# Rainbow Crypt: Securing Communication through a Protected Visual Channel

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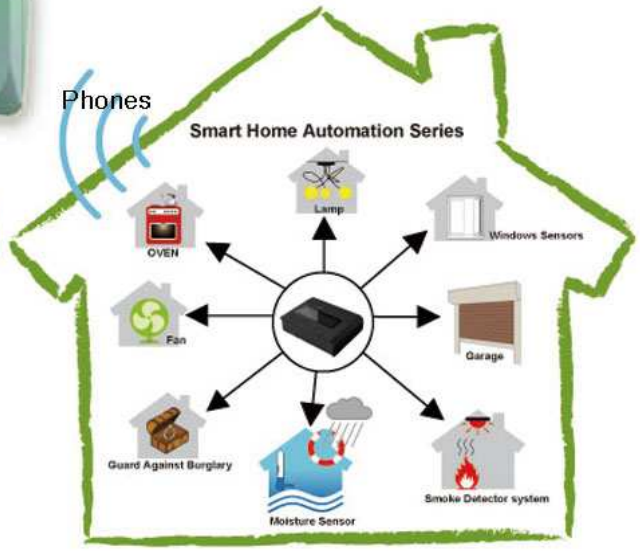
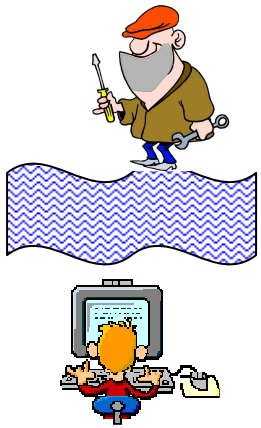
# Scenario


- Environment with "a lot" of wireless-enabled devices, sensor, gadgets


- Patient / hospital monitoring
- Home automation
- Access control
- ...
- "Ambient Intelligence"
- "Internet of Things"
- ...

# Problem




- Ensure Mutual Authentication of devices (**Secure Pairing**)
  - Device A should communicate with device B
  - (Possibly hostile) Device X must not be able to impersonate either device to the other

- **Very difficult**:
  - Wireless medium ⇒
    Messages may be **intercepted** and **replayed** easily
  - Hostile devices may be easily **concealed**

# Theory: Simple
# Practice: Very difficult

- Theory
  - Establish secret key between devices (somehow)
  - Plenty of protocols ensuring mutual authentication and secrecy
- Practice
  - VERY difficult to deploy these protocols
  - They rely on assumptions not met in this scenario
  - Their use is often difficult for the unexperienced user

# Example (basic idea)

- User identifies devices A and B "visually" (with his hands) and wants a secure pairing

- User must tell A that its partner is B
  - A must have a suitable input channel (e.g. a keyboard)
- How to identify B ?
  - B must have a suitable output channel (e.g. an LCD screen)
  - B must be certificated by a trusted authority, or

  - None of the above holds in practice

# Real-world example: Wi-Fi “Protected Setup” (I)

- Part of Wi-Fi specification
- Enables “easy and secure setup” between pairs of devices (**secure pairing**—sort of)
- Implemented in thousands of products

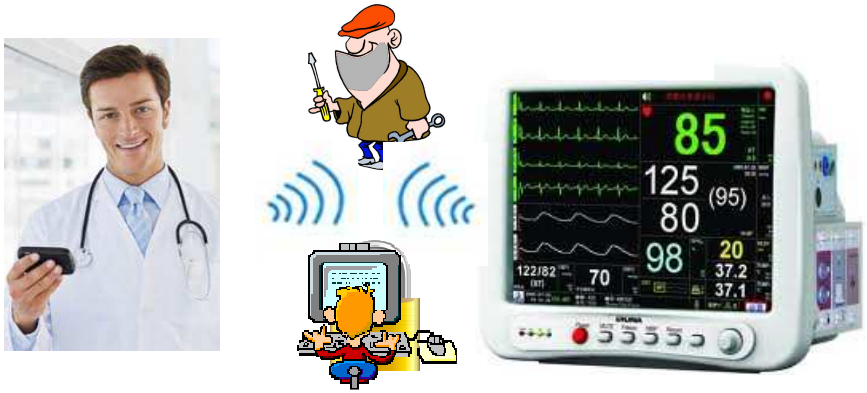

- **PIN-based**
  - The device must support the entering of a password
  - Inconvenient or unfeasible for many kinds of devices
- **…**

