Lecture #8: IoT Network Security

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Paper summaries

- You must have handed in your two summaries BEFORE this lecture
- You can use the summaries during the oral exam (“open book”)
- You **cannot** complete SSI without submitting 12 paper summaries!
- If you have done 12, you don’t need to provide summaries next week (but do attend the lecture :-)

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Interactive Lecture

- Goal: enable you to learn from each other and further increase your understanding of the papers (contributes to preparing yourself for the oral exam)

- Format:
  1. We'll ask someone to provide their **opinion** of the paper
  2. Summary by teachers (put any questions in the chat)
  3. Questions: discussion starters and fact questions
  4. Discussion (use your mic)
  5. We may ask someone specific to start the discussion

- Experimental format resulting from Corona pandemic, please provide feedback!

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Today's papers: IoT network security

[Lora] X. Wang, E. Karampatzakis, C. Doerr, and F.A. Kuipers, "Security Vulnerabilities in LoRaWAN", Proc. of the 3rd ACM/IEEE International Conference on Internet-of-Things Design and Implementation (IoTDI), Orlando, Florida, USA, April 17-20, 2018

[PHY] S. Naz Islam, Z. Baig, and S. Zeadally, "Physical Layer Security for the Smart Grid: Vulnerabilities, Threats, and Countermeasures", IEEE Transactions on Industrial Informatics, Vol. 15, Issue 12, Dec. 2019

“Security Vulnerabilities in LoRaWAN”, April 2018

X. Wang, E. Karampatzakis, C. Doerr, and F.A. Kuipers

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Quiz: warming up

What classical definition of security does the paper use?

A. Communication, Information, and Authority
B. Confidentiality, Integrity, and Availability
C. Authentication, Authorization, and Accounting
D. Stability, Resilience, and Transparency

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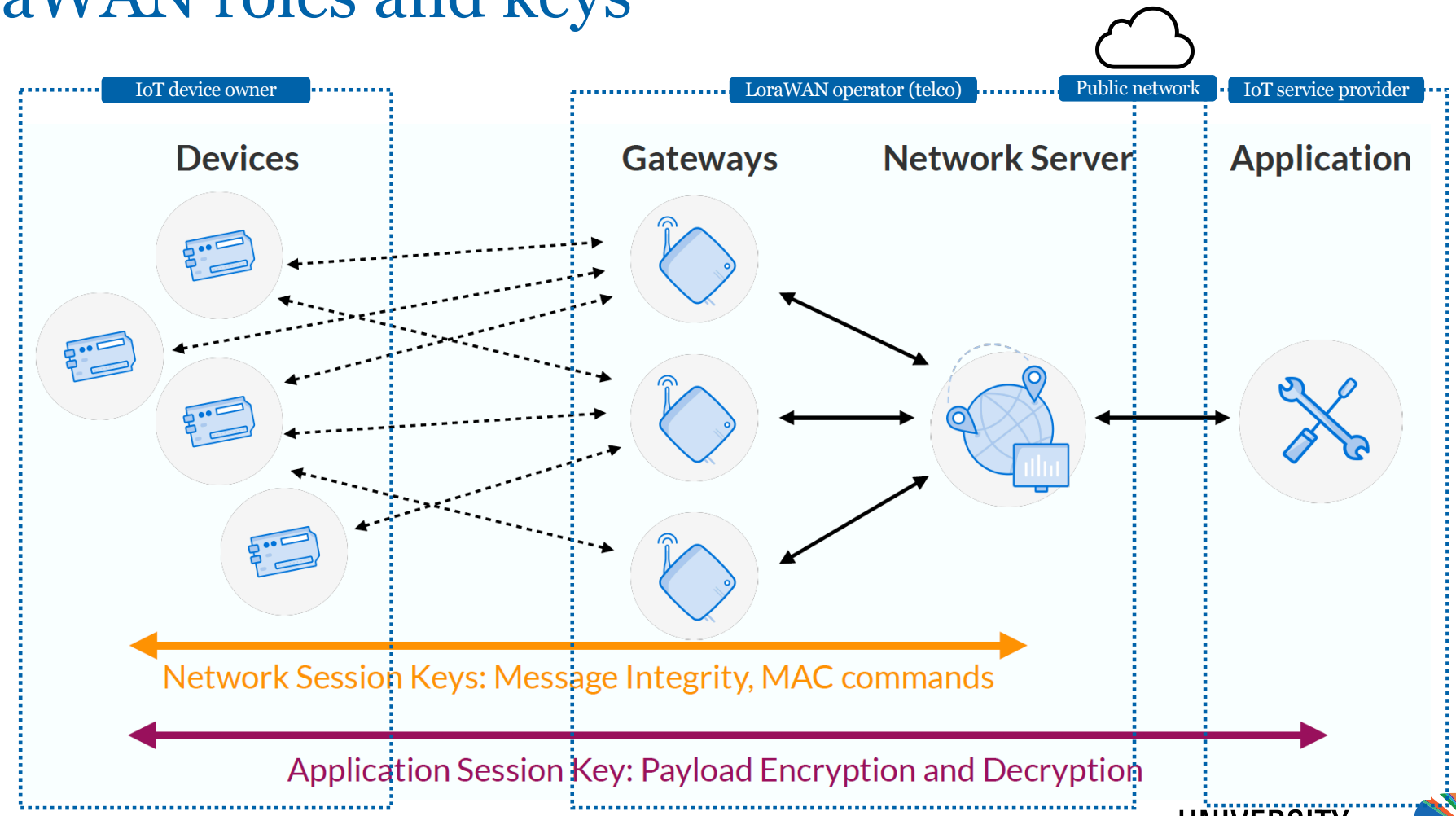
LoraWAN roles and keys



