TerraSwarm

A Toolkit for Construction of Authorization Service Infrastructure for the Internet of Things (IoT)

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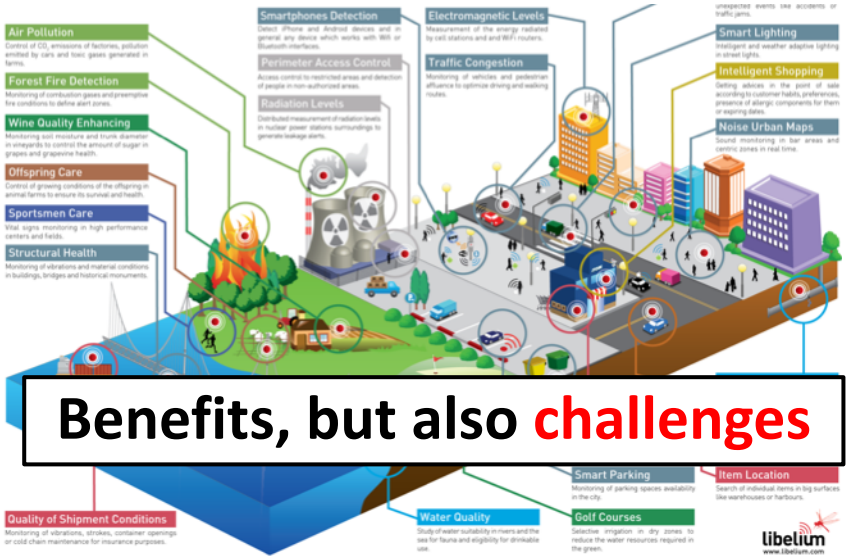
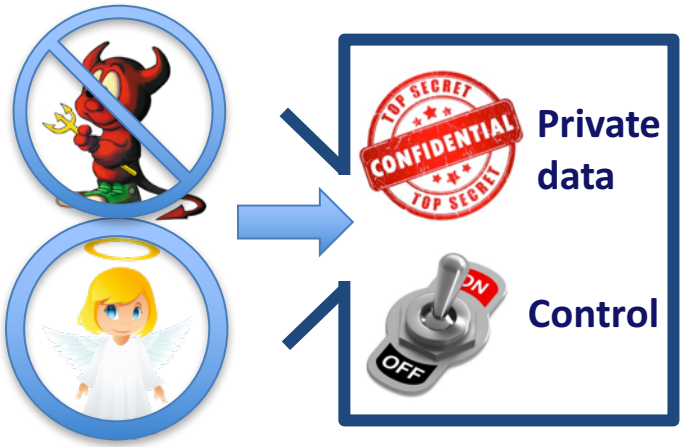
Overview – IoT & Authorization

- **Internet of Things**



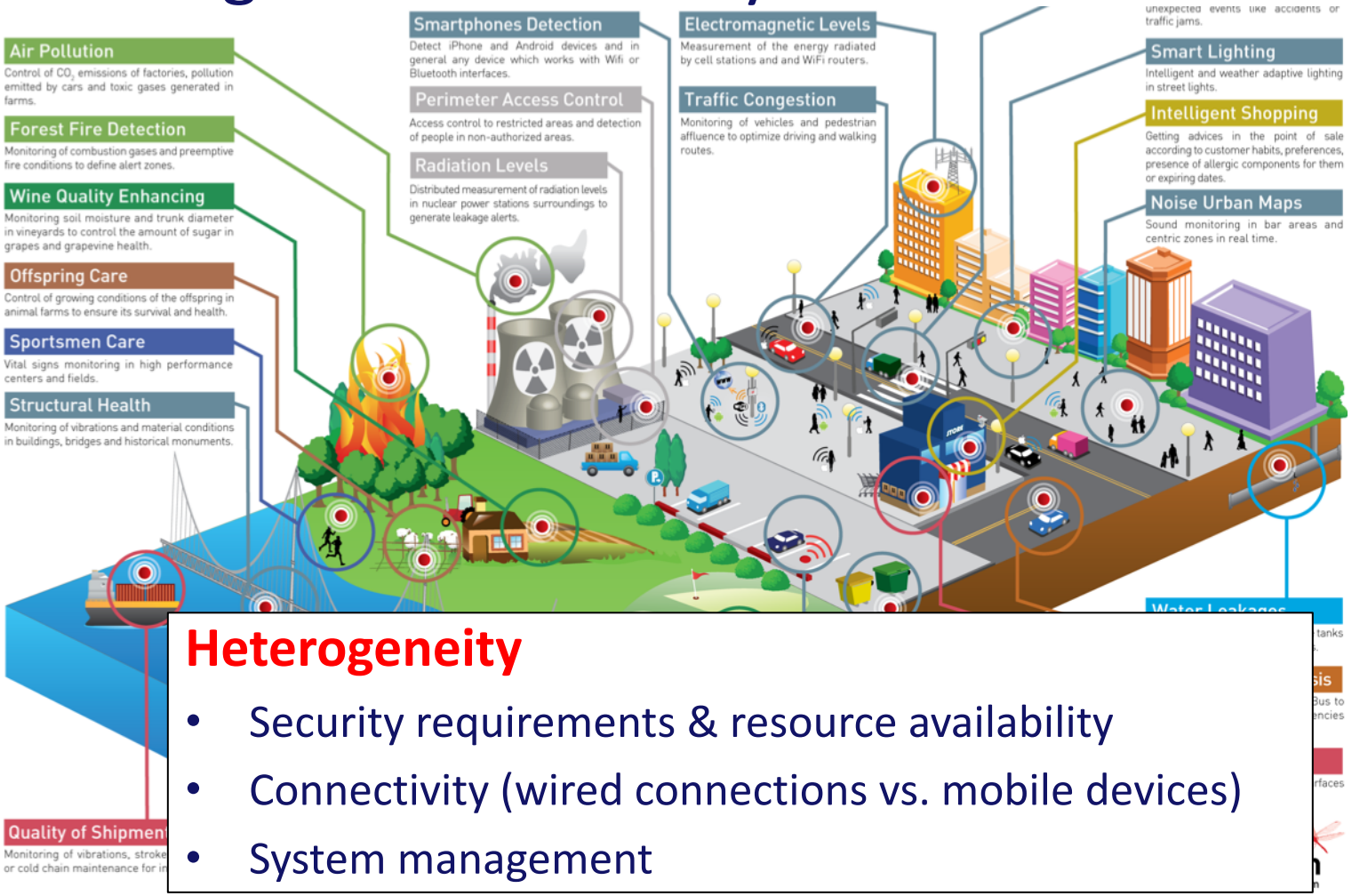
- **Authorization (access control)**
  - Critical for computer security



- **Existing security solutions?**
  - May work well for some parts of the IoT, but not for the entire IoT!
- **Proposed approach – SST**
  - SST: Secure Swarm Toolkit
  - An open-source toolkit for building authorization infrastructure for the IoT
  - To address IoT security challenges

Motivation

- Challenges in IoT security[1]



Heterogeneity

- Security requirements & resource availability
- Connectivity (wired connections vs. mobile devices)
- System management

[1] Singh *et al.*, 2016. "Twenty Security Considerations for Cloud-Supported Internet of Things"

Motivation (cont'd)

- Challenges in IoT security[1]

