A Secure Network Architecture for the Internet of Things Based on Local Authorization Entities

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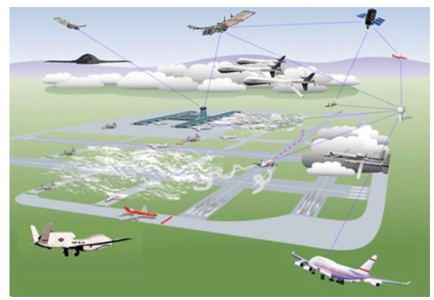
FiCloud 2016, August 22-24, 2016, Vienna, Austria

Challenges for IoT Security

- **Heterogeneity** in security requirements & resource availability
  - Examples of heterogeneity in the IoT

Cardiac monitor and emergency service

- Privacy
- Resource constraints consideration



Drones and ground air traffic control

- Strong and frequent authorization (safety-critical)
- Intermittent connectivity consideration

Apple pay

- Confidentiality
- Authentication
- Moderate resource constraints consideration

Ambient temperature sensors and receiver

- Data integrity
- Resource constraints consideration

- Images from www.dicardiology.com, diydrones.com, en.wikipedia.org, and safesoundfamily.com
- IoT security challenges from Miorandi *et al.*, AD Hoc Networks, 2012, Jing *et al.*, Wireless Networks, 2014, Sadeghi *et al.*, DAC, 2015

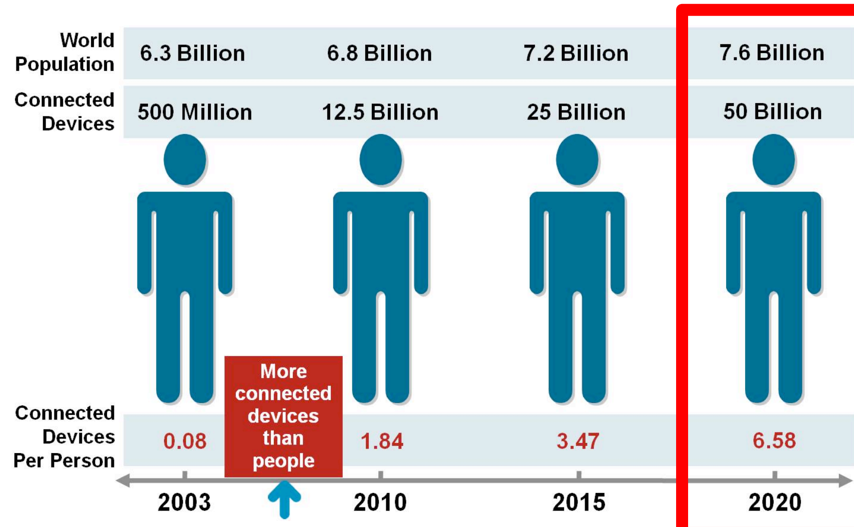
Challenges for IoT Security

- Operation under **open/untrusted environment**
  - More remotely/physically accessible

Traffic lights and controller in Ann Arbor, Michigan

- Ghena *et al.*, “Green Lights Forever: Analyzing the Security of Traffic Infrastructure,” WOOT 2014.

- **Scalability**
  - Security solutions for IoT should be scalable!



- Source: Cisco IBSG, April 2011

- IoT security challenges from Miorandi *et al.*, AD Hoc Networks, 2012, Jing *et al.*, Wireless Networks, 2014, Sadeghi *et al.*, DAC, 2015

IoT-related Security Requirements Breakdown

- Frequent authorization/authentication
- Automated mutual authentication
- Dealing with intermittent connectivity
- Support for one-to-many communication (for scalability)
- Consideration for resource constraints
- Privacy
- Dynamic entity registration

Goals & Contributions of Proposed Network Architecture

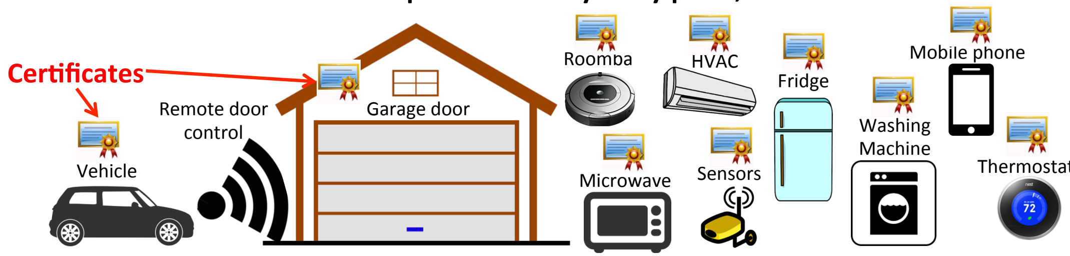
- Network-level approach using encryption/secure hash and authorization control over the Internet of Things

- New cipher/hash algorithms, new authentication/authorization system, new key management techniques? **No!**

- **Organization and integration** of existing approaches with emphasis on flexibility and usability
  - Specifically, to address IoT-related security requirements in the previous slide