Picture: Johan Stokking, The Thing Industries

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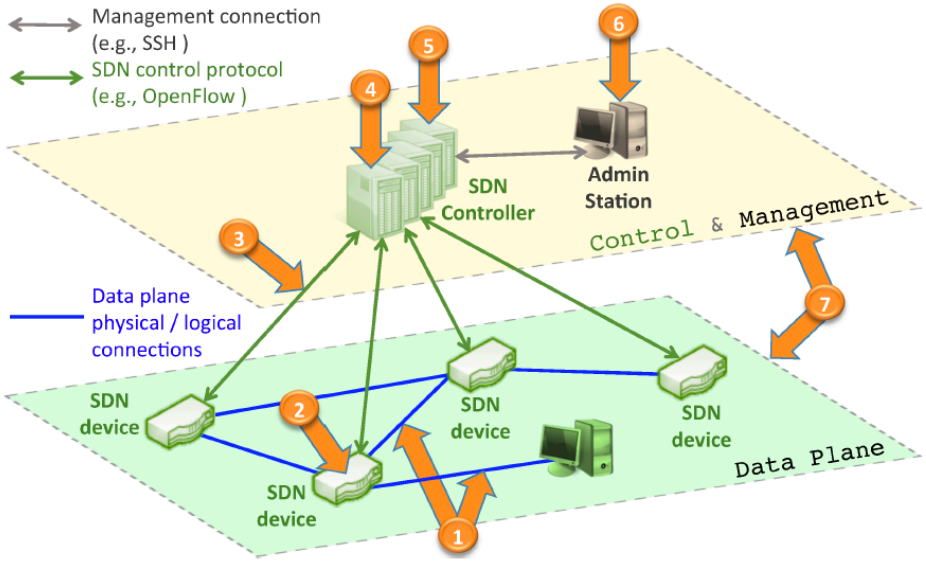
Key security functions

- Data plane (packet forwarding)
  - Encryption (counters)
  - Authentication of LoraWAN sources (MIC)
  - Message integrity verification (MIC)
  - Replay protection (counters)

- Management plane
  - Key derivation (symmetric)
  - Device enrollment protocol (OTAA and ABP)
  - Over the air firmware updates (guest lecture)



Source: D. Kreutz, F. M. V. Ramos, P. Verissimo, HotSDN'13, August 16, 2013, Hong Kong, China.

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Quiz: over-the-air activation

What's the root of trust in OTAA mode?

A. AppSKey

B. NwkSKey

C. AppKey

D. NwkKey

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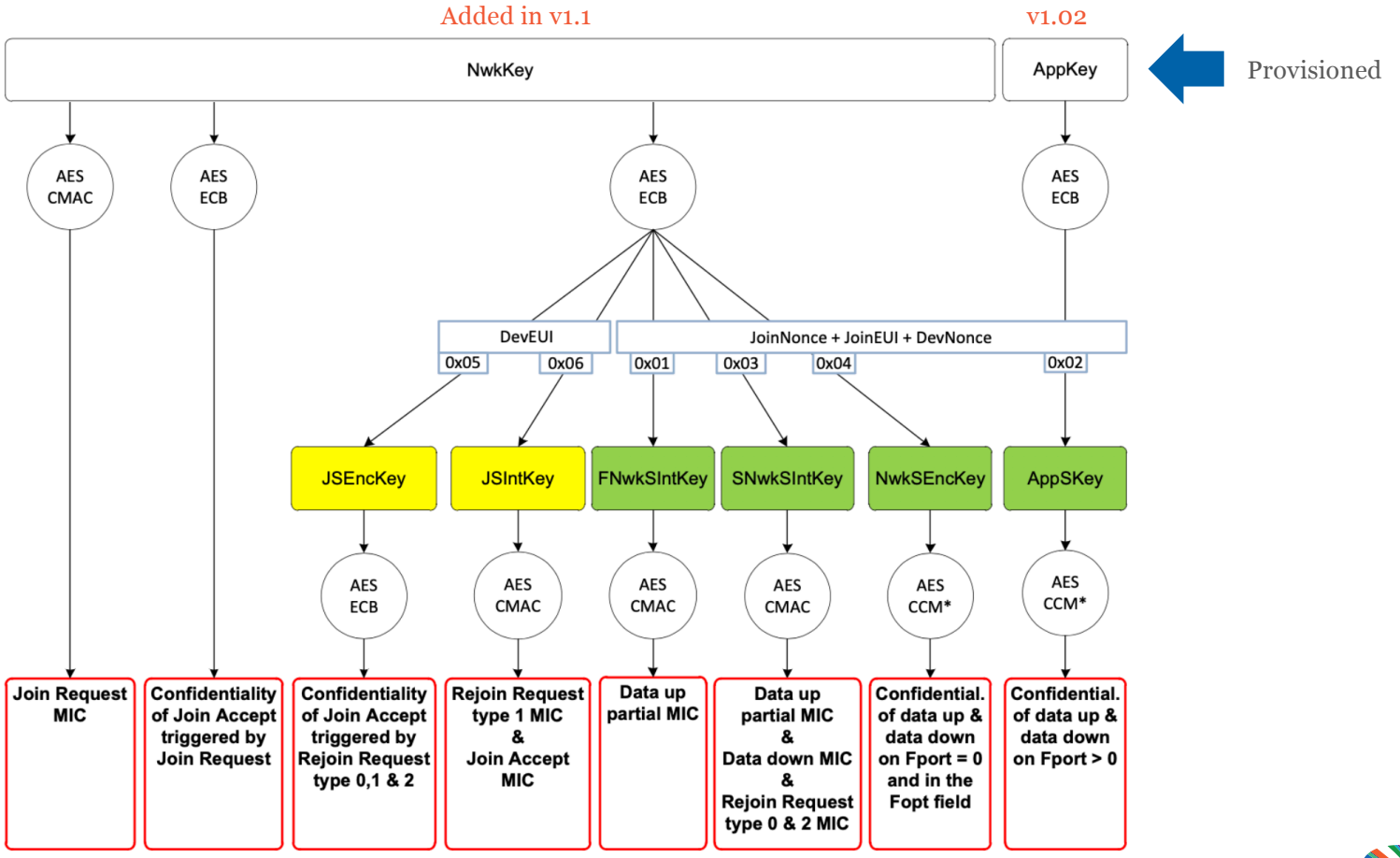
LoraWAN key derivation