# Real-world example: Wi-Fi “Protected Setup” (II-a)

- **Push Button Configuration (PBC)**
  - The user pushes a (possibly virtual) button on the devices more or less at the same time
  - The devices establish a shared secret key


# Real-world example: Wi-Fi “Protected Setup” (II-b)

- The problem is, it does **not** ensure secure pairing !




- “Users should be aware that **during the two-minute setup** period which follows the push of the button, **unintended devices could join the network** if they are in range.”

*Wi-Fi Protected Setup FAQ @ Wi-Fi Alliance*

# Proposed solutions

- **Out-of-band channel**
  - An **additional** channel is assumed to exist
    - …and this channel is **secure** by definition
  - Shared secrets are established on this channel
    - Devices must have I/O capabilities for this channel and for the user
  - *Several examples: text-to-speech, displays and alike*

- **Novel Wi-Fi protocols**
  - Recent proposal by MIT researchers
    *USENIX Security Symposium 2011*

# A very simple solution

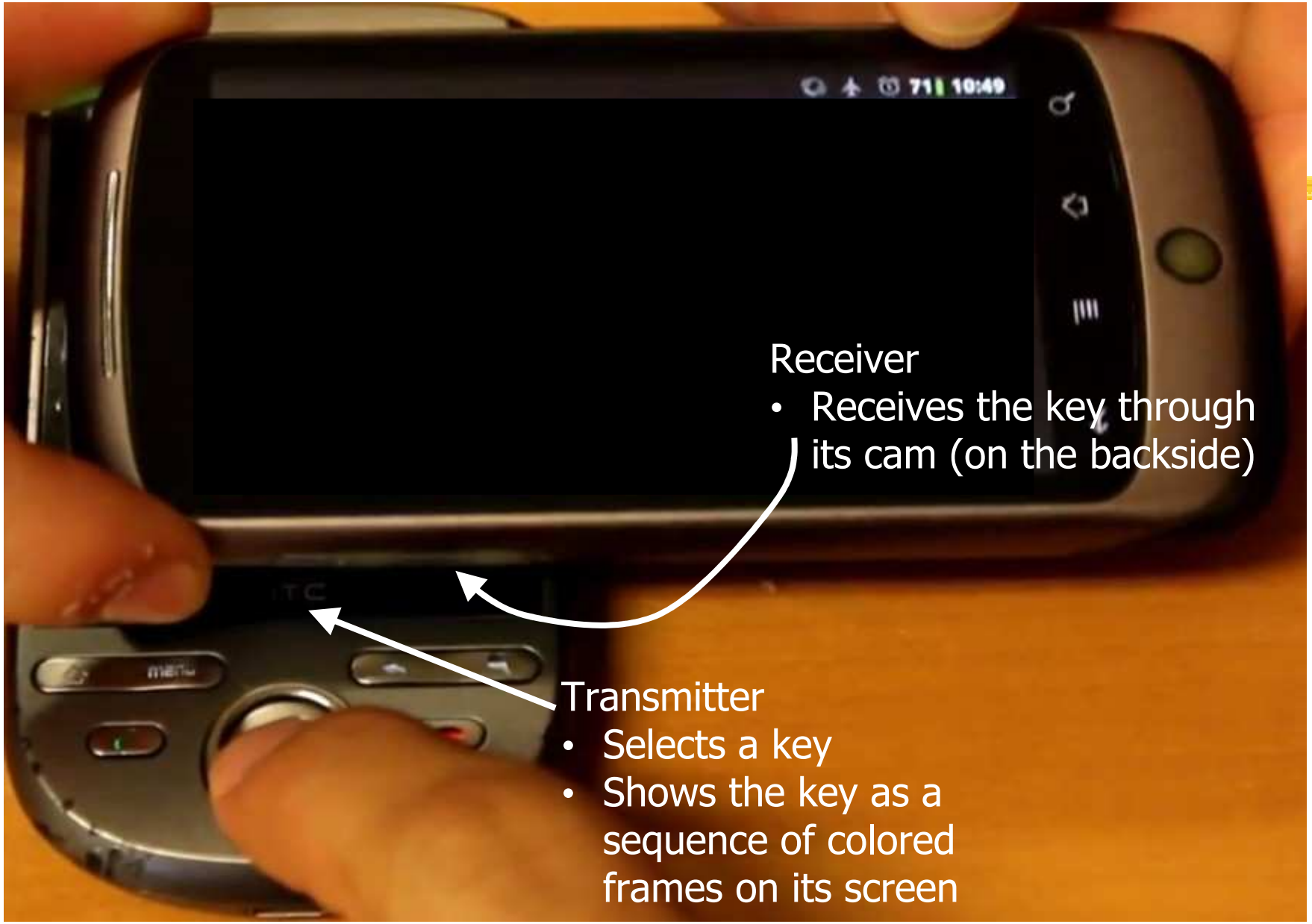
- **Physical contact** *(Stajano and Anderson 2000)*
  - User places devices A and B in physical contact (electrical)
  - While in contact, devices establish a shared secret
- **Systematic, Simple, Effective:**
  - User selects exactly the devices he needs (no concealed devices)
  - Attacker cannot intercept anything (no communication attacks)