Issues with Applying Widely-Used SSL/TLS for All Devices in the IoT

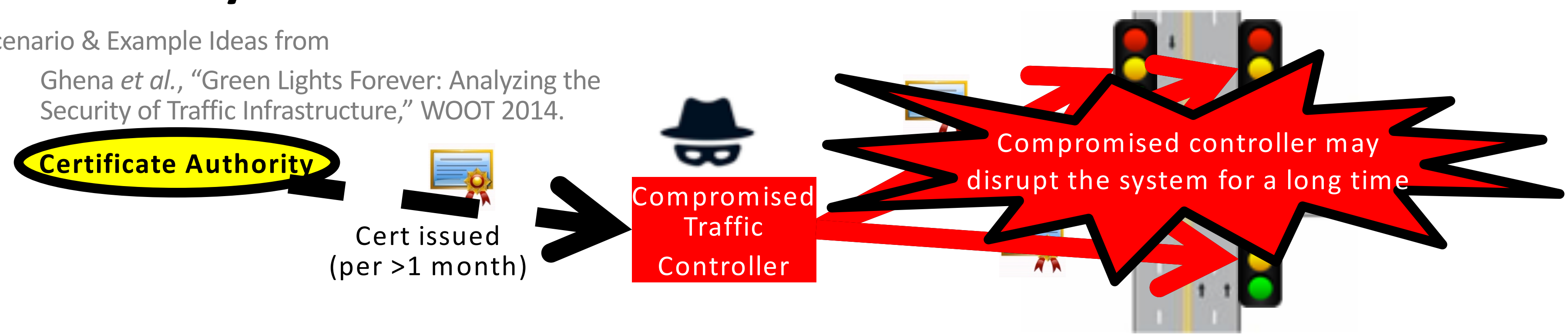
- Overhead for **resource-constrained devices**
  - Energy/computation overhead for public key crypto, communication bandwidth, memory, etc.



- Limited support **one-to-many communication** (e.g., pub/sub)
  - Connections are based on 1-to-1 connections (server/client model)
- **Security issue** for entities **under untrusted environment**

Scenario & Example Ideas from

- Ghena *et al.*, "Green Lights Forever: Analyzing the Security of Traffic Infrastructure," WOOT 2014.



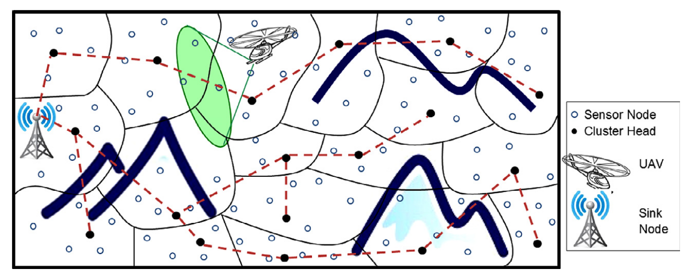
  - Once a certificate is issued, CA does not control connections between entities

Kerberos and Approaches in WSNs

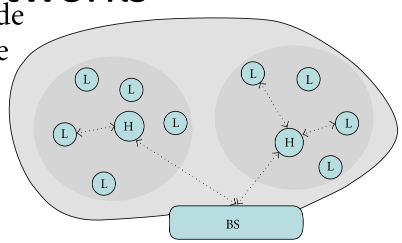
- **Kerberos authentication system**[1] provides direct control over connections between entities by issuing temporary tickets for authentication
- However, Kerberos has limited support for automated authentication and intermittent connectivity

[1] C.Neuman, T.Yu, S.Hartman, and K.Raeburn, “The Kerberos Network Authentication Service (V5),” RFC 4120, IETF, Jul. 2005.

- Huang *et al.*, 2011
  - For hierarchical/heterogeneous sensor networks
- Sahingoz, 2013
  - Using UAV for authentication of large-scale WSNs



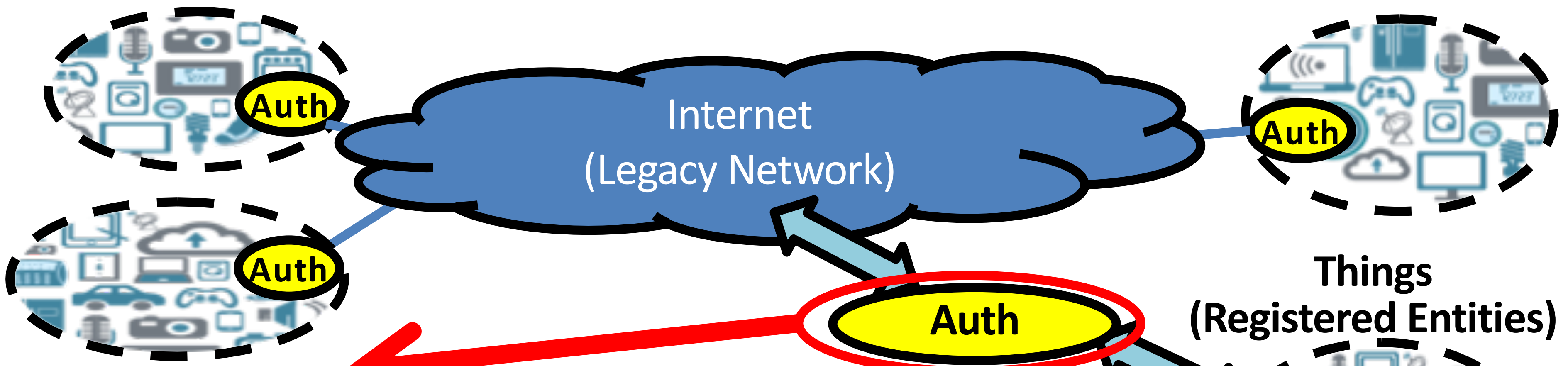
BS: Base station
H: H-sensor node
L: L-sensor node