Picture: Johan Stokking, The Thing Industries

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Denial of Service through replay

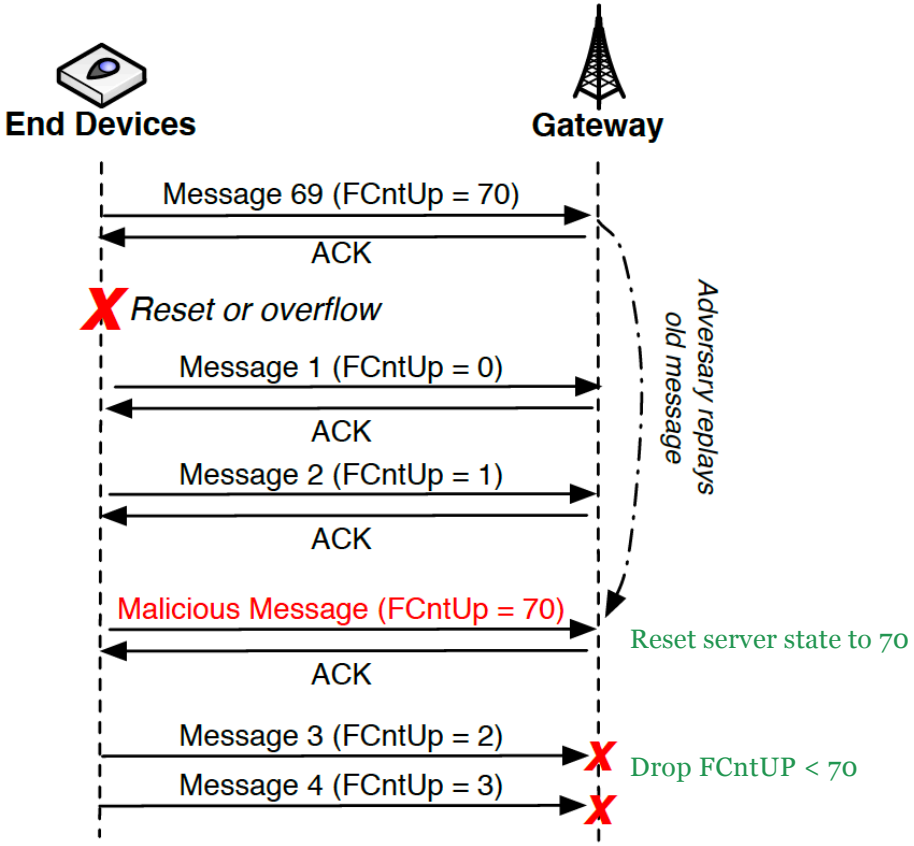

Fig. 4. An example of a replay attack for ABP.

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Quiz: eavesdropping

What's the root cause of an eavesdropping attack?

A. LoraWAN nodes use their message counters to encrypt messages
B. LoraWAN nodes use limited payload sizes
C. LoraWAN nodes use known formats for their messages
D. LoraWAN nodes use a block cipher in counter mode