- Did not succeed due to the **lack of common interfaces**

# Our work

- We demonstrate the Stajano&Anderson approach
  - May indeed be applied in practice
  - For a very specific, but very important, class of devices
- **Smartphones** (and potentially many other devices)
  - Small LCD color screen on one device
  - Low-end color camera on the other device

- We place the two devices **next to each other**
- A **few seconds** suffice to establish "reasonably long" keys (≈10 bps; 42 bits in 5 sec)
- Keys **cannot be intercepted**
- Quite more difficult than it seems. An empirical work


Receiver
• Receives the key through its cam (on the backside)
Transmitter
• Selects a key
• Shows the key as a sequence of colored frames on its screen

# Short demo app (video)

- Transmitter
  - Sends key K **and** text string encrypted in K
- Receiver
  - **Displays** on its screen what is being received (obviously it should not)

http://www.youtube.com/watch?v=FHPa_hx1RlM

# Practical problems: Focus distance

- Fact
  - Cameras of our interest require at least 50 cm from the subject
  - We use them instead at near-zero distance
- Key consequence
  - Every received frame is going to be a **single** blurred color
- Solution (fundamental constraint)
  - Each transmitted frame must be a uniform color image

# Practical problems: White balancing

- Fact
  - White balancing camera software attempts to average the image color to a neutral gray
- Key consequence
  - When the transmitted frame is a uniform color image, the received frame is a uniform but **different** color
  - Result hardly predictable: depends on settings and type of the device
- Solution
  - Disable white balancing software :-)

# Practical problems: Exposure

- Fact
  - Camera software modifies exposure interval of the sensor to obtain a standard luminosity
- Key consequence
  - The transmitted uniform color tonality may be received as an entirely **different** uniform color tonality
- Solution (...no, cannot be disabled in software...)
  - Quite a few experiments to figure out **how many different colors** can be detected reliably… and **which ones**

# Symbol alphabet

- As it turns out:
  - Only **4 colors** may be discerned (2 bits / frame)
  - It does not matter which ones, as long as they are "sufficiently different" from each other

- We used

| | | | |
|---|---|---|---|
| Red | 255 | 0 | 0 |
| Blue | 0 | 0 | 255 |
| Violet | 255 | 0 | 255 |
| Black | 0 | 0 | 0 |

