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A Cloud-Based Key Rolling Technique for Alleviating Join Procedure Replay Attacks in LoRaWAN-based Wireless Sensor Networks

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Agenda

- Introduction
- Background Theory
- Related Work
- System Architecture
- Implementation Details
- Evaluation Methodology & Results
- Discussion
- Conclusion

Introduction

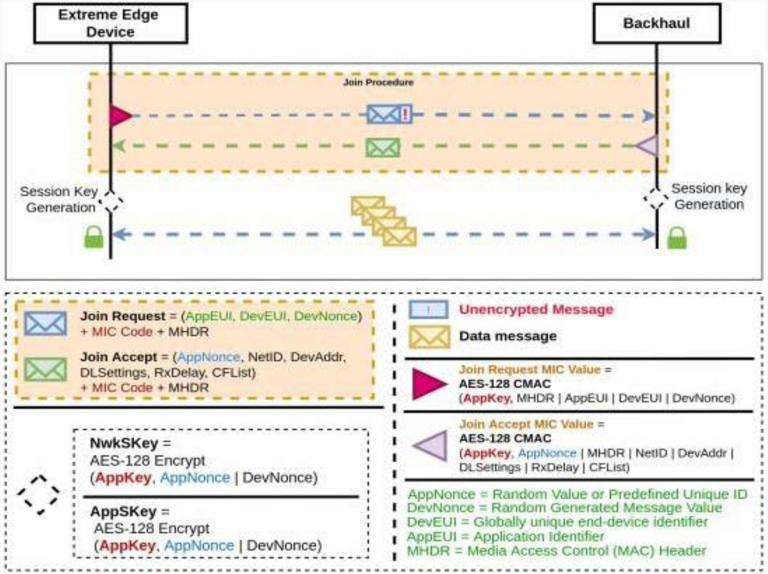
As IoT devices proliferate, Low Power Wide Area Networks like LoRaWAN have become pivotal for connecting devices over long distances with minimal energy consumption

- **Identified Challenge**: Join Procedure of the Over The Air Authentication (OTAA) mode begins with an ***unencrypted Join Request***, which contains a Message Integrity Code (MIC) which is the result of encrypting the contents of the message with the **AppKey**
    - Malicious actors acting as Man-in-the-Middle can reverse engineer the MIC value and derive the AppKey
    - This renders the Join Procedure vulnerable to replay attacks, where attackers can impersonate legitimate devices
- **Proposed Solution**: a dynamic key rolling technique, inspired by automotive security systems
    - Continuous regeneration of the AppKey, necessitating the device to re-join the network and re-authenticate
    - Enhanced authentication process without adding significant overhead

Background Theory (1/2)

LoRaWAN specification version 1.0.2 and 1.1

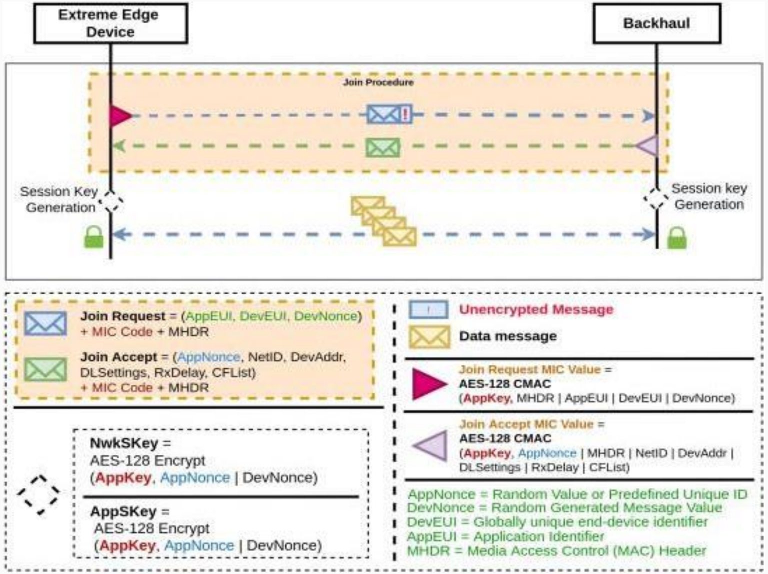
- Device Authentication:
  - **Join Request** includes:
    - AppEUI, DevEUI, DevNonce, MHDR heder
    - MIC value: the result of encrypting AppEUI, DevEUI, DevNonce, MHDR or combination of them by using the AppKey
  - **AppKey**:
    - Randomly generated and saved in the cloud
    - Manually entered in each extreme edge device
    - Used by the cloud to decrypt the MIC value of a Join Request in order to authenticate the extreme edge device
- Extreme edge device – Cloud communication:
  - **AppKey:**
    - used to generate the AppSKey and NwkSKey (session keys) by encrypting the DevNonce or AppNonce (randomly generated in the cloud) value
    - Used by the extreme edge device in conjunction with the DevNonce or AppNonce value to generate the same session keys as the cloud
  - **AppSKey and NewkSKey**:
    - Used by the extreme edge device and the cloud to encrypt and verify the communication between them