- Erfani *et al.*, 2015
  - A key management system for dynamic addition/deletion of mobile nodes

Proposed Architecture Overview

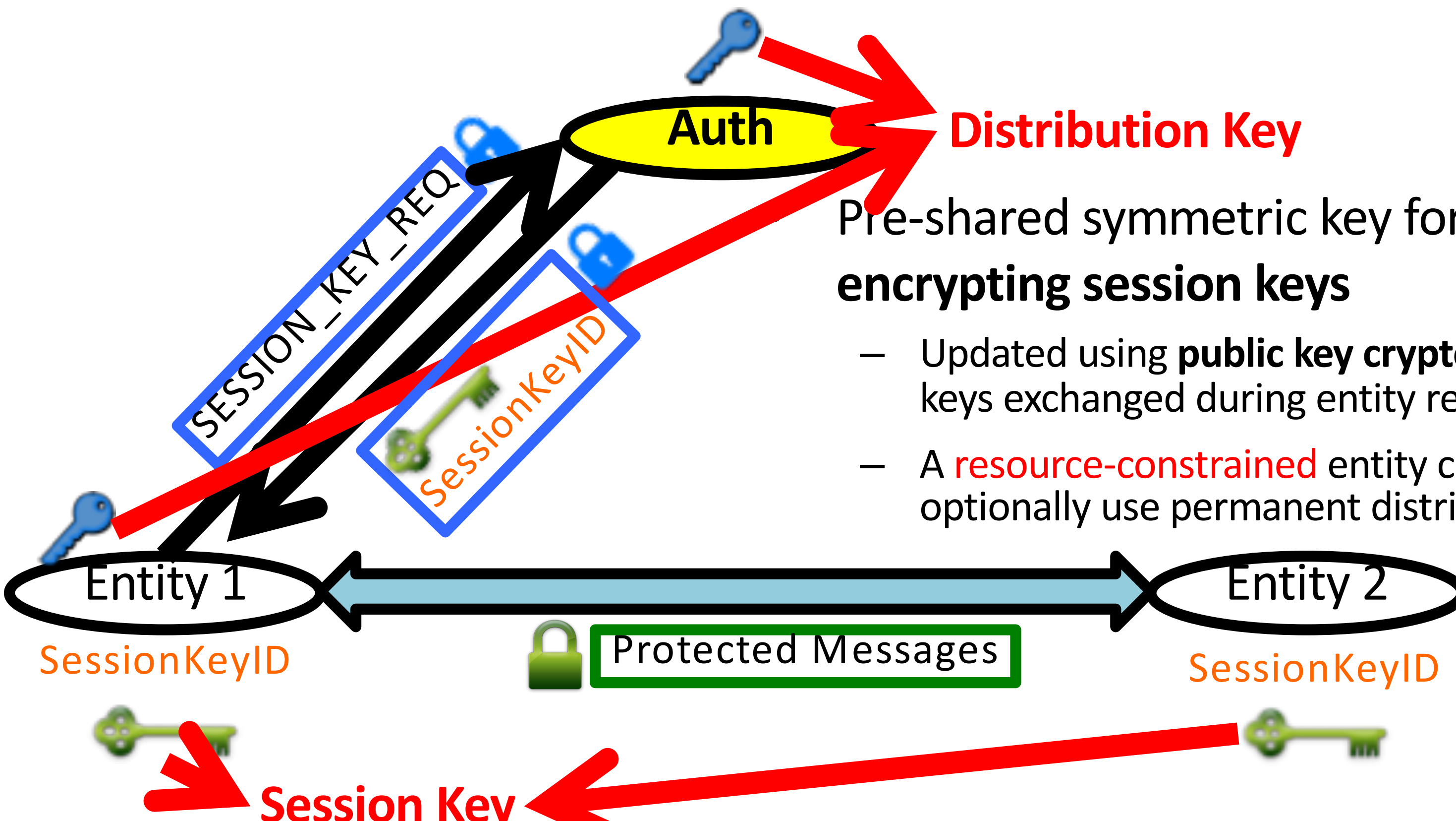
Auth – Local Authorization Entity



- **Local point of auth**(authentication/authorization) & trusted third party for locally registered entities
- Make communication authorization locally manageable
- Fully automated except for entity registration
- Deployed on bridges between the **Internet** and **Things** (e.g., Intel IoT gateways)

