An Efficient Protocol for the Security of UAS Collected Data and of UAS Control from GCS

Olivier Blazy[1], Pierre-François Bonnefoi[1], Emmanuel Conchon[1], Damien Sauveron[1,3]
Raja Naeem Akram[2], Konstantinos Markantonakis[2], Keith Mayes[2], **Serge Chaumette**[3]

1: XLIM (UMR CNRS 7252), MATHIS, Université de Limoges

2: Information Security Group Smart Card Centre, Royal Holloway, University of London

3: LaBRI (UMR CNRS 5800), Université de Bordeaux

Outline

- Introduction
- Our Contributions
- Requirements
- Cryptographic techniques used
- Protocol
  - Pre-protocol Setup
  - UAV processes
  - Protocol
- Formal Proof & Analysis of Efficiency
- Test-bed
- Conclusions and Future work

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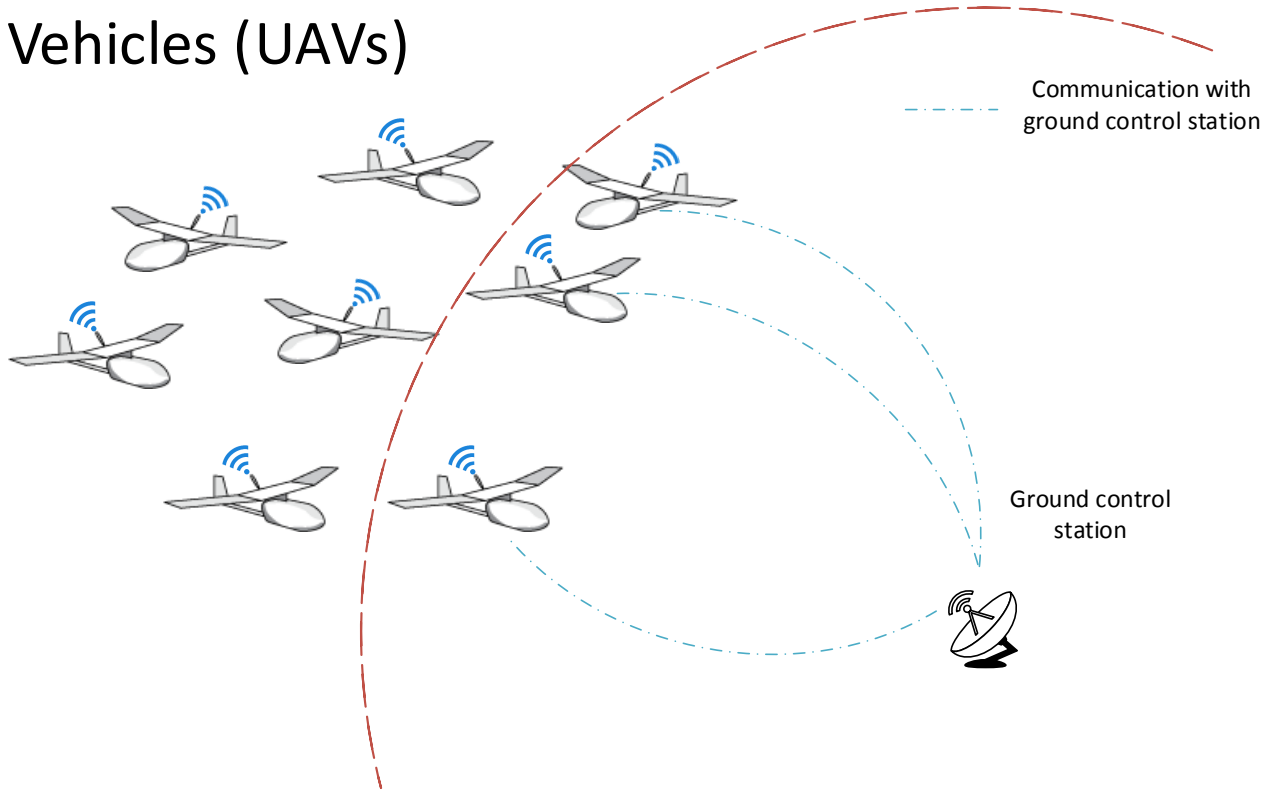
Introduction

- UAV vs. Unmanned Aerial Systems (UAS)
  - Ground Control Station (GCS or GS)
  - One or several Unmanned Aerial Vehicles (UAVs)

- UAVs sense and store data
- UAVs send data to GCS when communication is possible (UAVs in radio range)



Introduction (ctd.)