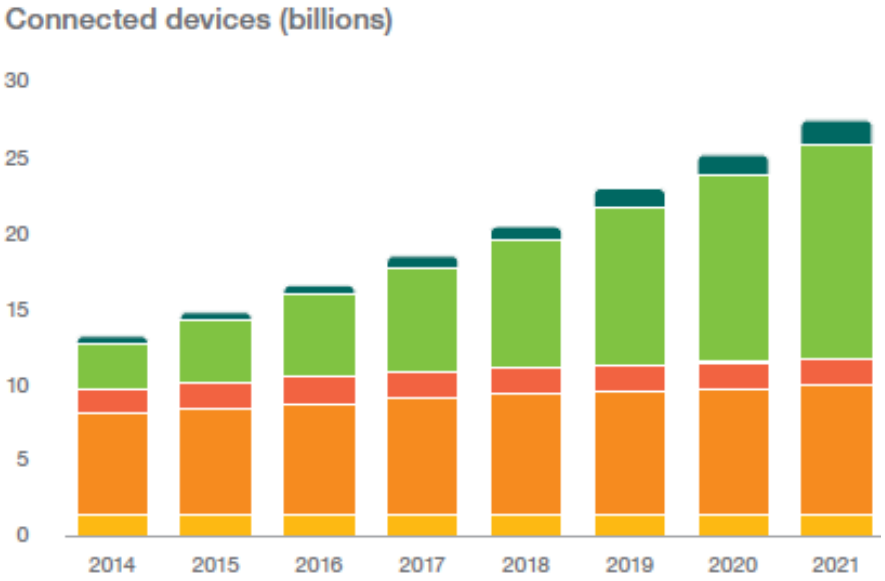
Operation in an open (or hostile) Environment

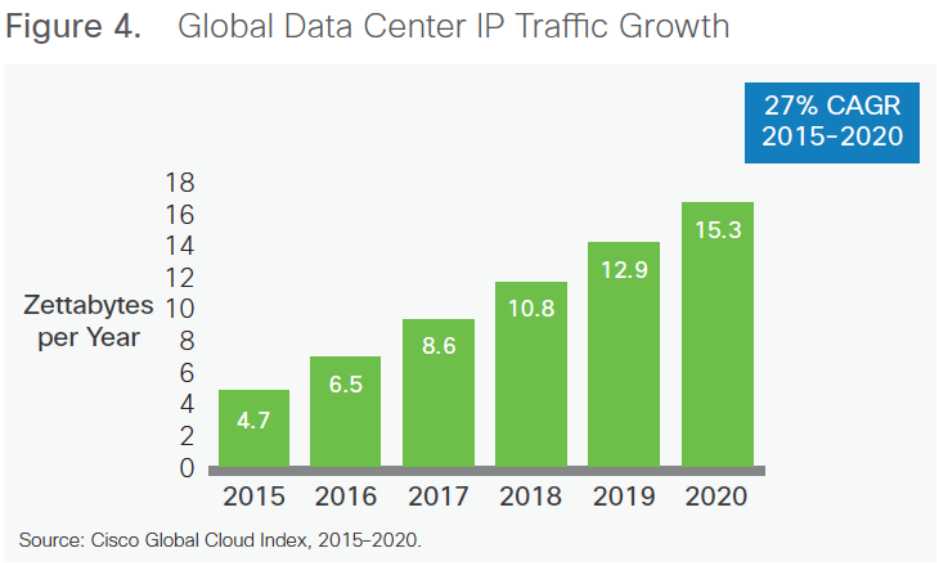
- Physical access & wireless access to IoT devices
- Higher risk of being compromised
- Must be able to revoke access of compromised IoT devices

[1] Singh *et al.*, 2016. "Twenty Security Considerations for Cloud-Supported Internet of Things"

Motivation (cont'd)

- Challenges in IoT security[1]





Sources: "Ericsson Mobility Report", June 2016 / "Cisco Global Cloud Index: Forecast and Methodology,2015–2020", Published in 2016

Scalability

- 28 billion connected devices in 2021
- 15.3 ZB data traffic in 2020
  - 1 ZB (Zetta byte) = 10^9 TB (Terra bytes)

[1] Singh *et al.*, 2016. "Twenty Security Considerations for Cloud-Supported Internet of Things"

Background: Authorization & IoT

- Authorization
  - Access control
    - "Can I enter the EECS building?"
  - Allowing/denying access to resources
  - Revoking access (e.g., lost ID card)
- Authentication
  - Identifying someone/something
    - "Member of EECS?"
  - Essential for authorization

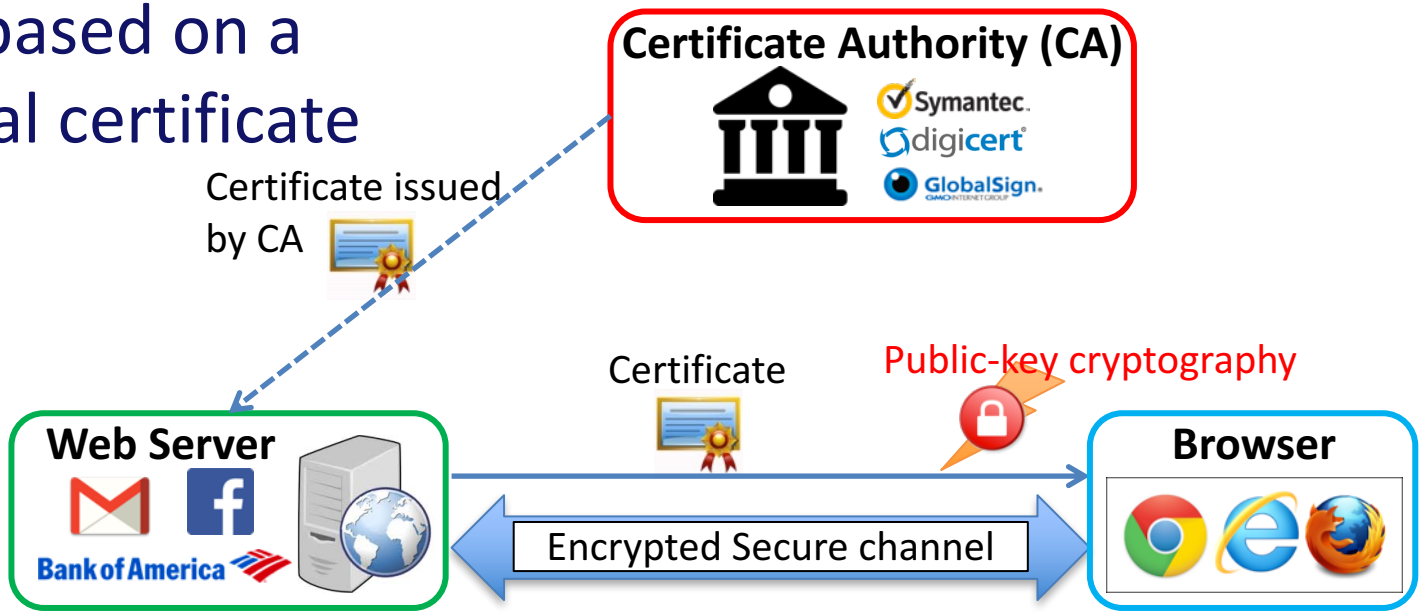
Background (cont'd)