Proposed Architecture Overview

Keys Used in Proposed Architecture



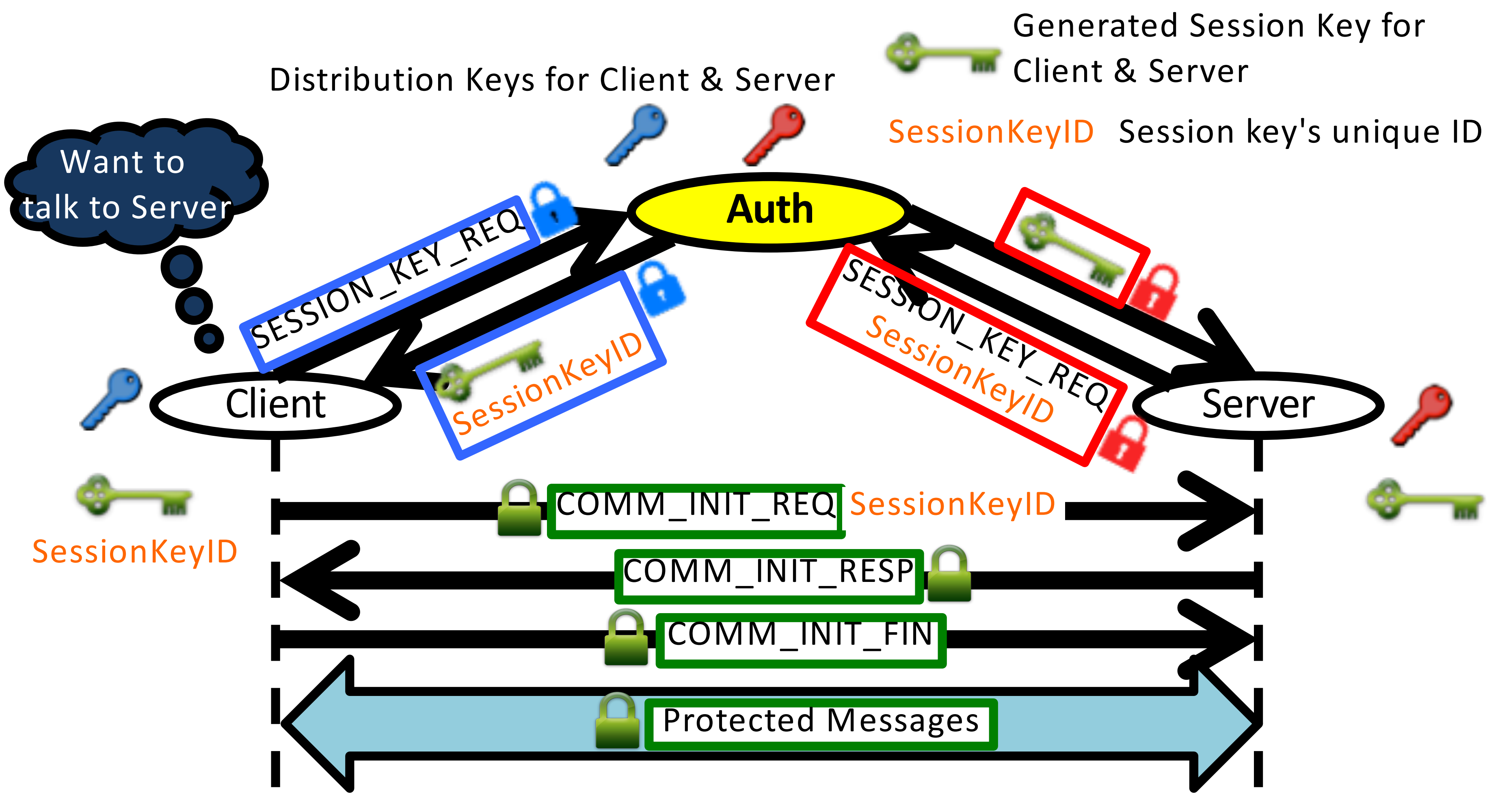
Pre-shared symmetric key for **encrypting session keys**

- Updated using **public key crypto** (public keys exchanged during entity registration)
- A resource-constrained entity can optionally use permanent distribution

- Symmetric crypto key for **protecting a single session** of communication
  - Given to only authorized devices
  - Unique **Session key ID**, including ID of Auth who generated it

