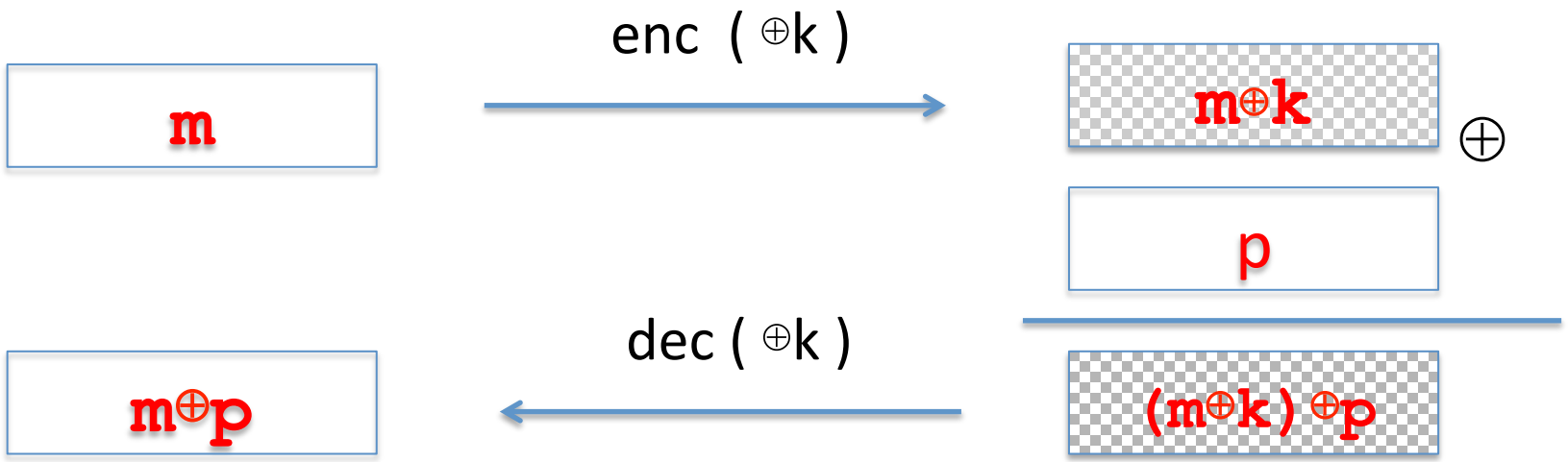


key for frame #1: (1 ll k)

key for frame #2: (2 ll k)

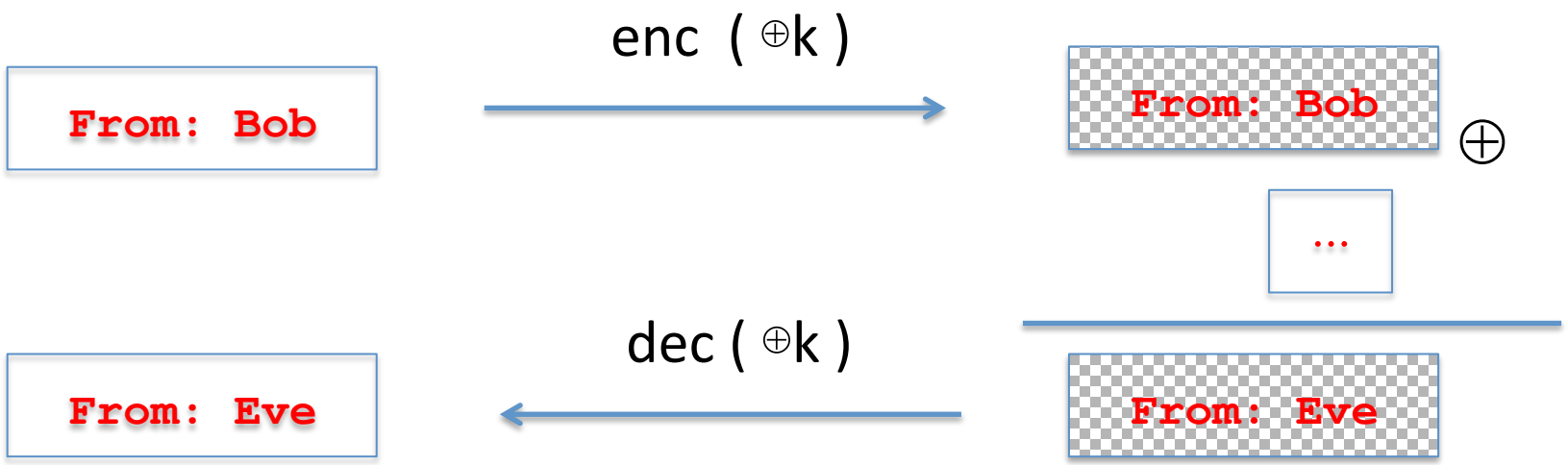
⋮

Attack 2: no integrity (OTP is malleable)



Modifications to ciphertext are undetected and have **predictable** impact on plaintext

Attack 2: no integrity (OTP is malleable)



Modifications to ciphertext are undetected and have predictable impact on plaintext

Codebook Cipher

- Literally, a book filled with “codewords”
- Zimmerman Telegram encrypted via codebook

Februar	13605
fest	13732
finanzielle	13850
folgender	13918
Frieden	17142
Friedenschluss	17149
:	:

- Modern block ciphers are codebooks!
- More about this later…

Claude Shannon

- The founder of Information Theory
- 1949 paper: *Comm. Thy. of Secrecy Systems*
- Fundamental concepts
  - **Confusion** — obscure relationship between plaintext and ciphertext
  - **Diffusion** — spread plaintext statistics through the ciphertext
- Proved one-time pad is secure
- One-time pad is confusion-only, while double transposition is diffusion-only

Taxonomy of Cryptography

- **Symmetric Key**
  - Same key for encryption and decryption
  - Two types: Stream ciphers, Block ciphers
- **Public Key** (or asymmetric crypto)
  - Two keys, one for encryption (public), and one for decryption (private)
  - And digital signatures — nothing comparable in symmetric key crypto
- **Hash algorithms**
  - Can be viewed as "one way" crypto

Taxonomy of Cryptanalysis

- From perspective of info available to Trudy
  - Ciphertext only attack
  - Known plaintext attack
  - Chosen plaintext attack
    - "Lunchtime attack"
  - chosen ciphertext attack
  - Related key attack
  - Forward search attack (public key crypto)
  - And others…