- Many IoT platforms use TLS (or DTLS[2]) for authentication/authorization
  - E.g., Amazon AWS IoT, OpenIoT[3], OSCAR[4], etc.
- TLS (Transport Layer Security, also called SSL/TLS)
  - Underlying security protocol for HTTPS
  - Widely used, very successful for web

[1] Variant of TLS over UDP, 2012 "Datagram Transport Layer Security Version 1.2. RFC 6347"
[2] John Soldatos et al., 2015. "OpenIoT: Open Source Internet-of-Things in the Cloud"
[3] Vucinic et al., 2015. "OSCAR: Object security architecture for the Internet of Things"

Background (cont'd)

- TLS based on a digital certificate

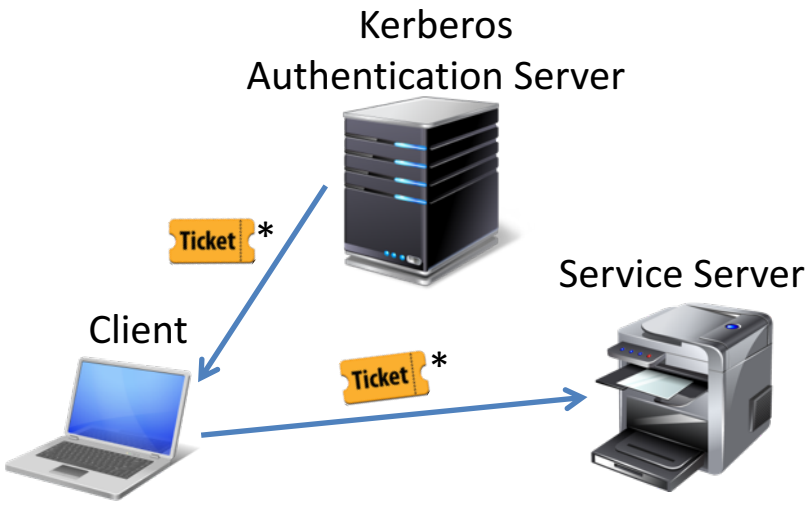


- Challenges with using TLS for the entire IoT
  - Energy overhead of public-key crypto & certificates
  - Scalability (managing certificates for ~28 billion devices)
  - Revocation of certificates can be problematic[1,2]
  - Limited support for one-to-many communication

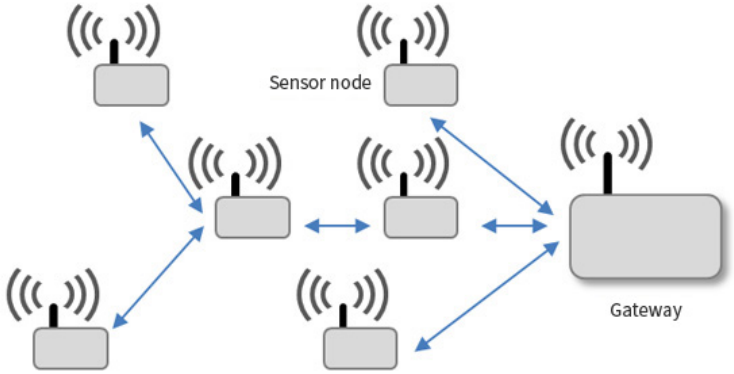
[1] Mutton, "Certificate revocation: Why browsers remain affected by Heartbleed", Netcraft, April, 2014
[2] Duncan, "How certificate revocation (doesn't) work in practice", Netcraft, May, 2013

Background (cont'd)

- Challenges with applying other security solutions



*Ticket: temporary token for accessing service



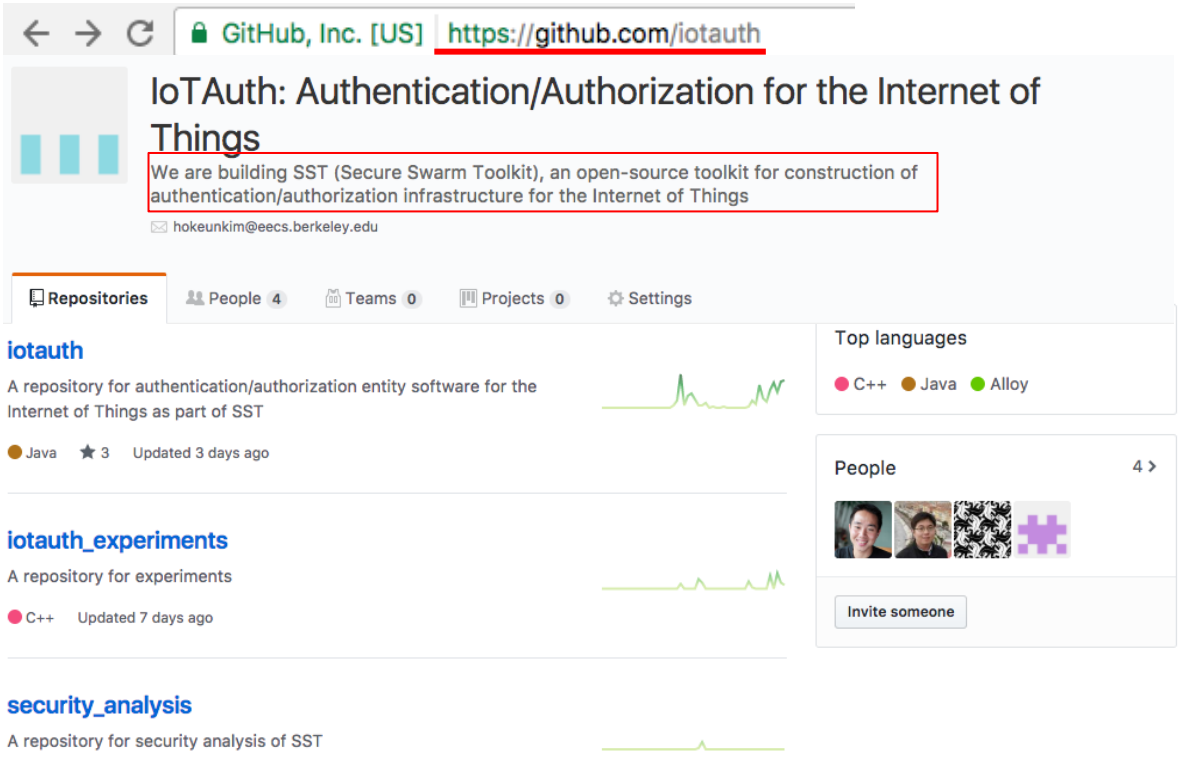
Source: http://www.yuden.co.jp/ut/solutions/wsn/

- Kerberos [1]
  - Advantages for access revocation
  - Requires stable connection
  - Centralized architecture
- Security solutions for "Things"
  - E.g., WSN, MANET or swarm devices
  - Assume homogeneous environments
  - Not designed for Internet scale[2]

[1] C. Neuman et al., 2005. "The Kerberos Network Authentication Service (V5)". RFC 4120
[2] Alcaraz et al., 2010. "Wireless sensor networks and the internet of things: Do we need a complete integration?"