Background Theory (2/2)

LoRaWAN specification version 1.0.2 and 1.1

- <u>Security Limitations</u>:
  - The **MIC value** results from the encryption of the contents of the Join Request using AES-128 blocks for encryption (AES-CMAC algorithm)
    - Literature has identified techniques to decrease the processing power required for decryption
  - **AppEUI, DevEUI, DevNonce value, MHDR header** are transmitted unencrypted over the air
  - **DevNonce** is susceptible to interception by using a brute force attack
  - **AppKey:** its static nature of the leads to vulnerabilities:
    - Replay attacks and impersonation risks
    - Challenges in securing unencrypted Join Requests



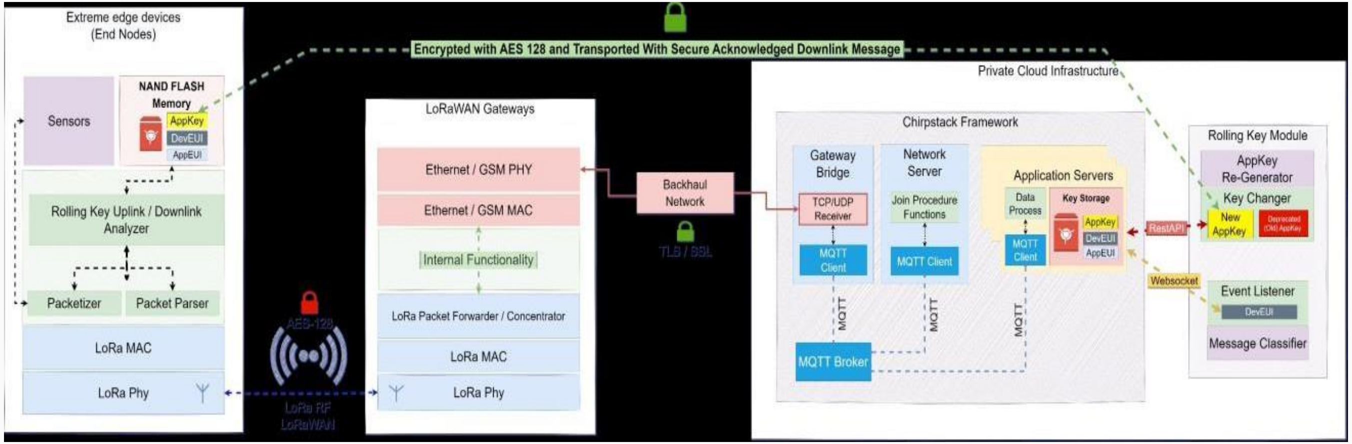
Related Work

Existing Approaches:

- **Masking Techniques**: leverage cryptographic operations, such as AES encryption, to obscure critical identifiers like the DevNonce and MIC.
  - → often require significant modifications to the LoRaWAN protocol, increasing complexity and deployment costs.
- **Timestamp-Based Mechanisms**: by incorporating temporal validation into message exchanges, these methods ensure that replayed packets are identified and rejected
  - → their reliance on synchronized clocks introduces vulnerabilities, as desynchronized devices may inadvertently reject legitimate packets or accept malicious ones.
- **Blockchain Solutions**: ensure integrity and traceability of network events, while smart contracts can enforce security policies
  - → computational overhead and high energy consumption make blockchain less feasible for the resource-constrained environments of IoT networks like LoRaWAN.
- **Adaptive Cryptographic Protocols**: periodically update session keys by using dynamic key management strategies, reducing the attack surface for replay attempts
  - → often involve additional computational and communication overhead, which can impact network efficiency.
- **Hybrid Approaches**: integrating masking with blockchain or timestamping offers promising results
  - → the trade-offs in complexity, compatibility, and scalability remain significant barriers to widespread adoption