  - Receiver: algorithm YUV $\Rightarrow$ RGB

# Transmission rate

- Fact:
  - Maximum frame sampling rate depends on the hw
  - Our cheapest platform supported 21 fps (42 bps)
- Early experiments
  - Transmission rate 10 fps (20 bps)
- Very bad results

# Practical Problem: Platform Limitations

- Fact
  - Android API allows applications to specify the desired frame sampling rate
  - But:
    - frame rate is **not uniform**
    - there may be **significant variance**
    - desired rate guaranteed only over “long periods”

# Example

Transmitted
(5 fps)

Received
(20 fps)
**IDEAL**

**REAL**

One
in excess

One
**in excess**

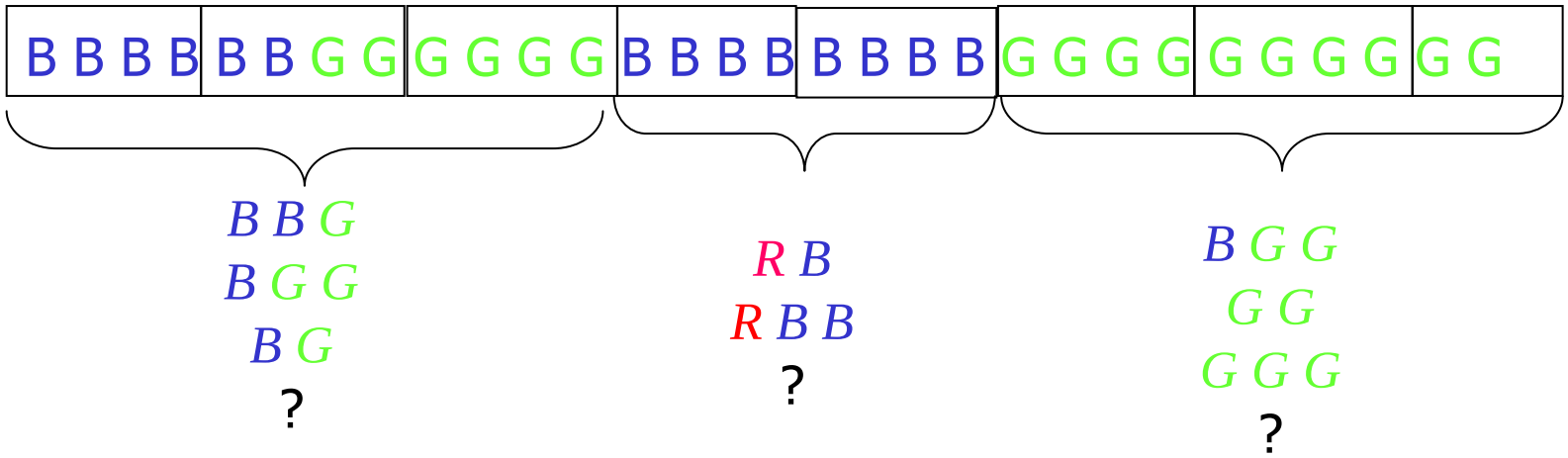
One
**missing**

Two
in excess

# Obvious consequence: Out of sync

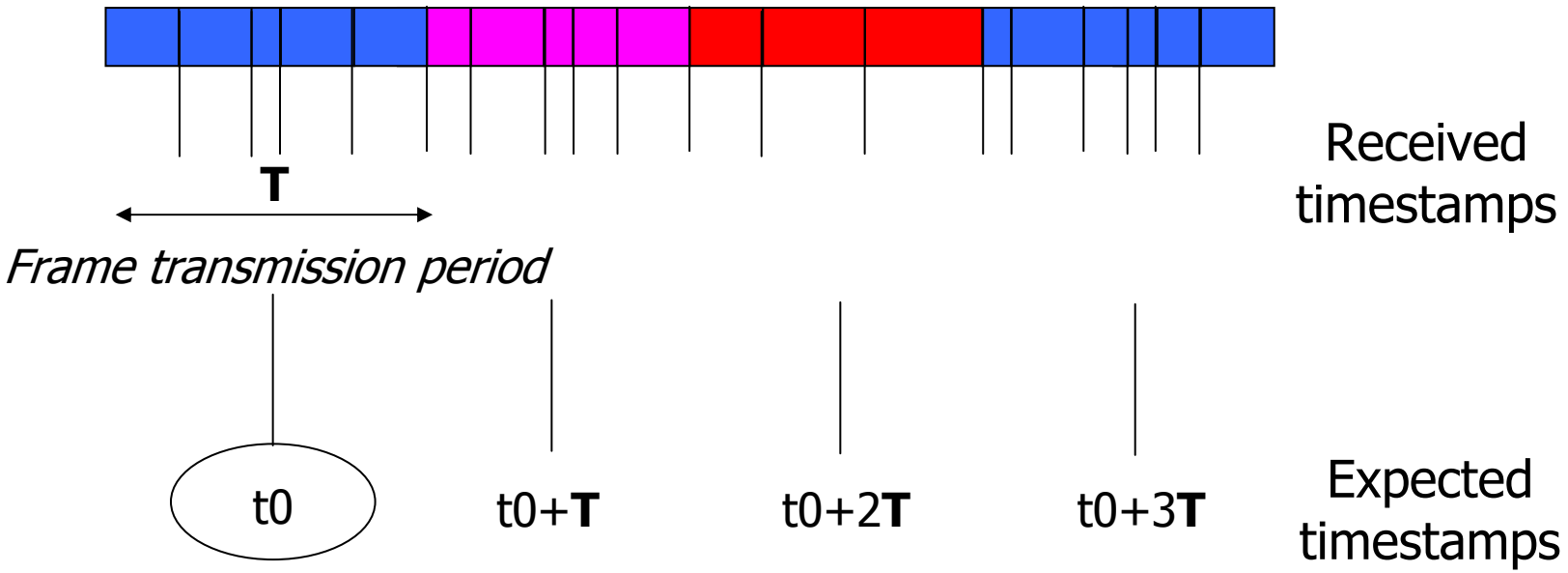
B B B B G G G G R R R R B B B B — Sequence of received frames

*B* *G* *R* *B* — Chosen symbol


# Our solution (I)

- Upon receiving a frame F ⇒ Associate F with timestamp t(F)




- Methods for
  - Choosing F at each **expectedTimestamp**
  - Based on sequence of < $F_i$ — **receivedTimestamp$_i$** >

# Our solution (II)

- The K-th symbol is selected as follows:
- **Nearest**
  - Frame with timestamp closer to t0+KT
- **Mean**
  - Associate each frame with closest expected timestamp
  - Average all frames in each group