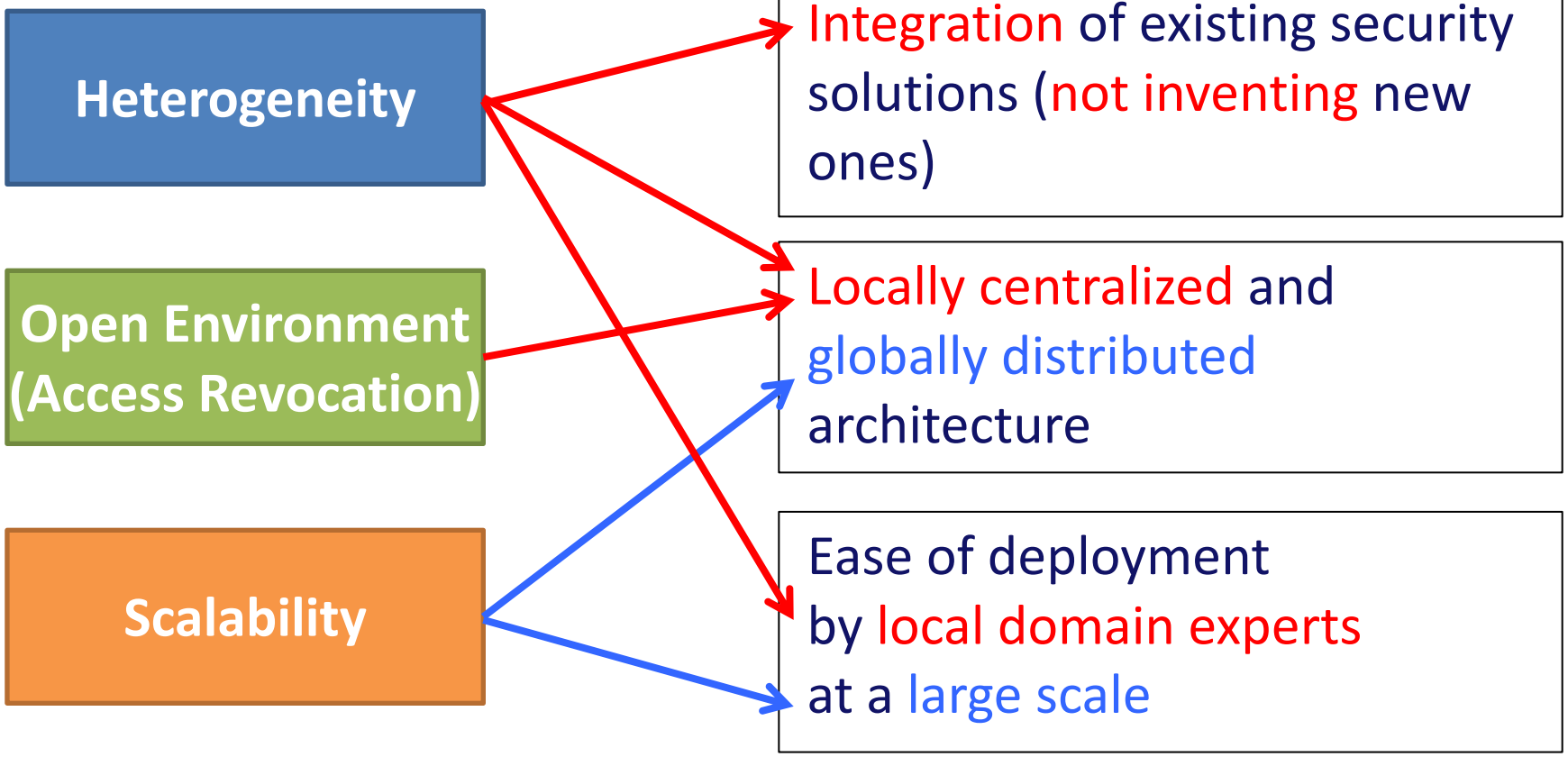
Proposed Approach

- **SST – Secure Swarm Toolkit**
  - An open-source toolkit for authentication/authorization of the IoT (available on https://github.com/iotauth)



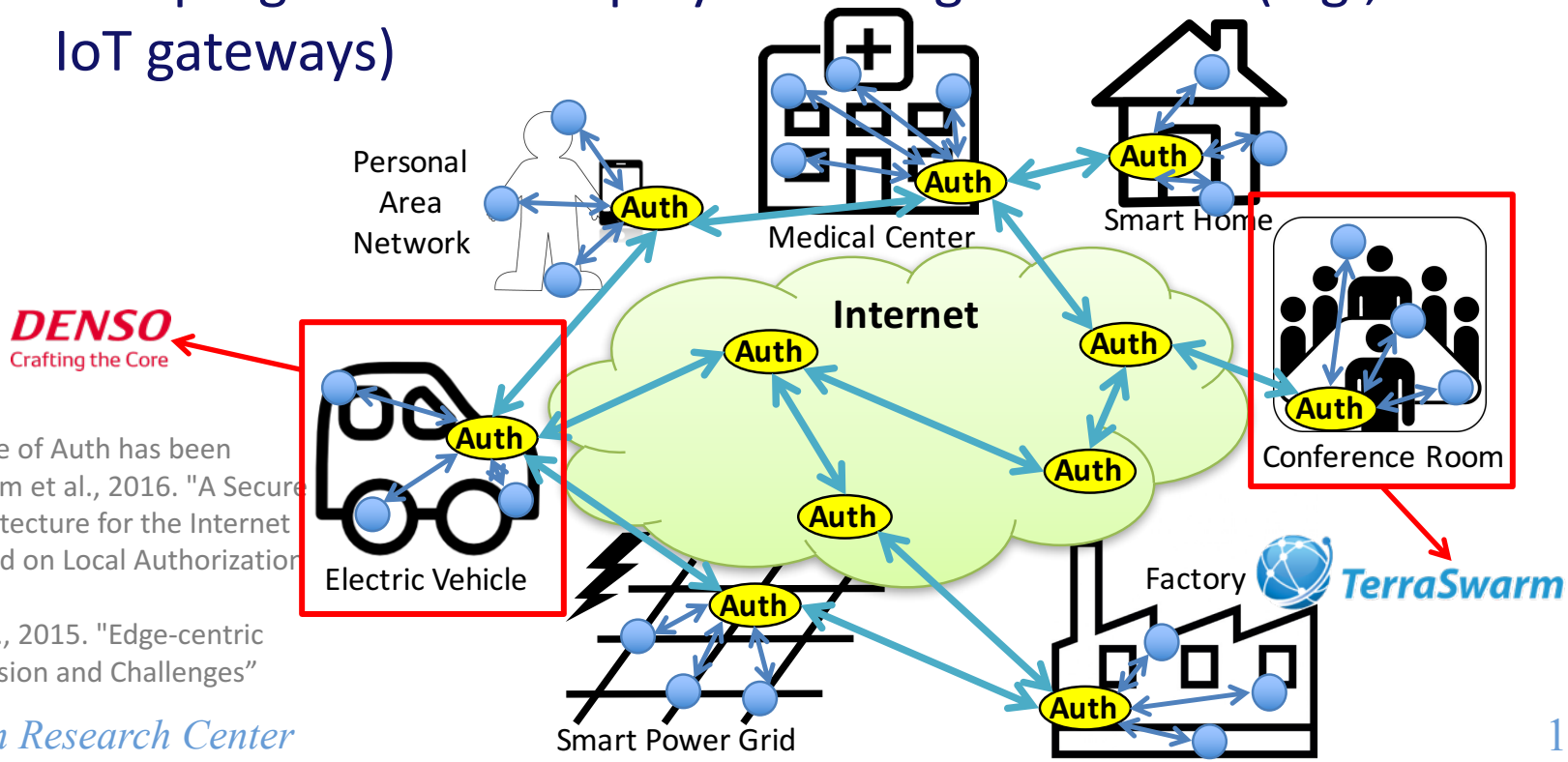
Proposed Approach (Cont'd)