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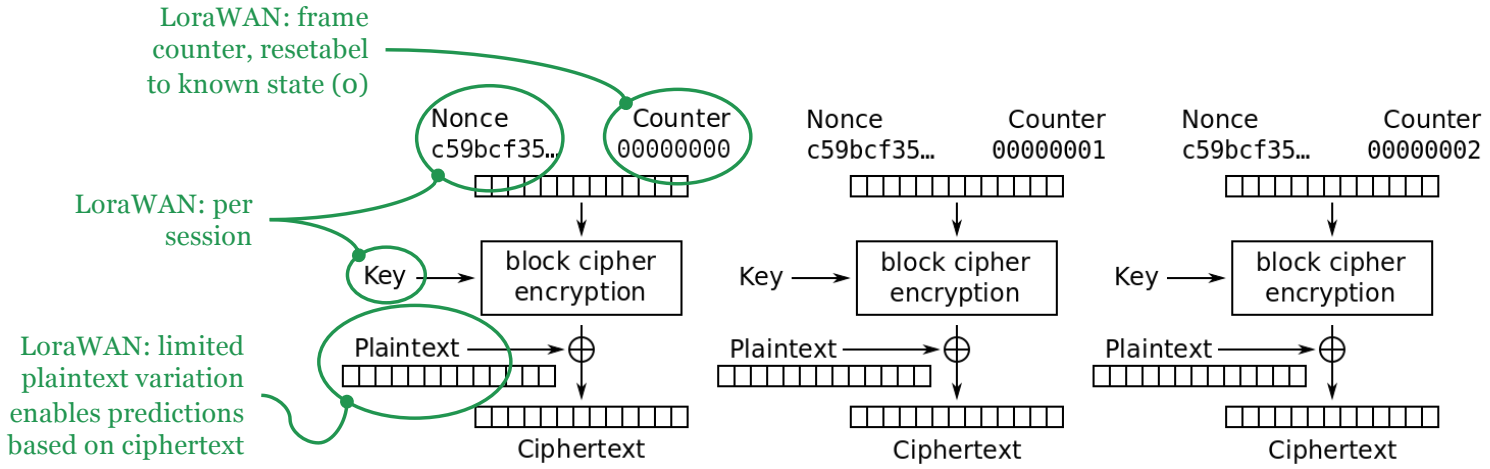

Counter (CTR) mode encryption

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

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Quiz: message integrity

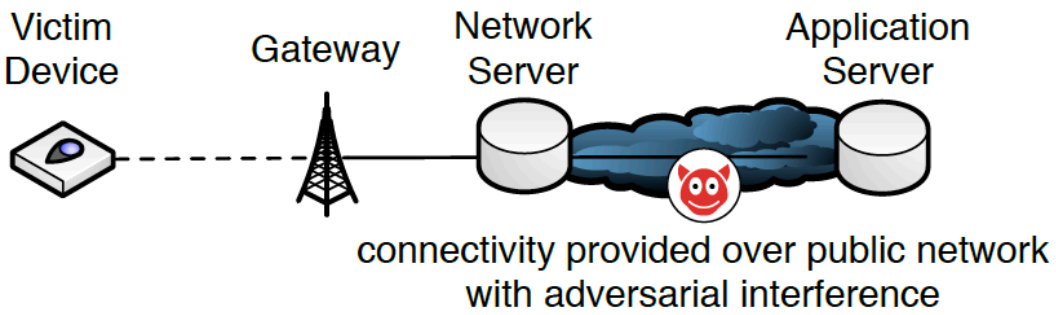
Why does LoraWAN not support end-to-end message integrity?

A. LoraWAN is a link-level technology

B. LoraWAN messages are encrypted

C. LoraWAN do not have an application-level MIC

D. LoraWAN messages can be subject to a routing hijack



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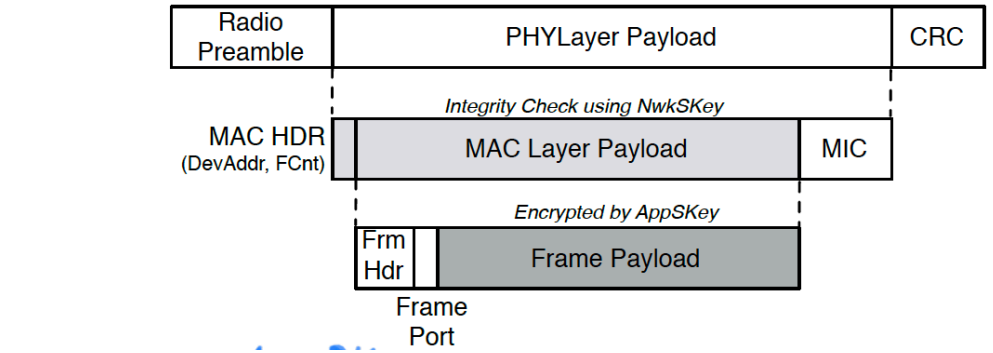
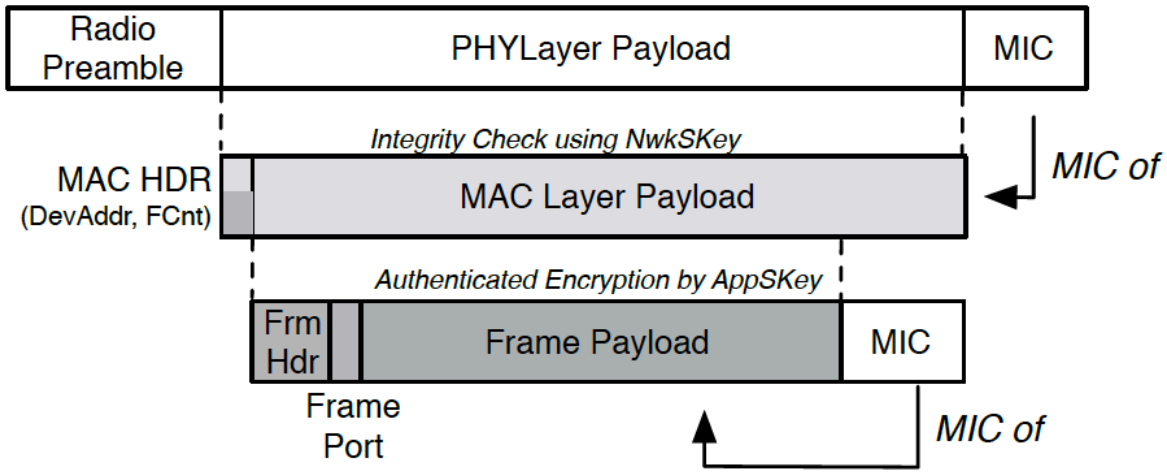
Proposed solution: 2 MICs

Why would they have not used an application-level MIC initially?