Attacker interests in UAS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Iran shows 'hacked US spy drone' video footage

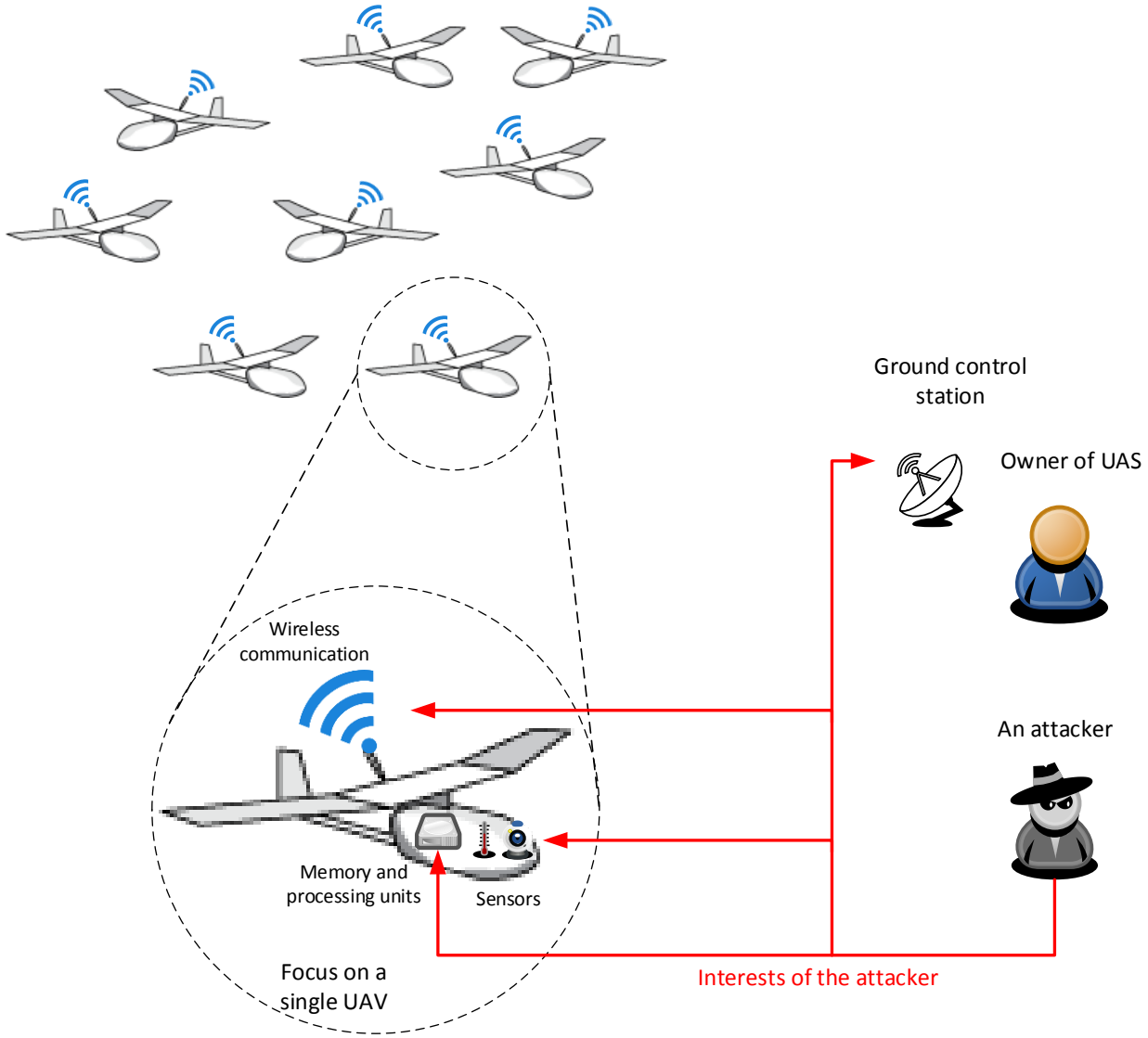
7 February 2013 | Middle East Share

Iran has released what it says is decoded video footage extracted from a US surveillance drone captured in 2011.