- Specific goals of SST



SST's Design and Implementation

- Auth[1]
  - Locally centralized, globally distributed **auth**entication/**auth**orization entity (software)
  - Java program to be deployed on edge devices[2] (e.g., Intel IoT gateways)

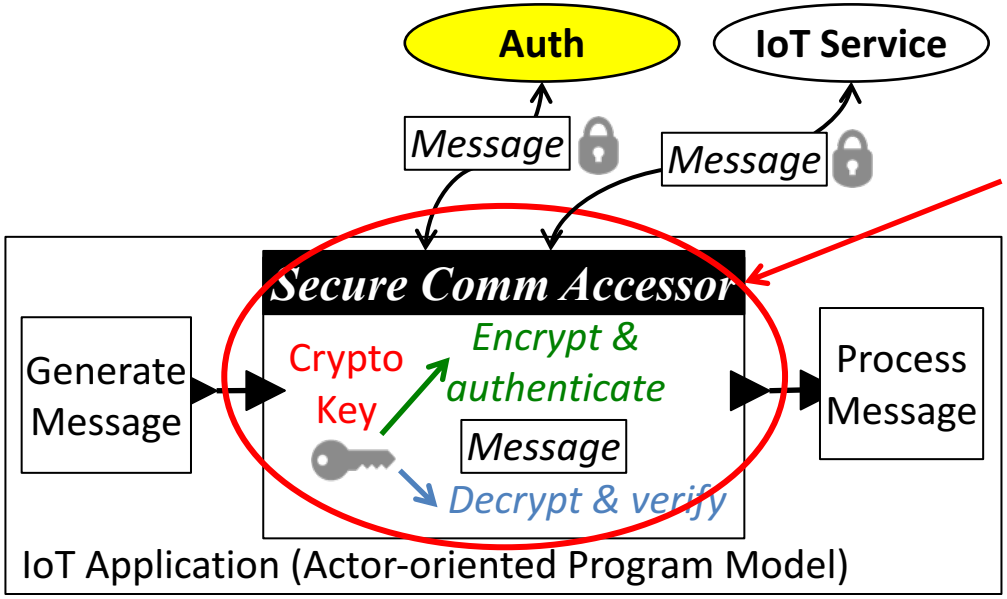


[1] A prototype of Auth has been proposed in Kim et al., 2016. "A Secure Network Architecture for the Internet of Things Based on Local Authorization Entities"

[2] Lopez et al., 2015. "Edge-centric Computing: Vision and Challenges"

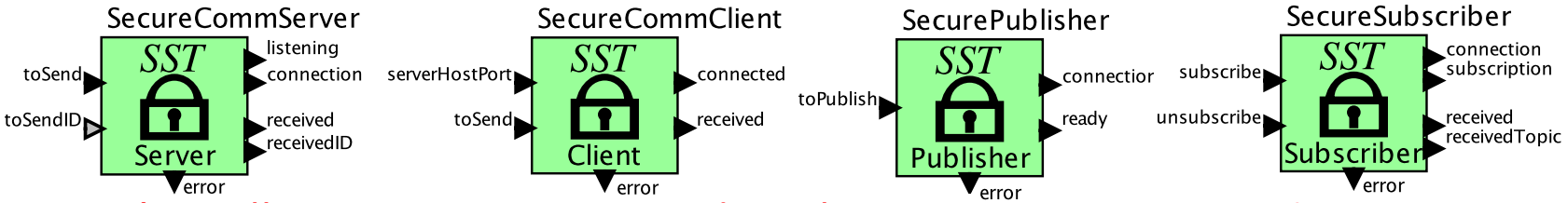
Design and Implementation (cont'd)

- Secure communication accessors



  - Software building blocks for securely accessing Auth and the IoT services
  - Encapsulate crypto keys & operations
  - Help IoT developers who are not security experts

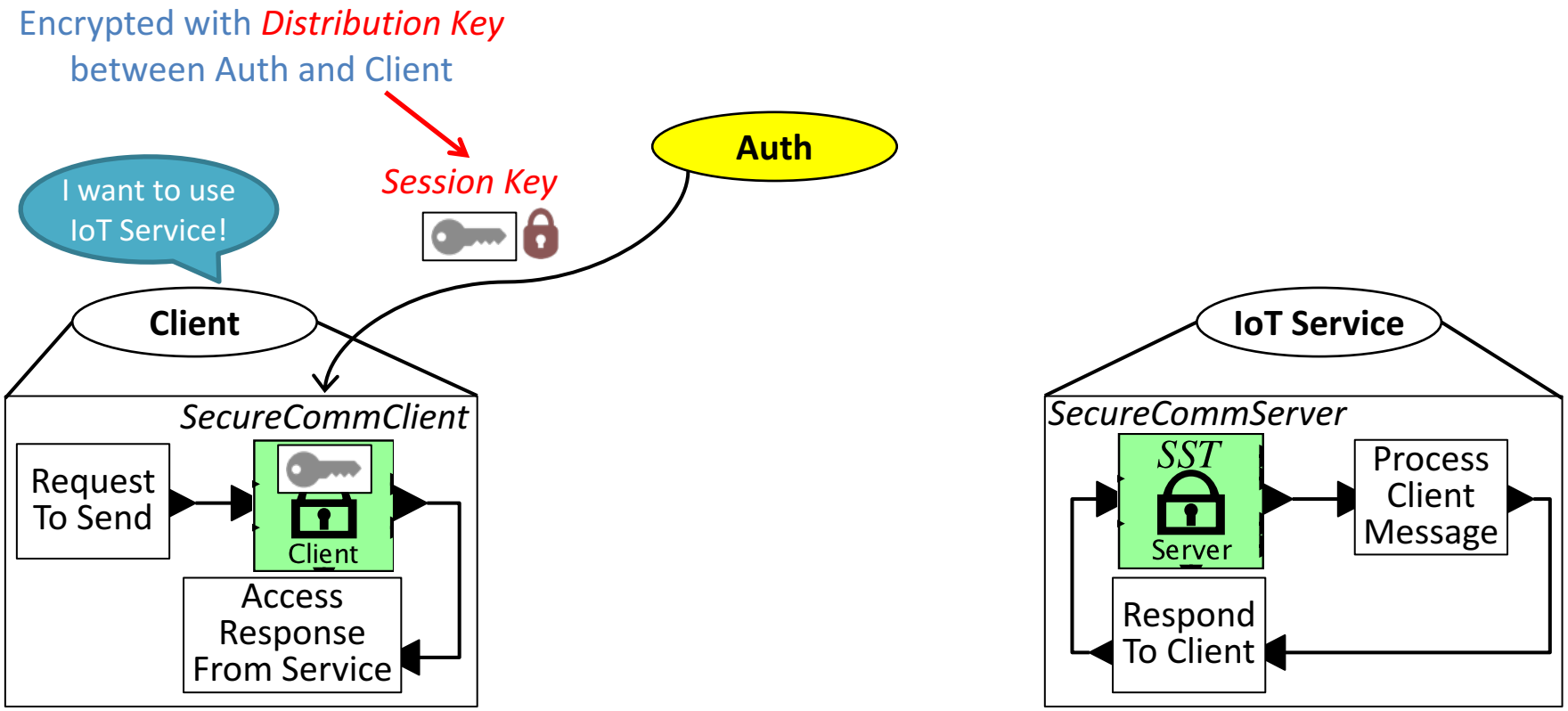
  - Currently available accessors (in JavaScript)