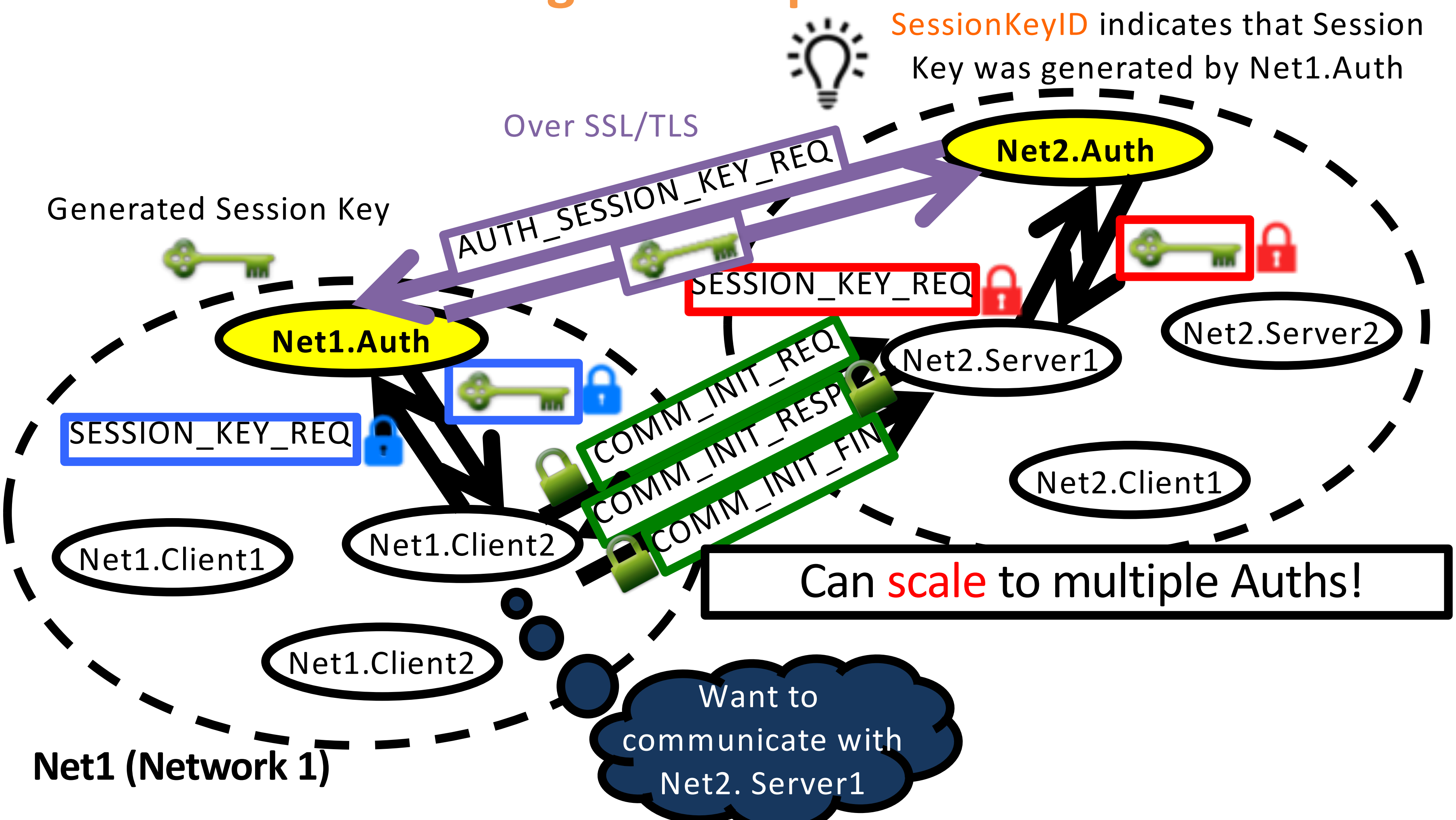
Proposed Architecture Overview

Operation Phases – With an Example Scenario



Proposed Architecture Overview

Scaling To Multiple Auths



Proposed Architecture Overview

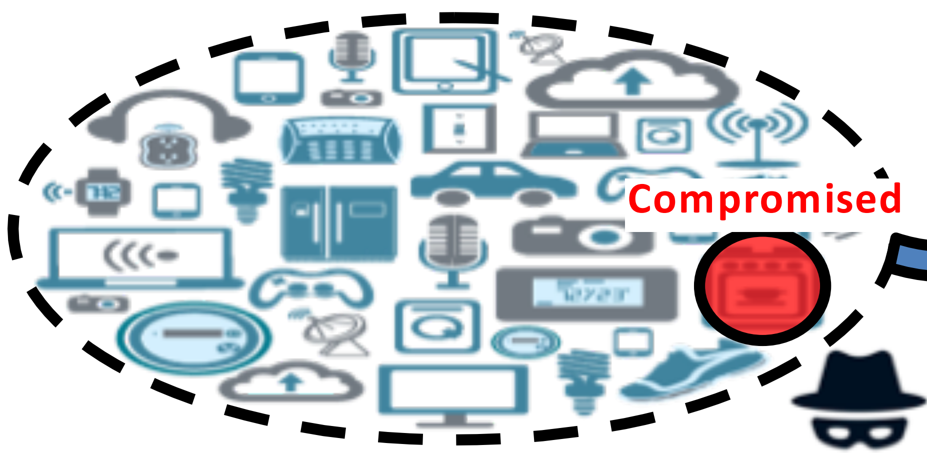
Auth DB – Information for Local Authorization

Main Database Tables

- Registered Entity Table
- Communication Policy Table
- Cached Session Key Table
- Trusted Auth Table