The material broadcast on Iranian state television purports to show a US base and the Afghan city of Kandahar. It is not clear if the footage is genuine.

The video footage has not been verified

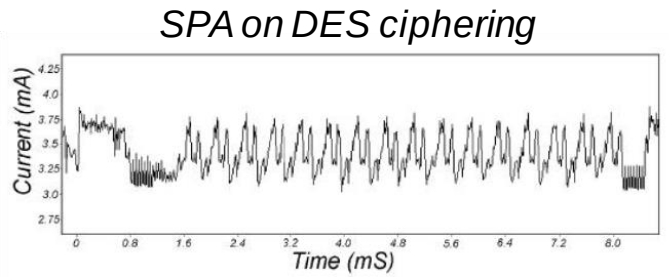
Last year Iran said it was building a copy of the drone - an RQ-170 Sentinel - after breaking its encryption codes.



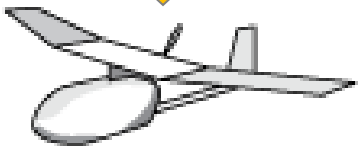
Introduction (ctd.)

- We consider a strong adversary model with a high attack potential.
  - the adversary has capabilities and knowledge to capture a UAV in a functional state

Then, he can perform advanced attacks

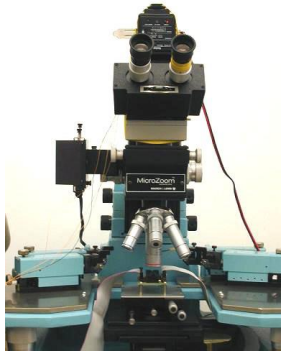


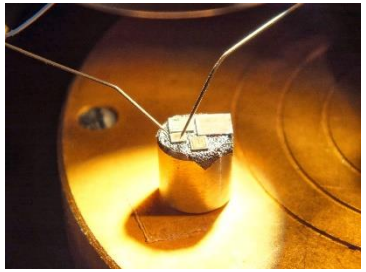
Side-channel attacks



Fault injection attacks

Physical attacks





Our Contributions

1. An Efficient Protocol for UAS Security

   - To ensure confidentiality of sensed data
     - using efficient cryptographic techniques (still, the encryption scheme is left to the choice of the implementer)
     - withstanding an adversary with a high attack potential

   - To minimize message exchanges between UAVs and the GCS
     - 1 round is required (except in an optional case: 1.5 rounds).

2. A Formal Proof of the Proposed Protocol

Requirements

- Each UAV must have its own cryptographic means (keys)
  i.e. capture and forensic of UAVs should not compromise the security of the whole UAS

- Keys must evolve during the mission to ensure the Perfect Forward and Backward Secrecy properties

  and Cryptographic means of UAVs should even be renewed/refreshed from time to time
  (The C2 links can be used to refresh them)

- Collected (sensed) data must be sent to the Ground Control Station as soon as a connection is available to avoid potential loss

- Assumption: The GCS is secure (else the whole network would be corrupted).