  - We're still at a starting point and working on more accessors!
  - For more information, see https://accessors.org

Design and Implementation (cont'd)

- Example: How SST (Auth and accessors) works



Design and Implementation (cont'd)

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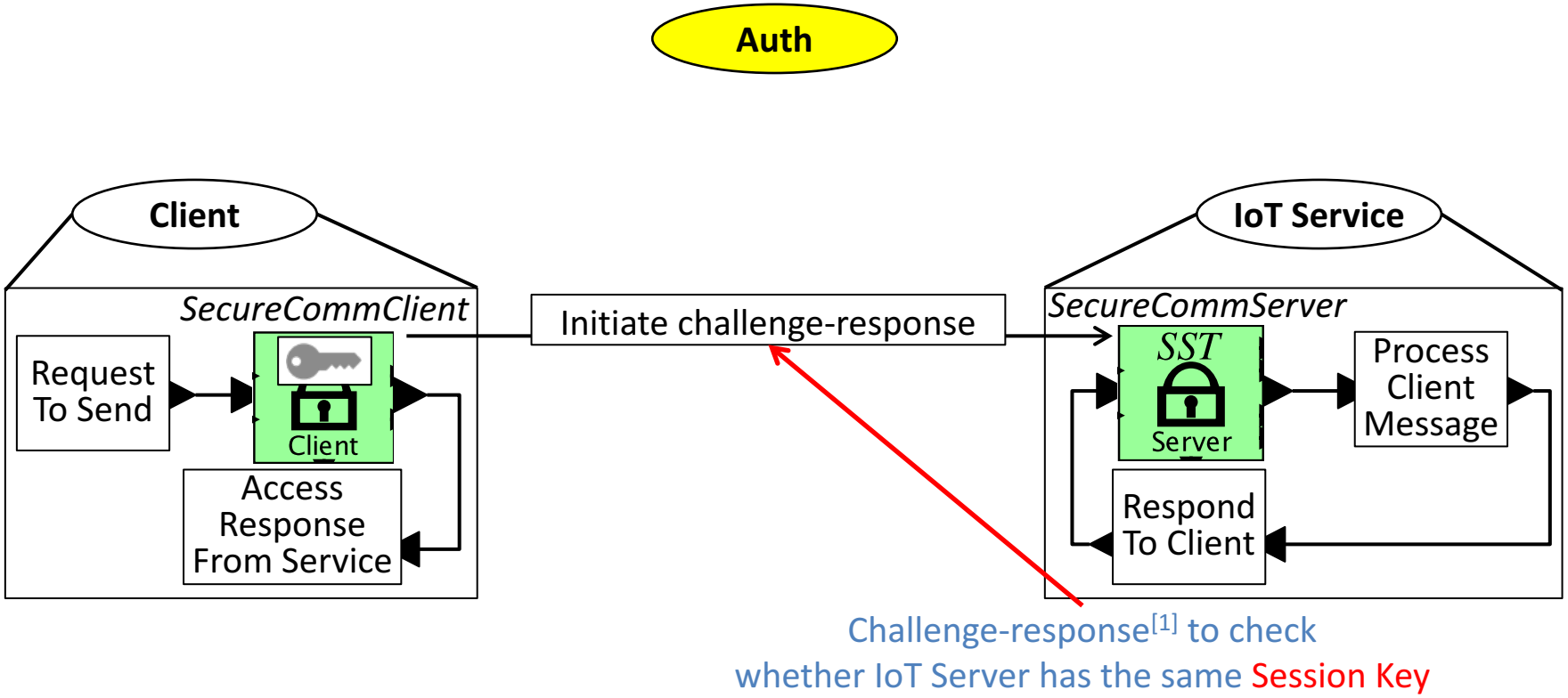

[1] Similar to TLS PSK extension by Eronen and Tschofenig. 2005. Pre-Shared Key Ciphersuites for TLS. RFC 4279.

Design and Implementation (cont'd)

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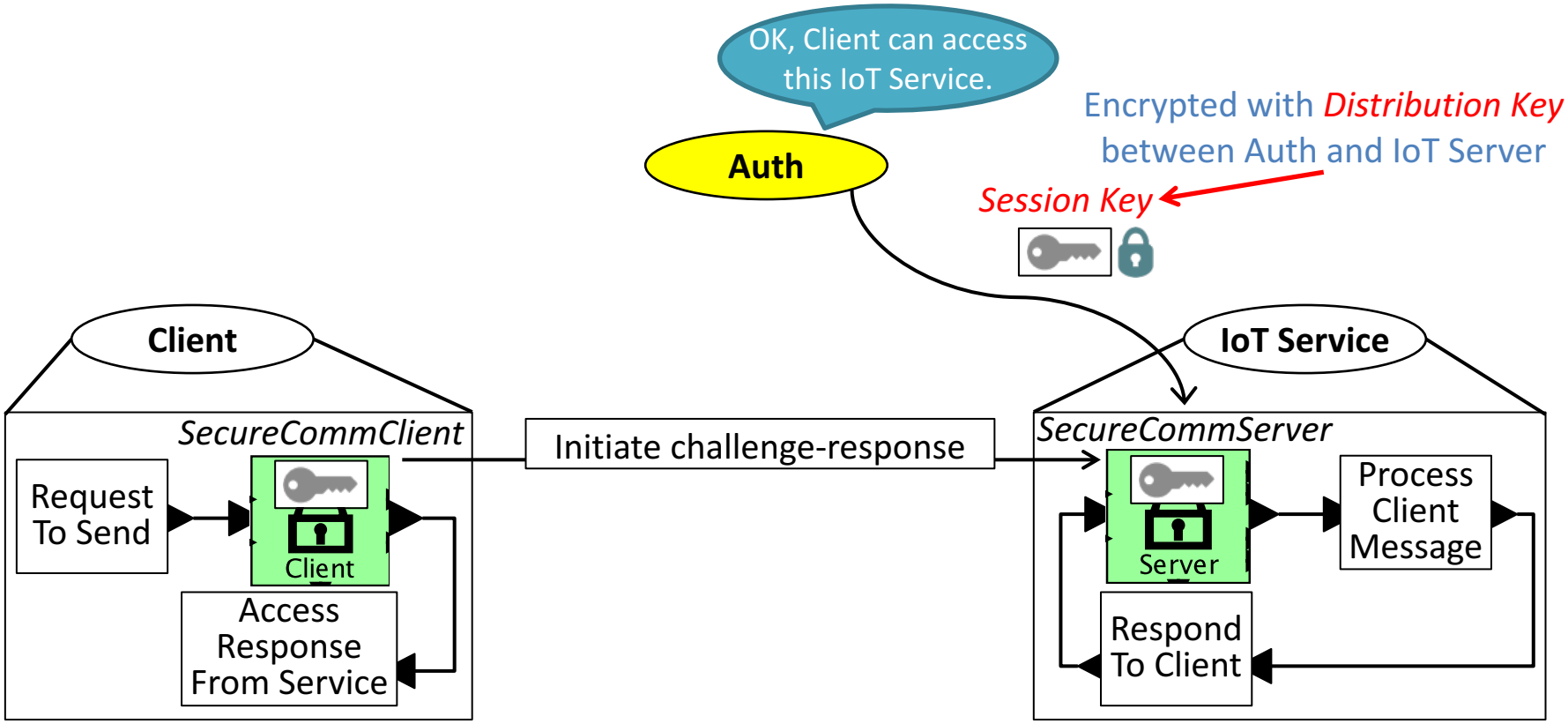