Auth DB

Auth



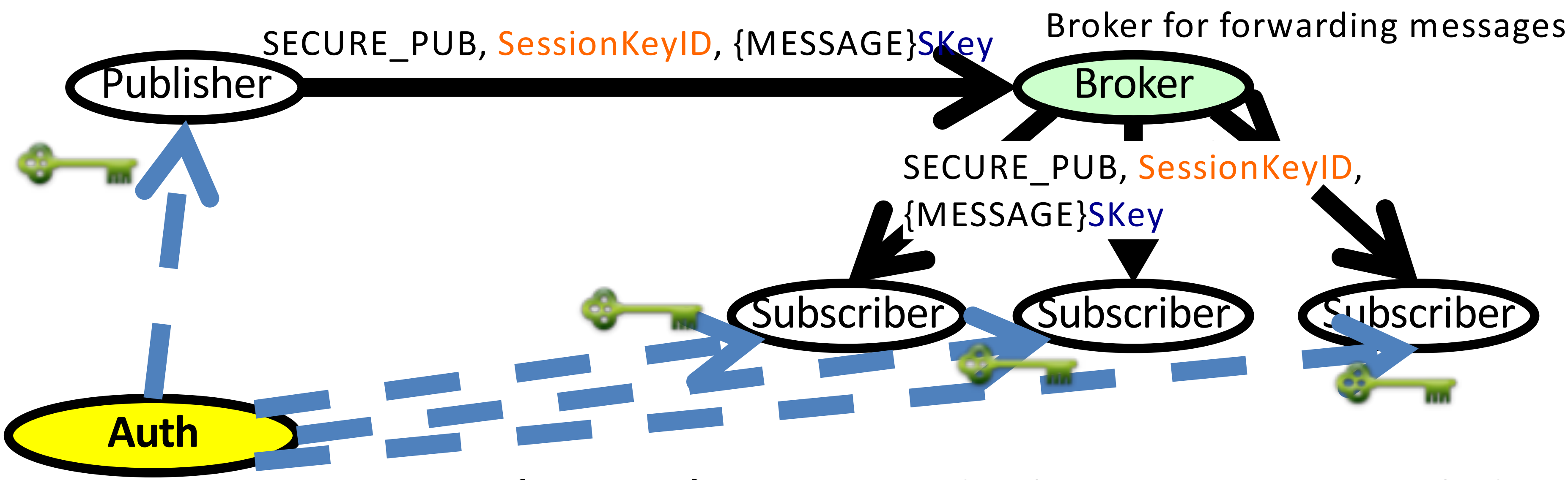
Auth DB will be updated to revoke credentials

- Invalidate cached keys
- No more keys for authorization

If an intrusion or a compromised entity is detected

Support for One-to-Many Communication

- Distributing shared key for securing one-to-many communication (e.g. broadcasting, publish-subscribe protocol such as MQTT)



- **{MESSAGE}SKey:** Encrypted with Session Key, MAC attached

- Possible **integration** with one-to-many communication authentication protocols, such as TESLA[1] (Timed Efficient Stream Loss-tolerant Authentication)

[1] A. Perrig, R. Canetti, J. Tygar, and D. Song, "The TESLA Broadcast Authentication Protocol," RSA CryptoBytes, 2005.

Experimental Setup & Implementation

- Compare security overhead with **SSL/TLS**
  - Widely used, can support strong crypto including public key crypto
  - Compare security overhead (crypto operations & sent/received packets)
- Prototype implementation
  - Use **Node.js** to implement Auth and Entities for Proposed and SSL/TLS
  - Modify **OpenSSL library** included in Node.js to capture crypto operations
- Overhead ➔ Energy consumption (energy numbers are obtained from [1],[2])

Same cipher/hash algorithms for **Proposed** and **SSL/TLS**

Operation	Energy cost
RSA-2048	91.02 mJ per encrypt/sign operation
	4.41 mJ per decrypt/verify operation
AES-128-CBC	0.19 µJ per byte encrypted/decrypted
SHA-256	0.14 µJ per byte digested
Send* packet	454 µJ + 1.9 µJ × packet size (bytes)

[1] Rifa-Pous and Herrera-Joancomarti, "Computational and Energy Costs of Cryptographic Algorithms on Handheld Devices," Future Internet, 2011.

[2] Feeney and Nilsson, "Investigating the energy consumption of a wireless network interface in an ad hoc networking environment," INFOCOM 2001

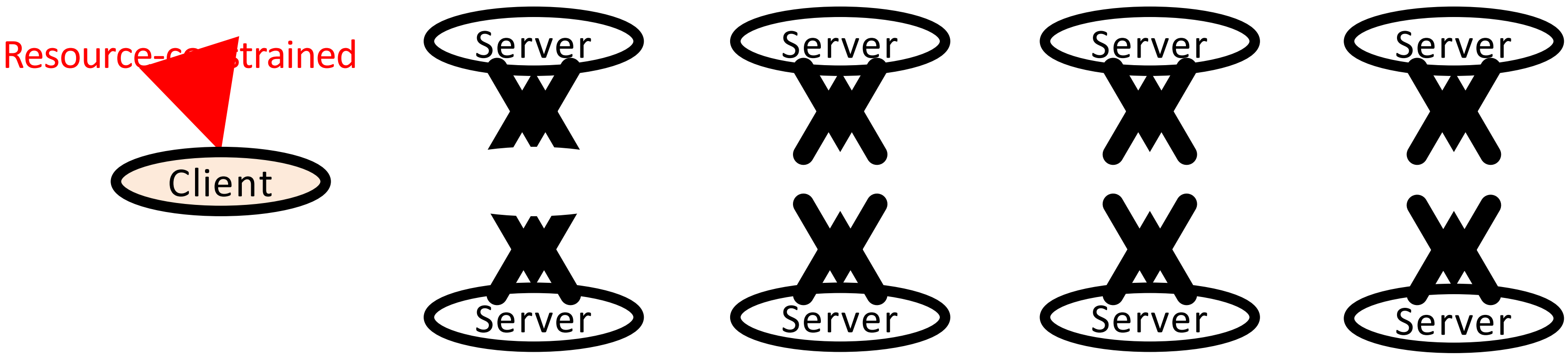
❖ Energy consumption for crypto operations measured on a PDA, HP Hx2790