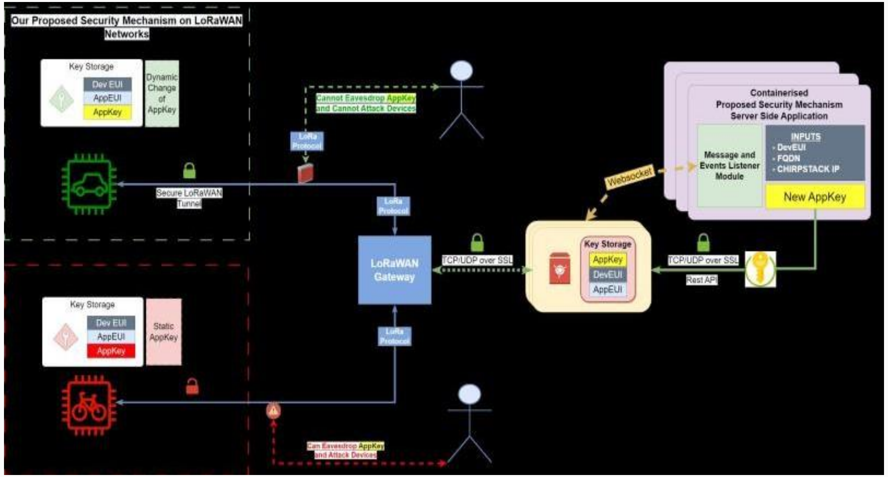
System Architecture

- **Components**:
  - Edge devices
  - LoRaWAN Gateways
  - Private Cloud Infrastructure including the Chirpstack framework and the Key Rolling Module.
- **Key Rolling Module**:
  - Dynamic AppKey updates
  - Transmission of the new AppKey from the cloud to the extreme edge device using secure tunnels.



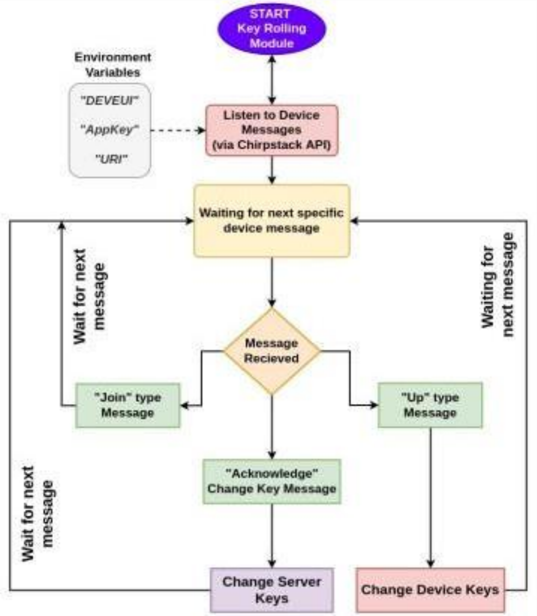
Implementation Details (1/2)

- Assumptions:
  - AppEUI IDs of all extreme edge devices were assigned as "0000000000000000“ → Chirpstack framework does not require an AppEUI in LoRaWAN versions 1.0.2 and/or higher
  - LoRaWAN specification version 1.0.2 was employed due to the specifications of the extreme edge devices and the gateway used → the suggested solution can be modified to support newer versions as well
- Setup:
  - Tools: Chirpstack framework, PyCom FiPy devices, Lorix One devices.
  - Cloud integration with RESTful API and WebSockets.
- Process:
  - Replacing static AppKey with a dynamic key.
  - Secure downlink message transmission and acknowledgment.

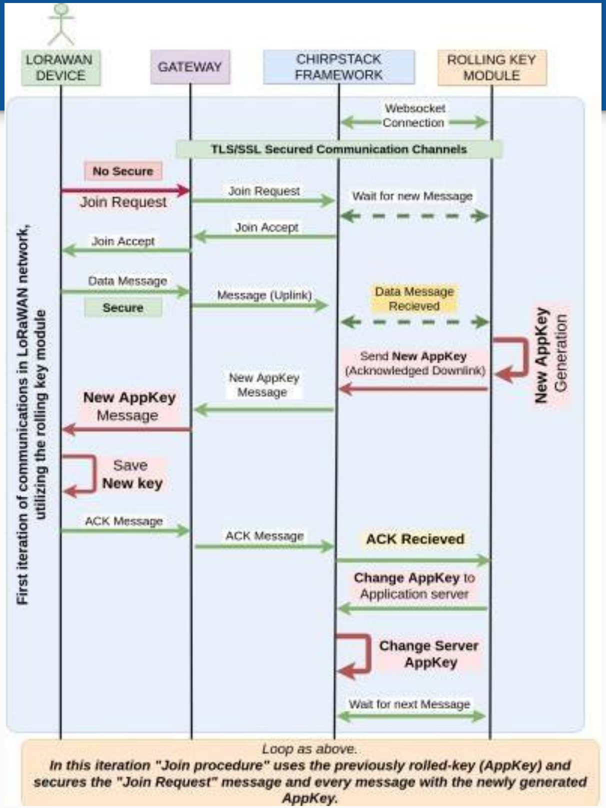


Implementation Details (2/2)