Design and Implementation (cont'd)

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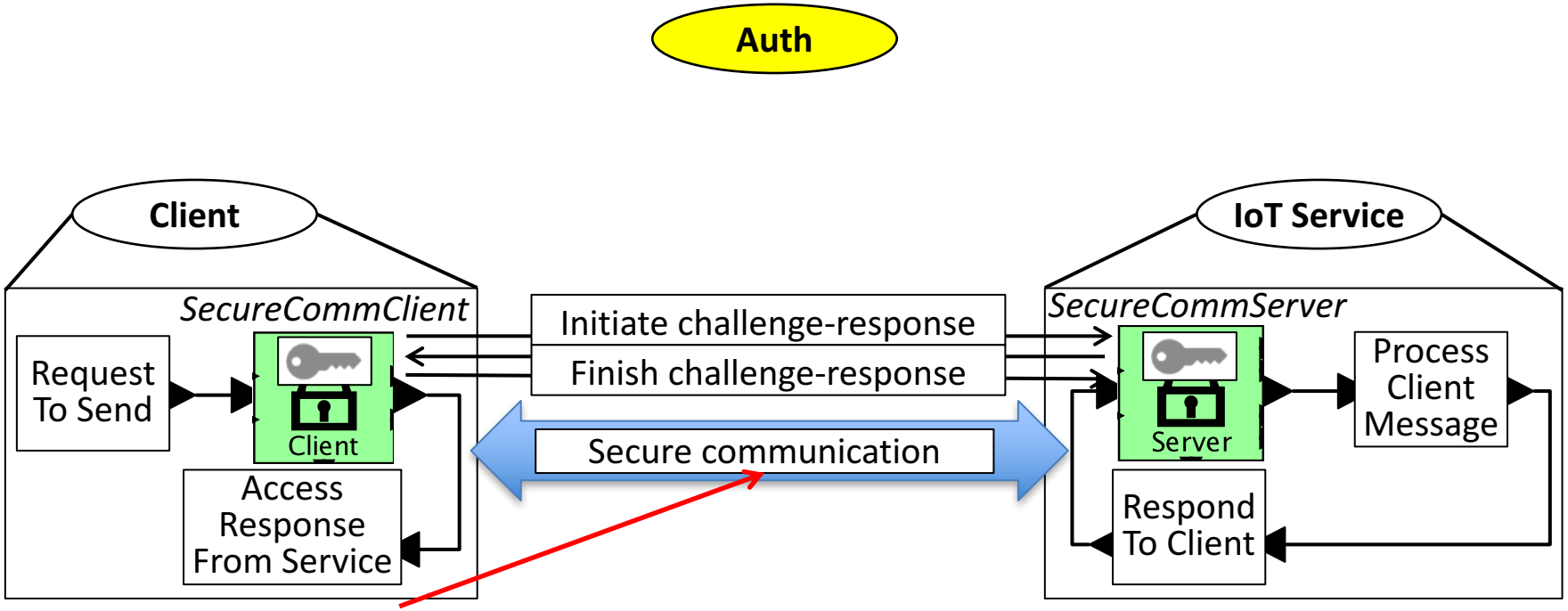


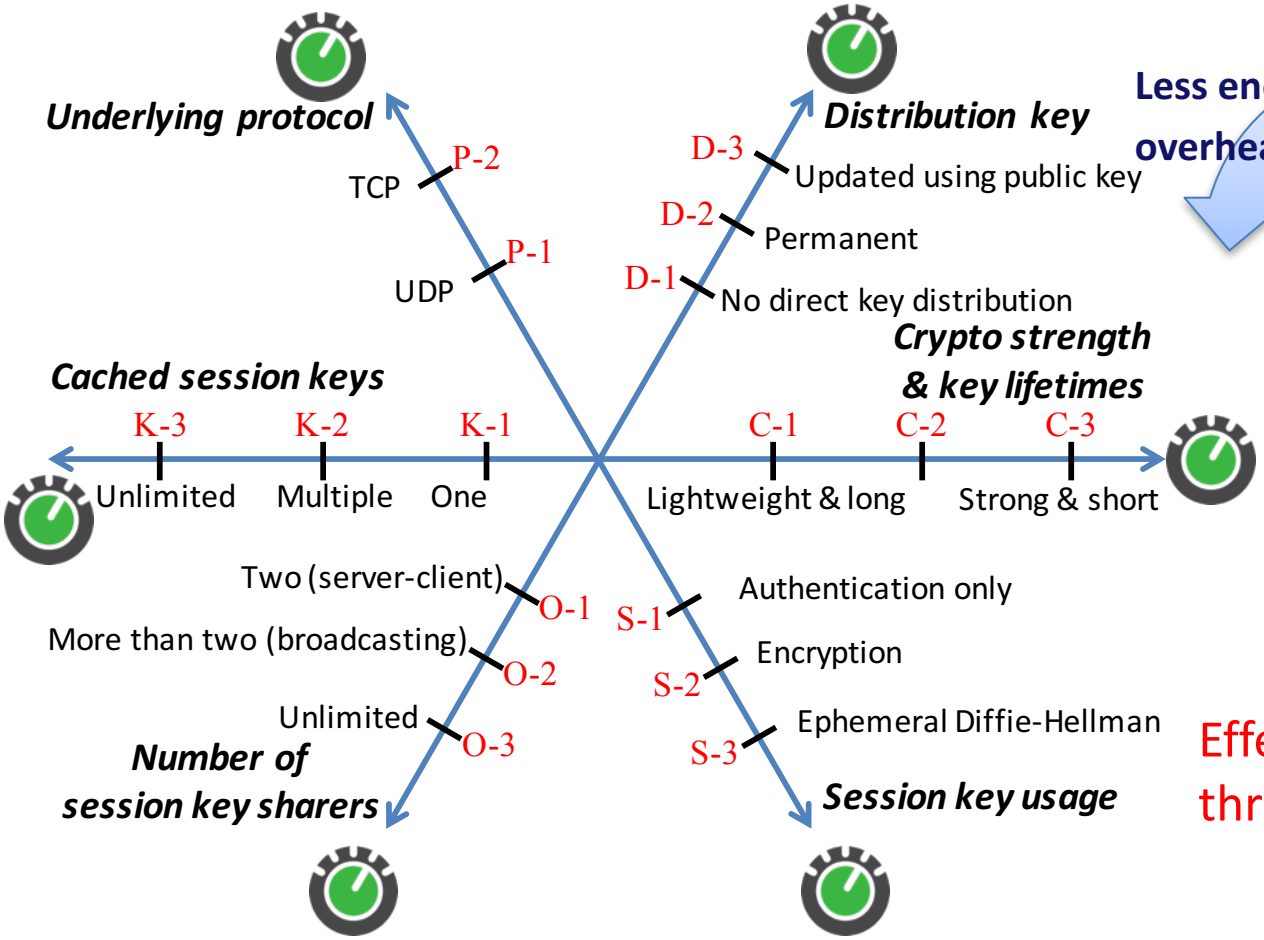
Protected communication channel using session key and standard cryptography[2]