❖ Energy consumption for IEEE 802.11 … WaveLan … onment

Experiments are carried out using two scenarios that can occur frequently in the IoT

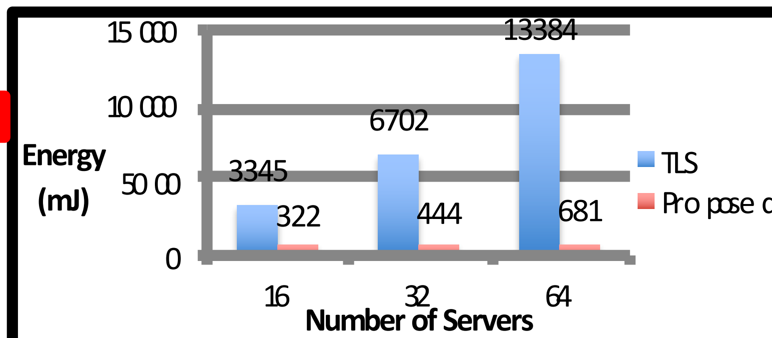
Scenario 1 Experiments & Results

- **Scenario 1**
  - A **resource-constrained client** establishes secure connection with **servers**



- **Results**: client setup/close with 16, 32, 64 servers

Number of Servers	16 servers		32 servers		64 servers	
Approaches	TLS	Proposed	TLS	Proposed	TLS	Proposed
RSA-2048 (Enc/Decrypted)	32/32	2/2	64/64	2/2	128/128	2/2
AES-128-CBC (Bytes)	5,120	3,744	10,240	7,392	20,480	14,688
SHA-256 (Bytes)	188,976	1,957	377,952	3,349	755,904	6,133
Packets (Sent/Received)	159/145	135/120	332/300	263/232	650/587	511/449
Sent Bytes	56,168	11,031	113,120	21,143	222,502	40,735
Received Bytes	66,808	9,453	134,176	17,805	263,956	34,023