- **Weighed Mean**
  - Like Mean,
    with weights depending on squared distance from t0+KT
- **Weighed Mean with Sync**
  - Like Weighed Mean,
    with initial RBRB sync sequence

# Solution (III)

- Quite a few exploratory experiments for choosing:
  - Transmission rate: 5 fps (**10 bit/s**)
  - Sampling rate: 20 fps

| Method | Average (%) | StdDev (%) |
|---|---|---|
| Nearest | 12.0 | 23.6 |
| Mean | 11.4 | 20.2 |
| wMean | 10.3 | 20.2 |
| wMean Sync | 0.3 | 1.0 |

# Concluding remarks

- Secure pairing for an important class of devices
  - Several (potential) interesting applications
  - Systematic, Simple, Effective—Stajano&Anderson
- Pairing channel 10 bps
- Severely limited, but suffices for initial key exchange (42-bits in ≈5 sec)
- Certainly many opportunities for improvement (transmission method quite naive)
- Hardware will certainly improve

# Thanks for your attention...

# Practical Problem: Exposure (again)

- Transmitted symbol is "too dark" ▪
- Receiver increases exposure:
  - Sampling interval much greater than 50 ms
  - May even be greater than 1 s (with black frames)

- Transmitter sends K symbols
- Receiver merges them all into one symbol

- Not quite predictable
- Not controllable in software / Cannot be disabled

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