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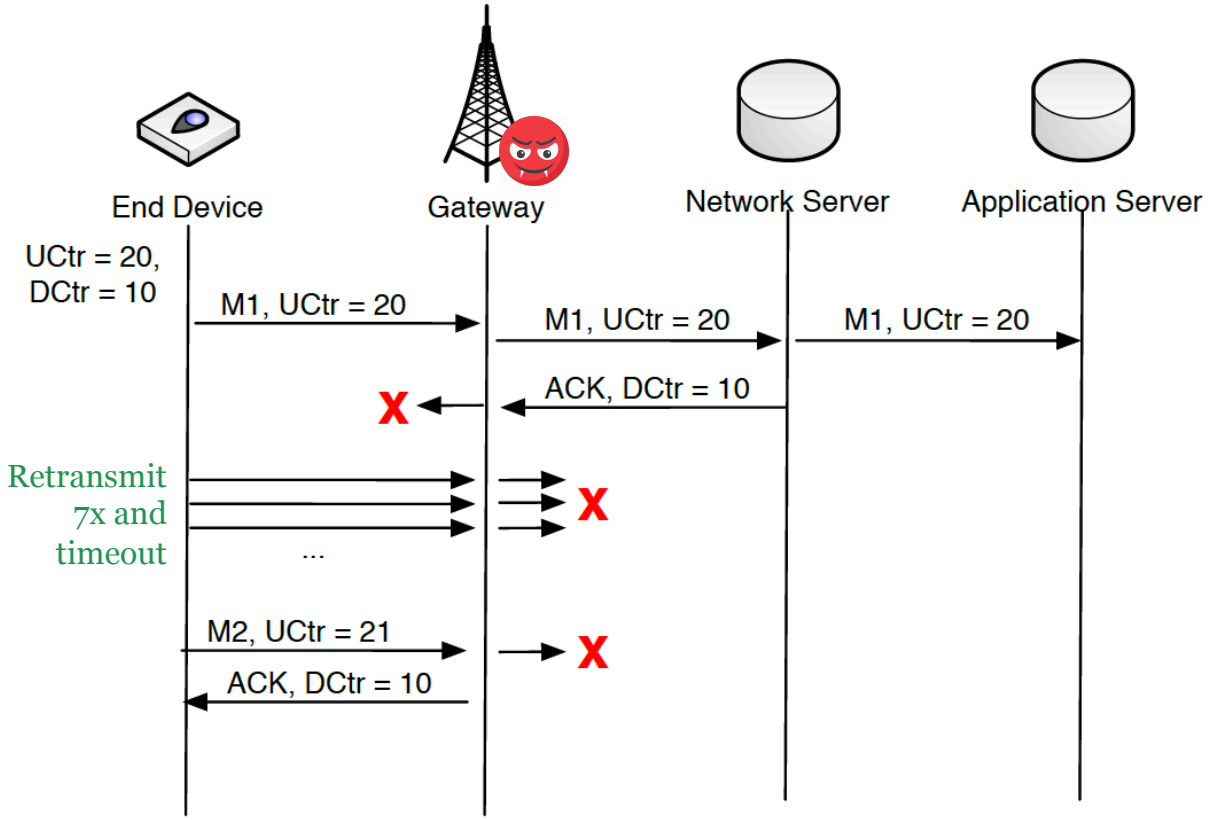
ACK spoofing



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Quiz: ACK spoofing

The fundamental problem with the ACK spoofing attack is that ACKs do not indicate which message they confirm. How do the authors propose to extend ACK messages to tackle this problem?

A. Include a nonce signed by the gateway's private key

B. Include the frame counter value of the uplink message

C. Include cryptographic checksum that covers the uplink packet

D. Accept the risk because adding more info to ACKs would be too expensive

Key takeaways

- Designing network security protocols is challenging
- Many different corner cases that folks will exploit
- My “favorite” attacks
  - Content guessing based on typical packet content (small messages, known data formats, etc.)
  - Remote battery draining

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Discussion

- What would you do to better in the development process to make LoraWAN more secure?
  - IETF-like standardization?
  - Formal verification?
  - Open source implementation?
  - …

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Physical Layer Security for the Smart Grid:

Vulnerabilities, Threats, and Countermeasures

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Opening question: This paper was easy to understand

- True
- False

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Cont.: Some of the proposed solutions were too obvious (ie. use encryption)

- True
- False

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Motivation

- Smart energy grids are made up of two broad components
  - The traditional electricity grid
  - Data communication layer
- Up until now, only specific vulnerabilitie were investigated
  - Moreover, the physical layer threats were n considered