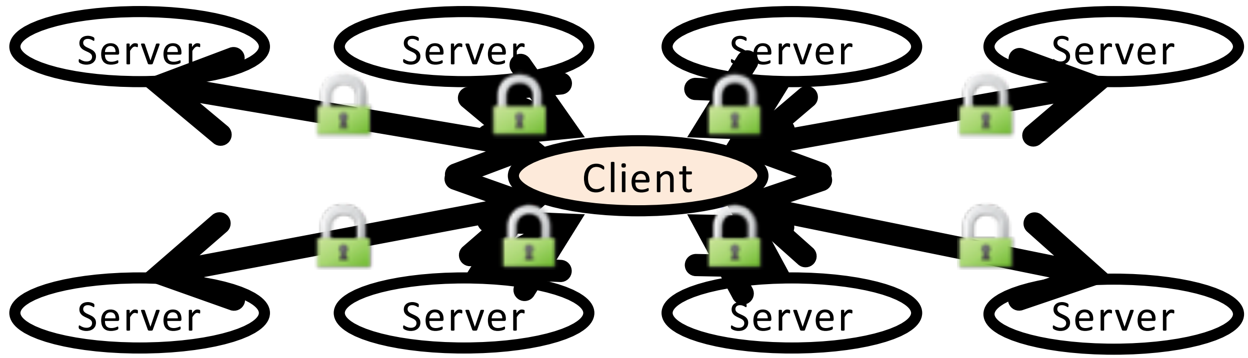


Less energy, by optimizing the use of crypto algorithms

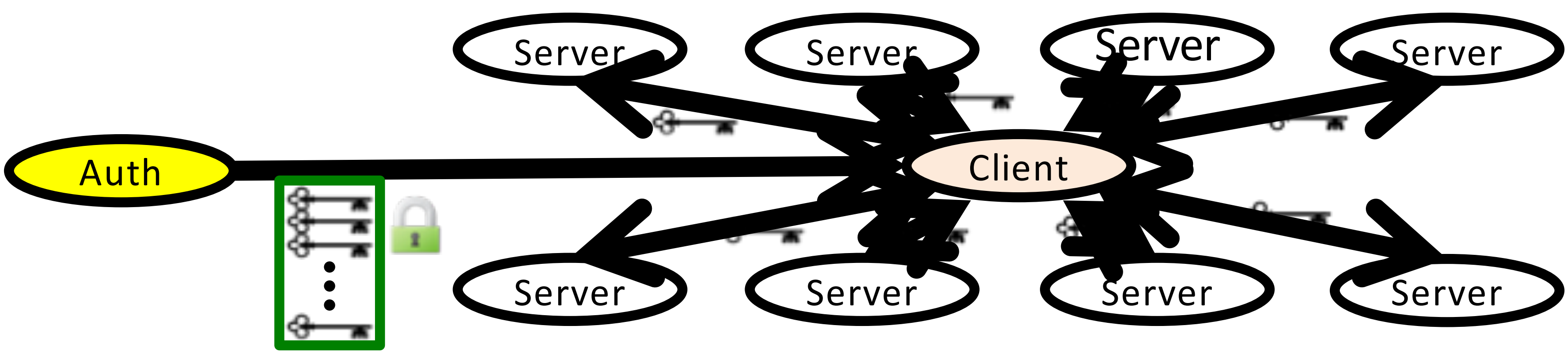
Scenario 1 Experiments & Results

: Public key crypto operations

- **SSL/TLS** – each connection with servers needs public key operations



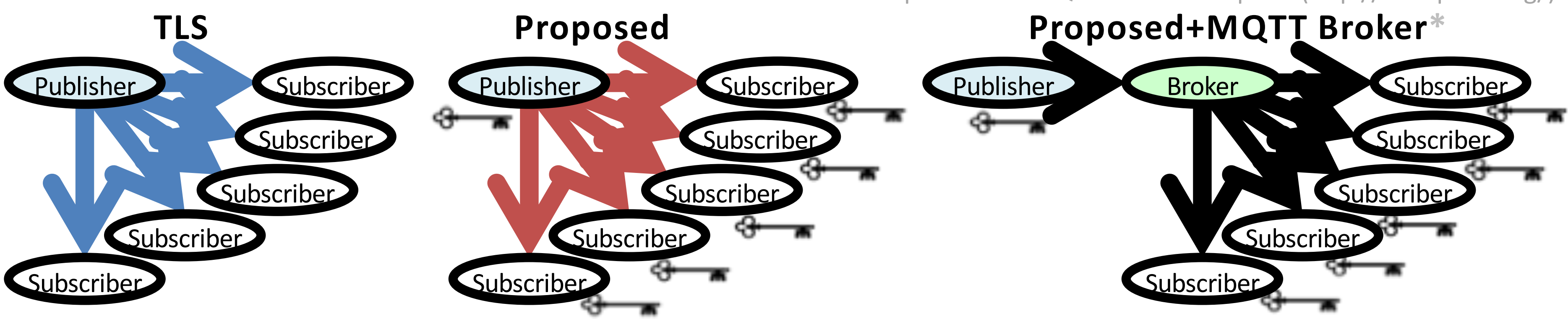
- **Proposed** – public key operations only necessary for communication with Auth



Scenario 2 Experiments & Results

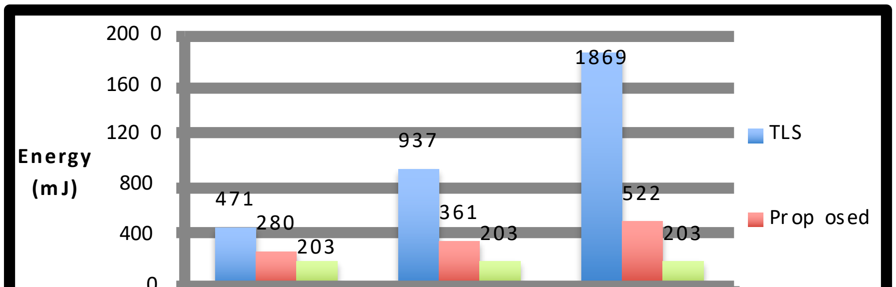
- **Scenario 2**
  - A **resource-constrained publisher** publishes a message that **only authorized subscribers** can read

* Open source MQTT broker Mosquitto (http://mosquitto.org/)

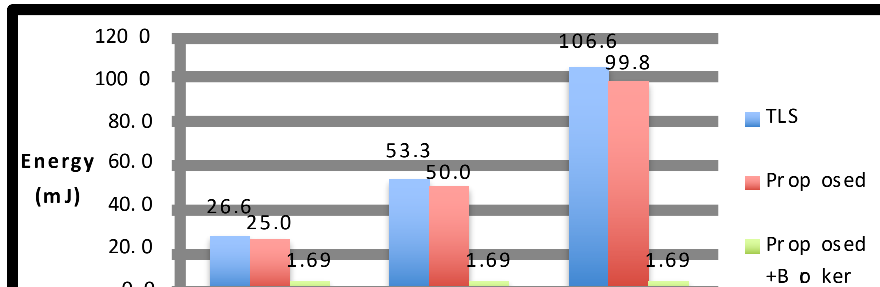


: Shared session key for a pub-sub topic

- Estimated energy for **publisher setup**



- For **publishing** a 256-byte message



Saves not just crypto operations, but also communication

Wrap-up Discussion

- How proposed approach can meet IoT security requirements

Requirements	Proposed Approach
Frequent authentication/authorization	– Auth controls every communication, short key validity period
Automated mutual authentication	– No human intervention required
Intermittent connectivity	– Use of cached keys
Support for scalability features	– Shared session key for more than two entities for publish-subscribe
Consideration for resource constraints	– Use of small, lightweight symmetric session key for authentication
Privacy	– No unique identifier for authentication (temporary session key)
Dynamic entity registration	– Register/unregister can be done within Auth

Conclusion & Future Work

- Proposed **secure network architecture** based on local authorization entities, which can
  - Integrate existing network security measures
  - Address IoT-related heterogeneous security requirements
- Implemented **prototypes** of proposed approaches, obtained preliminary but **promising results**
- Currently working on
  - An open-source implementation of Auth in Java, and example codes for entities in various programming languages
  - Security analysis of protocol
  - Building software components for accessing Auth service

Thank you!

- Q & A

- Contact
  - hokeunkim@eecs.berkeley.edu
  - https://eecs.berkeley.edu/~hokeunkim

- Open-source project page
  - https://github.com/iotauth