Cryptographic Techniques Used

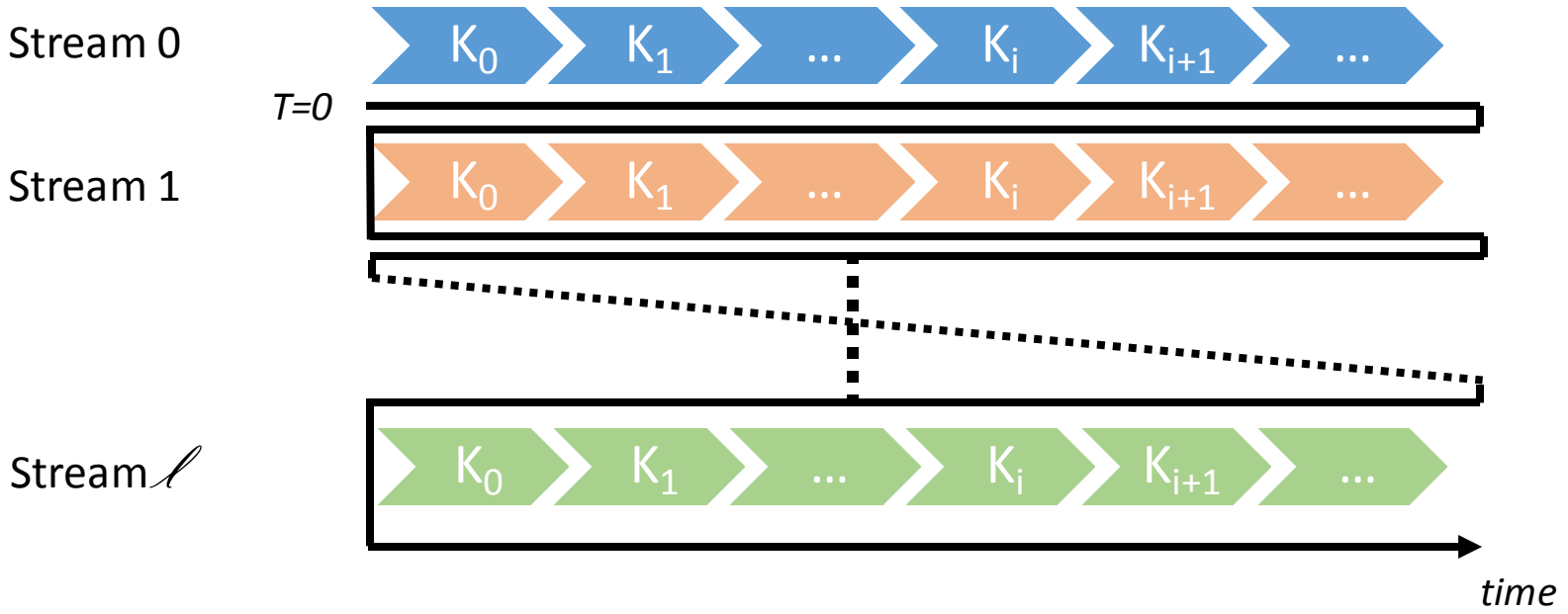
- Keys streams
  - Based on an origin (the first key)
  - Subsequent keys are generated using a function (and potential parameters to diversify the result)

  - We use a keyed hash function diversified with the ID of the considered UAV

$$K_{i+1} = H_{\mathrm{UAV_{ID}}}(K_i)$$

Cryptographic Techniques Used

- Keys streams are timely updated to prevent attacks (since it is well known that an attacker can find subsequent keys in a stream if he knows only one key)



Cryptographic Techniques Used

- One–time key: each key is used only once to encrypt data
  - The key is used:
    - to encrypt data
    - to compute a triplet of Authentication Tickets (used later in the protocol for C2)

$$(H_1, H_2, H_3)$$

$$H_1 = H(K_i \| 1)$$
$$H_2 = H(K_i \| 2)$$
$$H_3 = H(K_i \| 3)$$

    - to generate the subsequent key of the stream
  - Then, the key is cleared from memory and it thus cannot be recovered by anyone

Pre-Protocol Setup

- Each UAV is preconfigured with origin of its first keys stream

$$K_0 = K^0_{\mathrm{UAV_{ID}}}$$

- The GS is pre-configured with the first keys stream for each UAV of the UAS

UAV in Mission – Sensing & encryption Process

- Each sensed data block SDj is immediately encrypted and then stored in non-volatile memory of the UAV using the current key, Ki
  - SD_j is encrypted with any efficient symmetric algorithm using K_i and the result $[SD_j || UAV_{ID}]^{K_i}$ is stored in NVM. UAV_{ID} is added to encrypted data to allow the GS to verify the result has meaning when coming from the UAV
- For each above encryption, UAV also computes and stores the triplet of Authentication tickets (H_1, H_2, H_3)

$$H_1 = H(K_i \| 1)$$
$$H_2 = H(K_i \| 2)$$
$$H_3 = H(K_i \| 3)$$

  These tickets will be used later to decrypt commands on C2 link.