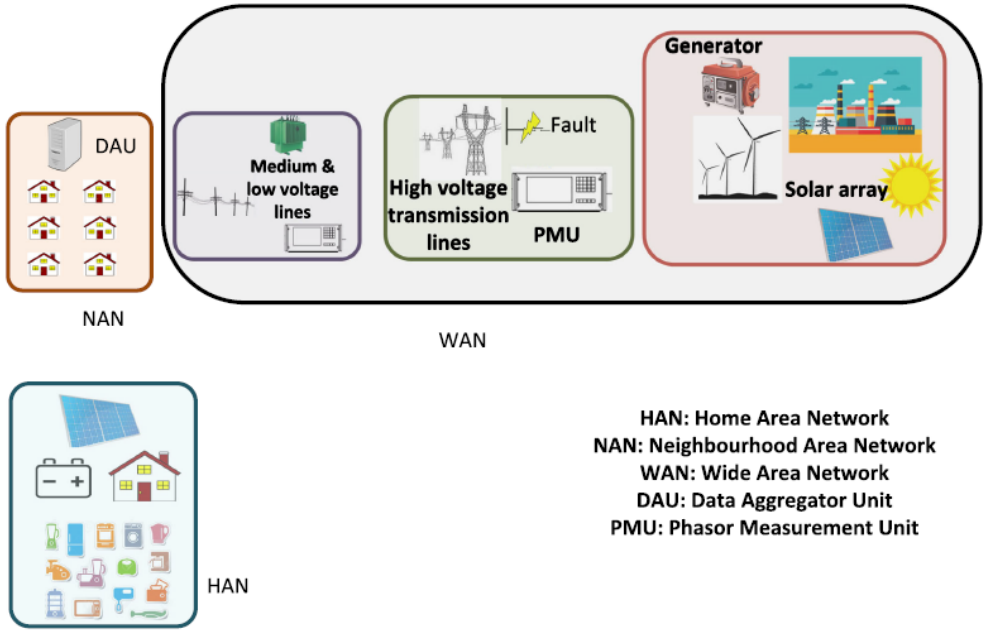

Fig. 1. Smart energy system.

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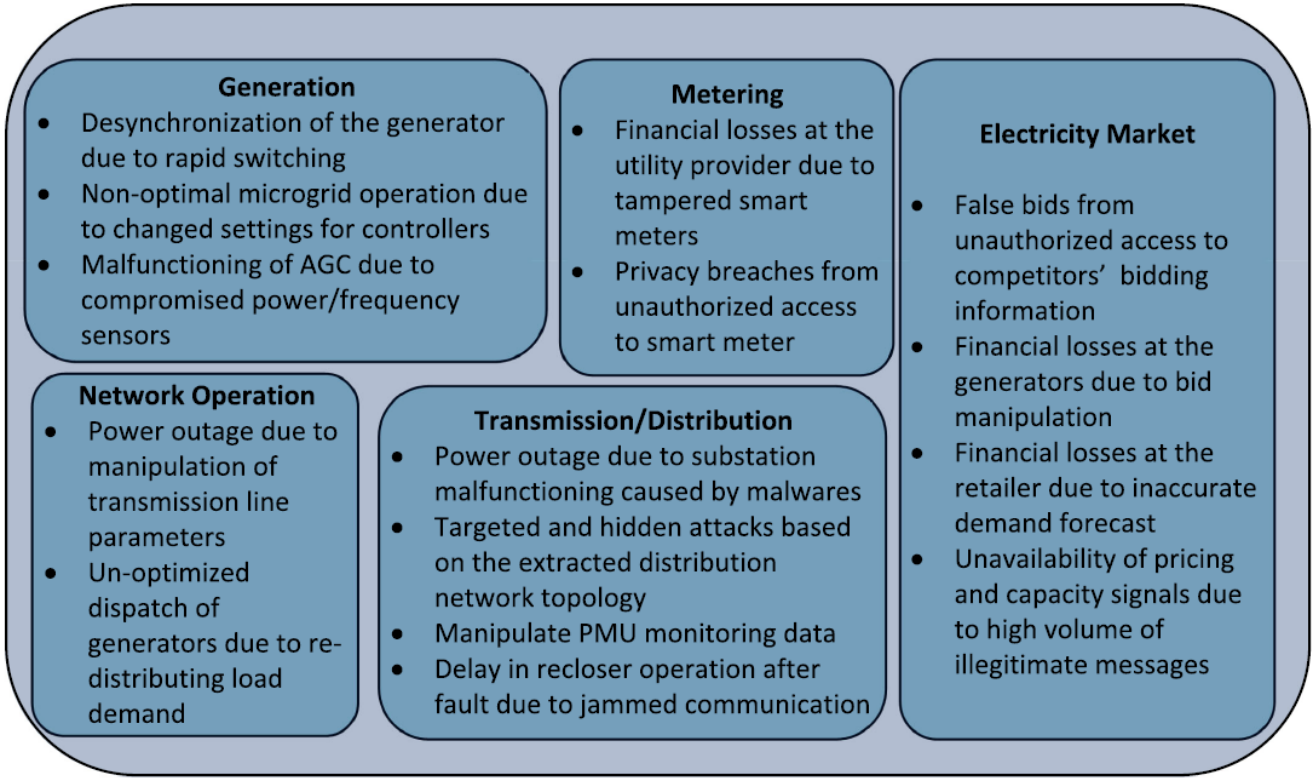
SECURITY VULNERABILITIES OF SMART ENERGY SYSTEMS