Flow Chart



Sequence Diagram



Evaluation Methodology & Results (1/2)

- Experiments Conducted:
  - **Alpha and Beta** experiments (with and without key rolling mechanism) → evaluating the effectiveness of the proposed approach in mitigating replay attacks
  - **Delay** experiment to measure performance impact → evaluating the key rolling mechanism's performance and the delay induced in sequential procedures
- Variables:
  - **Independent**:
    - Time window: 20 minutes duration for optimal measurements
    - Transmission time: 60 sec of client transmission
    - Packet data:
      - Alpha and Beta experiments:
        - Benign: "Temp: 28 C"
        - Malicious: "Temp: 50.0 C"
      - Delay experiment:
        - Benign: "Temp: 32.0 C"
  - **Dependent**:
    - Alpha and Beta experiments:
      - Packets per minute
    - Delay experiment:
      - Delay in AppKey update.

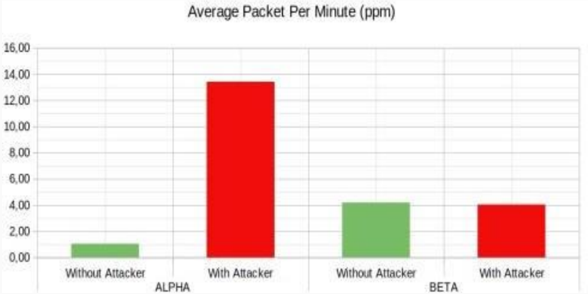
→ **Assumption for all three experiments**: the attacker has already acquired the AppKey from the "victim" device.

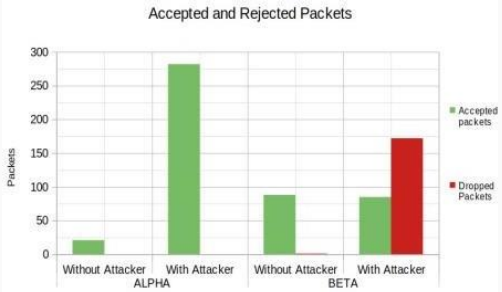
→ 2 phases for the Alpha & Beta Experiments:

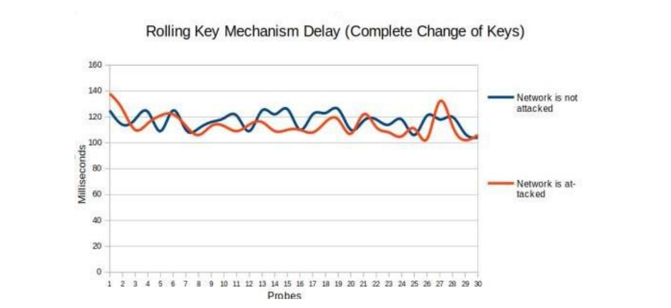
- **"With Attacker":** an attacker executed a replay attack by flooding the LoRaWAN network with packets every 4 seconds
- **"Without Attacker":** no attack performed

Evaluation Methodology & Results (2/2)

- Alpha vs. Beta Experiments:
  - Significant **reduction in malicious packets** with key rolling enabled:
    - Alpha - no key rolling module:
      - With Attacker: 13.42 ppm
      - Without Attacker: 1.05 ppm
    - Beta – key rolling module included:
      - With Attacker: 4.09 ppm
      - Without Attacker: 4.19 ppm
  - **Rejected packets**:
    - Alpha - no key rolling module:
      - With Attacker: 0/282 packets were rejected
    - Beta – key rolling module included:
      - With Attacker: 172/257 packets were rejected
- Delay Experiment:
  - **Minimal delay** induced by the proposed solution for rolling the new AppKey: 113-116ms
  - **Impractical** for attackers **to execute replay attacks** within this window.







Discussion

- Effectiveness:
  - Successfully mitigates replay attacks.
  - Minimal impact on network performance.
- Limitations:
  - Physical attacks and potential future risks with quantum computing propose future steps for research

Conclusion

- Summary:
  - The proposed dynamic key rolling technique enhances security in LoRaWAN networks.
  - Backwards compatible and low complexity.
- Future Work:
  - Explore blockchain integration and real-world scalability.

Thank you for your attention

Q&A

Presented by:
e-mail:

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