- The subsequent key K_{i+1} is computed and the current one, K_i, is deleted from memory

$$K_{i+1} = H_{\mathrm{UAV_{ID}}}(K_i)$$

UAV in Mission – Communication Process

- When a UAV is in communication range of GS, it sends the available encrypted data: $[SD_j \,||\, UAV_{ID}]^{K_i}$, …, $[SD_{j+n} \,||\, UAV_{ID}]^{K_{i+n}}$ and keeps them until it receives an authenticated command from GS (usually a ack)

  One authenticated command is required by encrypted SD. If UAV does not received the related authenticated command, it will send these encrypted data again and again until it receives it.

- When a UAV receives commands from the GS, it authenticates them with the computed Authentication tickets (H_1, H_2, H_3): it can then delete from its memory the encrypted data acknowledged along with the corresponding Authenticate tickets.

  - There are 3 types of commands:
    - The ACK command is only used by GS to acknowledge receipt of data
    - The NKS command is used to change the key stream to a new one. The new origin is provided along with the command. Note to avoid some desynchronization attacks, for this specific command the UAV has to acknowledge it has changed of keys stream
    - Other commands can be normal C2 commands.

Protocol Notations

UAV	:	Denotes an Unmanned Aerial Vehicle.
GS	:	Denotes a Ground Station.
$A \rightarrow B$	:	Message sent by an entity A to an entity B.
X_{ID}	:	Represents the identity of an entity X.
$X \| Y$	:	Represents the concatenation of the data items X, Y in the given order.
$X \oplus Y$	:	Represents the xor operation of the data items X, Y.
$[D]^k$	:	Data D are encrypted by a one-time key k.
$H(Z)$	:	Is the result of generating a hash of data Z.
$H_k(Z)$	:	Result of generating a keyed hash of data Z using key k.
$K^{\ell}_{\mathsf{UAV_{ID}}}$	:	The ℓ^{th} keys stream origin. This key is randomly chosen to initialize the ℓ^{th} stream of keys used to encrypt the sensed data. It is generated by the GS and sent to UAV $\mathsf{UAV_{ID}}$. In the pre-protocol setup, $K^{0}_{\mathsf{UAV_{ID}}}$ is set by the GS in UAV $\mathsf{UAV_{ID}}$.
K_i	:	A one-time key which evolves at each encryption of sensed data. The first key, K_0 is initialized using the value of the current keys stream origin $K^{\ell}_{\mathsf{UAV_{ID}}}$. Subsequent keys are computed with $K_{i+1} = H_{\mathsf{UAV_{ID}}}(K_i)$
SD_j	:	Denotes the j^{th} block of sensed data.
H_1	:	Denotes the following computation $H(K_i \| 1)$.
H_2	:	Denotes the following computation $H(K_i \| 2)$.
H_3	:	Denotes the following computation $H(K_i \| 3)$.
i_{lastKS}	:	Denotes the rank of the last key used in the previous keys stream.
Command	:	Denotes any command from the GS to UAV. Two examples of command are: 1) ACK to inform UAV that data have been received by GS and then can be deleted from its internal non-volatile memory. 2) NKS to inform the UAV to change the keys stream origin to $K^{\ell+1}$.
$\mathsf{Command}_{ack}$	:	Denotes an Acknowledgment to some commands by UAV. An example of such acknowledgment is for the NKS command for which the UAV informs the GS of the last K_i of the current keys stream used to encrypt the sensed data.

UAV to GS Secure Communication Protocol

1.	UAV $\rightarrow$ GS	:	$\mathsf{UAV_{ID}} \| [\mathsf{SD}_j \| \mathsf{UAV_{ID}}]^{K_i}$
2.	GS $\rightarrow$ UAV	:	$\mathsf{UAV_{ID}} \| \mathsf{Command}$
		:	with $\mathsf{Command} = H_1 \oplus \mathsf{ACK}$ for ACK
		:	with $\mathsf{Command} = H_2 \oplus (\mathsf{NKS} \| K^{\ell+1}_{\mathsf{UAV_{ID}}})$ for New Keys Stream
		:	with $\mathsf{Command} = H_3 \oplus (< any\ command >)$ for any other command
3.	UAV $\rightarrow$ GS	:	$\mathsf{UAV_{ID}} \| \mathsf{Command}_{ack}$
	(optional step)	:	with $\mathsf{Command}_{ack} = [\mathsf{ACK_{NKS}} \| \| i_{lastKS}]^{K_0}$ with $K_0 = K^{\ell+1}_{\mathsf{UAV_{ID}}}$