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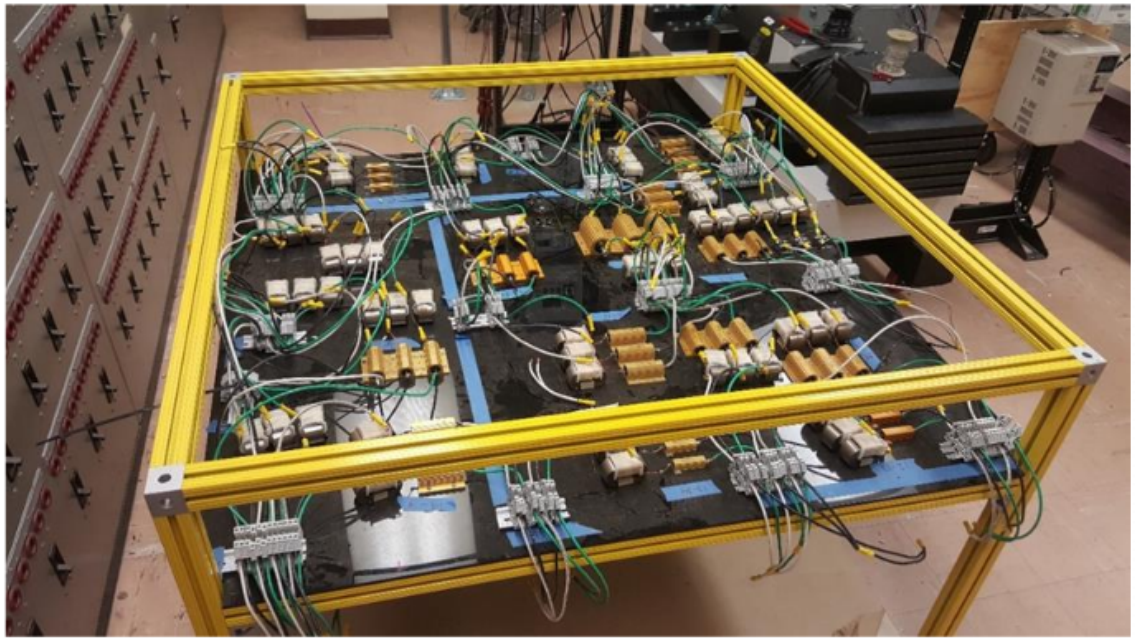
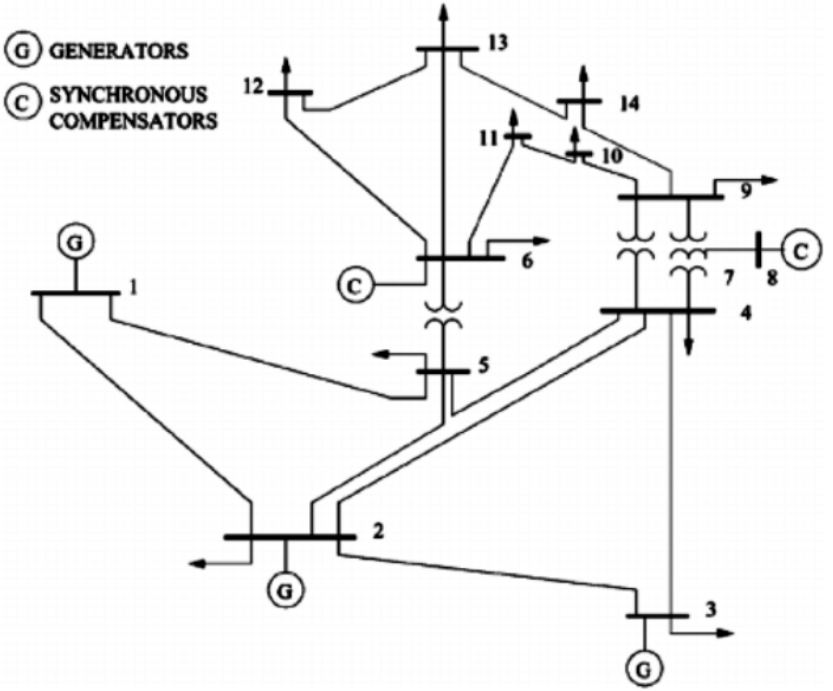
IEEE 14 Bus Power System