Formal Proof & Analysis of Efficiency

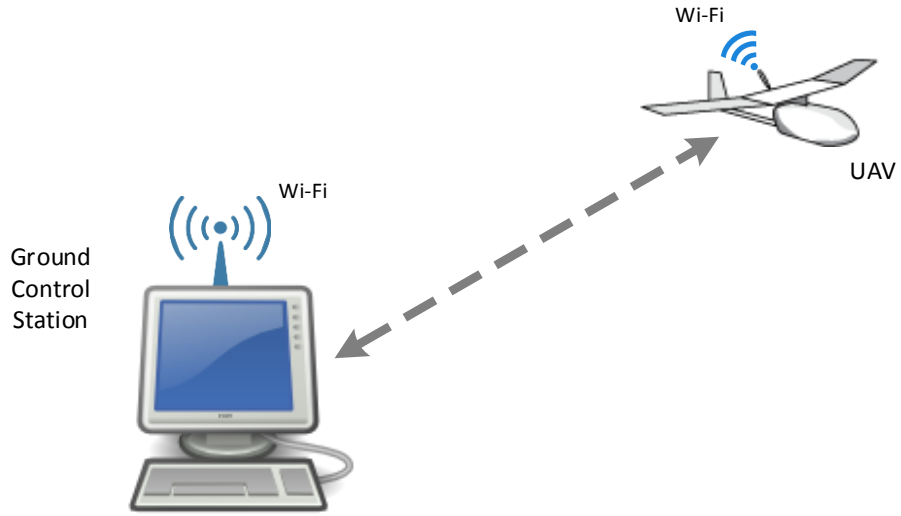
- Using security experiments, in the random oracle model, we have proven that the proposed protocol is secure under the security of the chosen encryption scheme.

- Most operations used in the protocol are lightweight: xor, hash function, keyed hash function

- The only possibly non lightweight operation is the chosen encryption scheme, denoted by [ ], whose choice is left free to implementer.

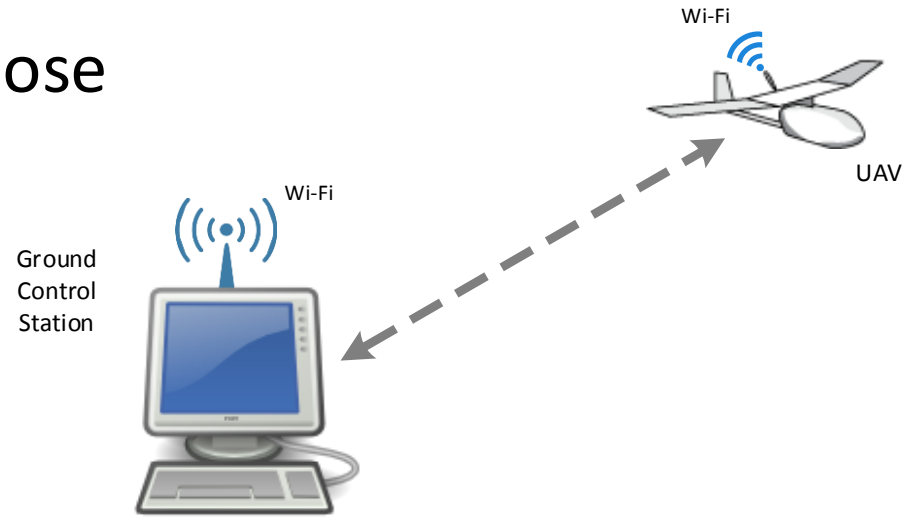
Test-bed for UAS

- The UAV is a Parrot AR.Drone2 running Linux
  - Encryption scheme chosen is AES
  - Hash and keyed-hash functions are based on SHA-256
- The Ground Control Station is a desktop computer with a Wi-Fi card.



Conclusions and Future work

- Our protocol for UAS is efficient and secure against an attacker with a high attack potential.
- In addition, it is flexible: implementer can choose the encryption scheme



- We plan to extend it to hierarchical UAS
  - Several GCSs
  - Network with big UAVs acting as cluster head

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Thank You!
Any Questions or Suggestions