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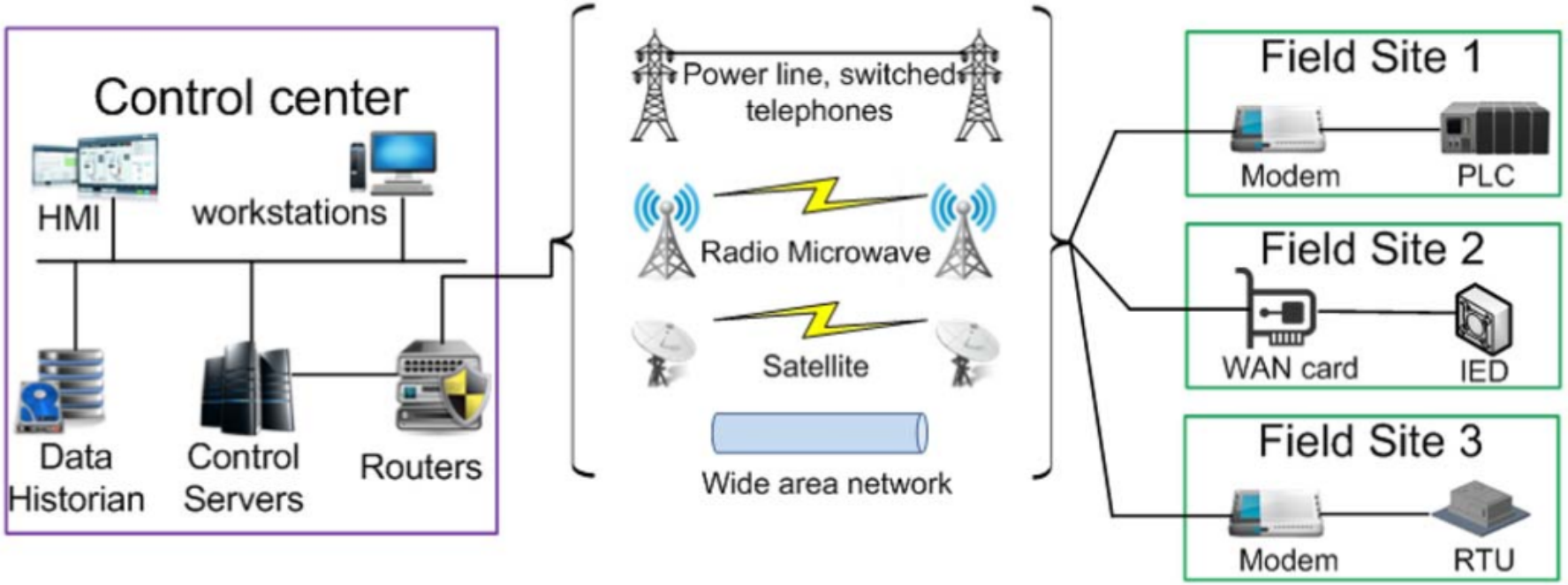
Physical Layer Security For Smart Energy Systems



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Physical Layer Security For Smart Energy Systems

- IoT-enabled smart grids connect various smart grid components, including smart meters, controllers, DAUs, PMUs, PDCs, and fault isolators over the Internet, to enable ubiquitous connectivity.
- As a result, these IoT-enabled smart grid devices and corresponding communication links expose an increasing number of vulnerabilities.

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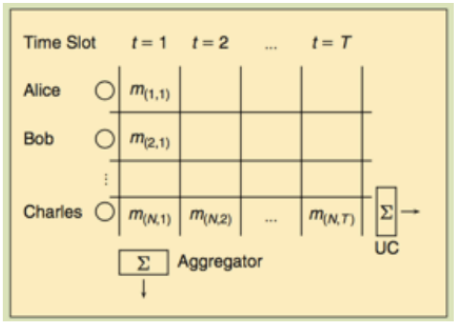
Physical Layer Security For Smart Energy Systems

Data Aggregation

public ← $M = \sum_{i=1}^{N} m_i$ → private



- Setting:
  - Service provider
  - Aggregator(s) (*optional)
  - Customers: e.g. households
- Questions: Can we compute aggregated data without learning individual consumption?
  - Spatial?
  - Temporal?
  - Missing data?
  - in different security models

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Physical Layer Security For Smart Energy Systems

Homomorphic Encryption

$$E_{pk}(m_1) \otimes E_{pk}(m_2) = E_{pk}(m_1 \oplus m_2)$$

Encrypted/Ciphertext Domain

Plaintext Domain

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Physical Layer Security For Smart Energy Systems

Paillier Encryption Scheme

- Additively Homomorphic
- Another one, Okamoto-Uchiyama

$$n = pq \qquad g^n \equiv 1 \bmod n^2 \qquad r \in \mathbb{Z}_n^*$$

$$\lambda = lcm(p-1, q-1) \qquad L(x) = \frac{x-1}{n}$$

$$E_{pk}(m) = g^m r^n \bmod n^2$$

$$D_{sk}(c) = \frac{L(c^\lambda \bmod n^2)}{L(g^\lambda \bmod n^2)} \bmod n$$

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Additive Homomorphism

$$
\begin{aligned}
E_{pk}(3, r_1) \times E_{pk}(5, r_2) &= g^3 \cdot r_1^n \times g^5 \cdot r_2^n \bmod n^2 \\
&= g^{3+5} \cdot (r_1 \cdot r_2)^n \bmod n^2 \\
&= E_{pk}(3+5, r_1 r_2)
\end{aligned}
$$

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Physical Layer Security For Smart Energy Systems

ET12: Modified Paillier Encryption

$$\text{Alice: } \mathcal{F}_{pk}(m_{1,t}) = g^{m_{1,t}} \cdot r^{n_1} \bmod n^2,$$
$$\text{Bob: } \mathcal{F}_{pk}(m_{2,t}) = g^{m_{2,t}} \cdot r^{n_2} \bmod n^2,$$
$$\text{Charles: } \mathcal{F}_{pk}(m_{3,t}) = g^{m_{3,t}} \cdot r^{n_3} \bmod n^2,$$

$$n_1 + n_2 + n_3 = n$$

$$\prod_i \mathcal{F}_{pk}(m_i) = g^{\sum_i m_{i,t}} \cdot r^{\sum_i n_i} \bmod n^2$$
$$= g^{\sum_i m_{i,t}} \cdot r^n \bmod n^2 := \mathcal{E}_{pk}\left(\sum_i m_{i,t}\right).$$

- In practice, you need time-stamps
- Cryptographic tools: Paillier, Hash, PRF
- Cannot deal with missing data (external party needed)

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Discussion

- What do you think?

- (Completely open discussion)

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Discussion & feedback

Next lecture: **Wed Jun 17, 10:45-12:30**
Topic: IoT edge security systems (re-sit)
Everyone welcome to attend!

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