[2] Followed TLS 1.2's standard, including sequence number, encrypt-then-MAC

SST for Heterogeneity

Heterogeneity
Open Env.
Scalability

- SST's configuration alternatives

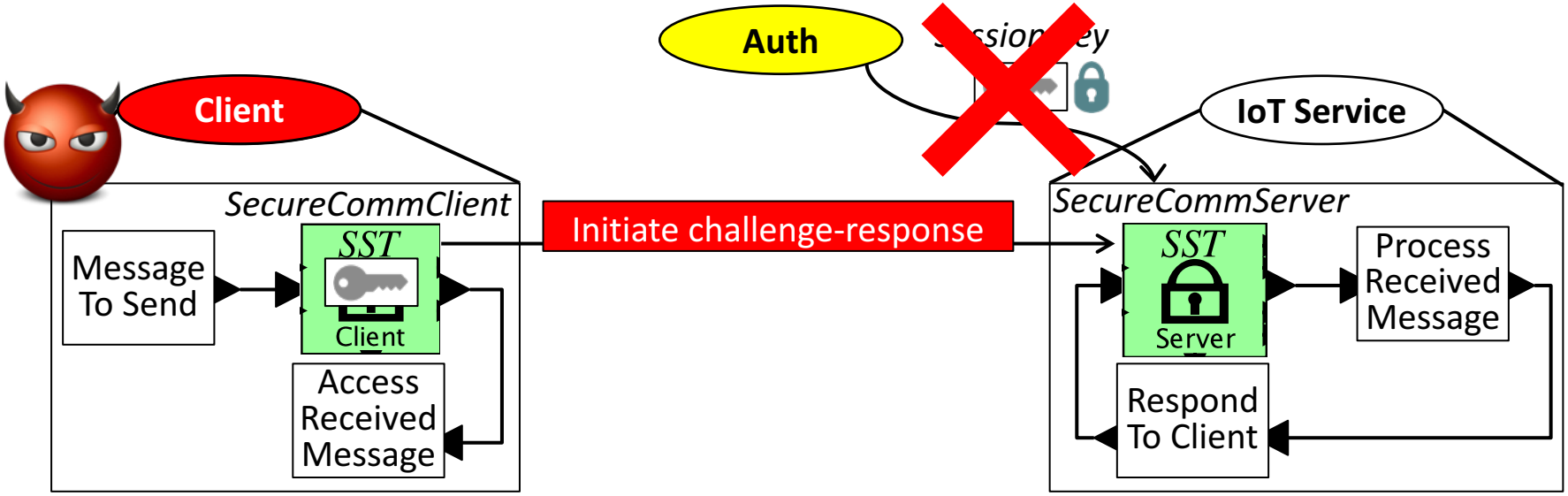


Effect of knobs will be shown through experiments!

SST for Open Environment

Heterogeneity
Open Env.
Scalability

- Limiting damage from compromised entities
  - SST's design to timely revoke keys (session & distribution keys)
    - Must always be authorized by Auth
    - Revocation takes effect immediately

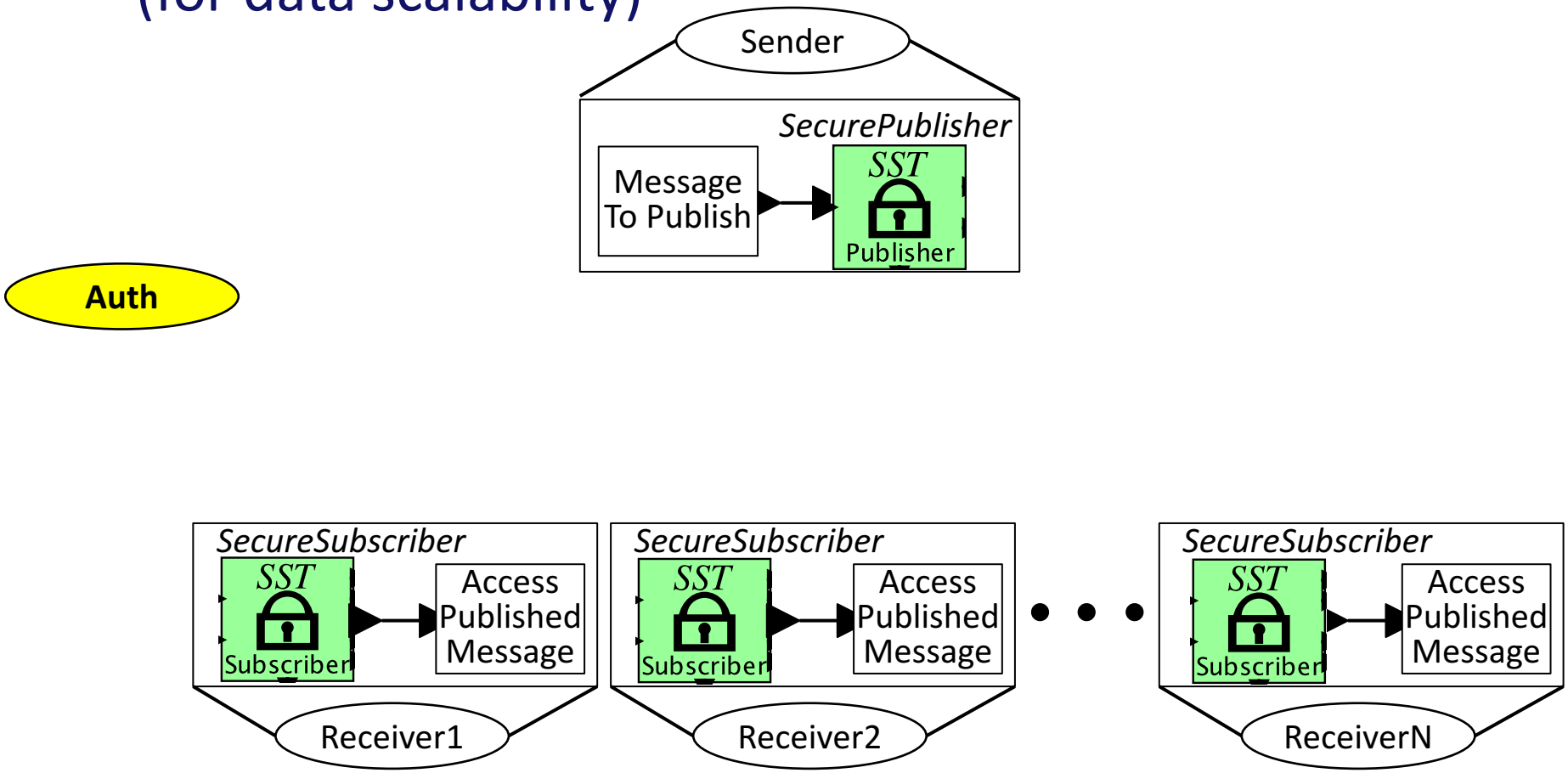


  - Even when Client with a valid session key is compromised, Auth can prevent its access to IoT Server!

SST for Scalability

Heterogeneity
Open Env.
Scalability

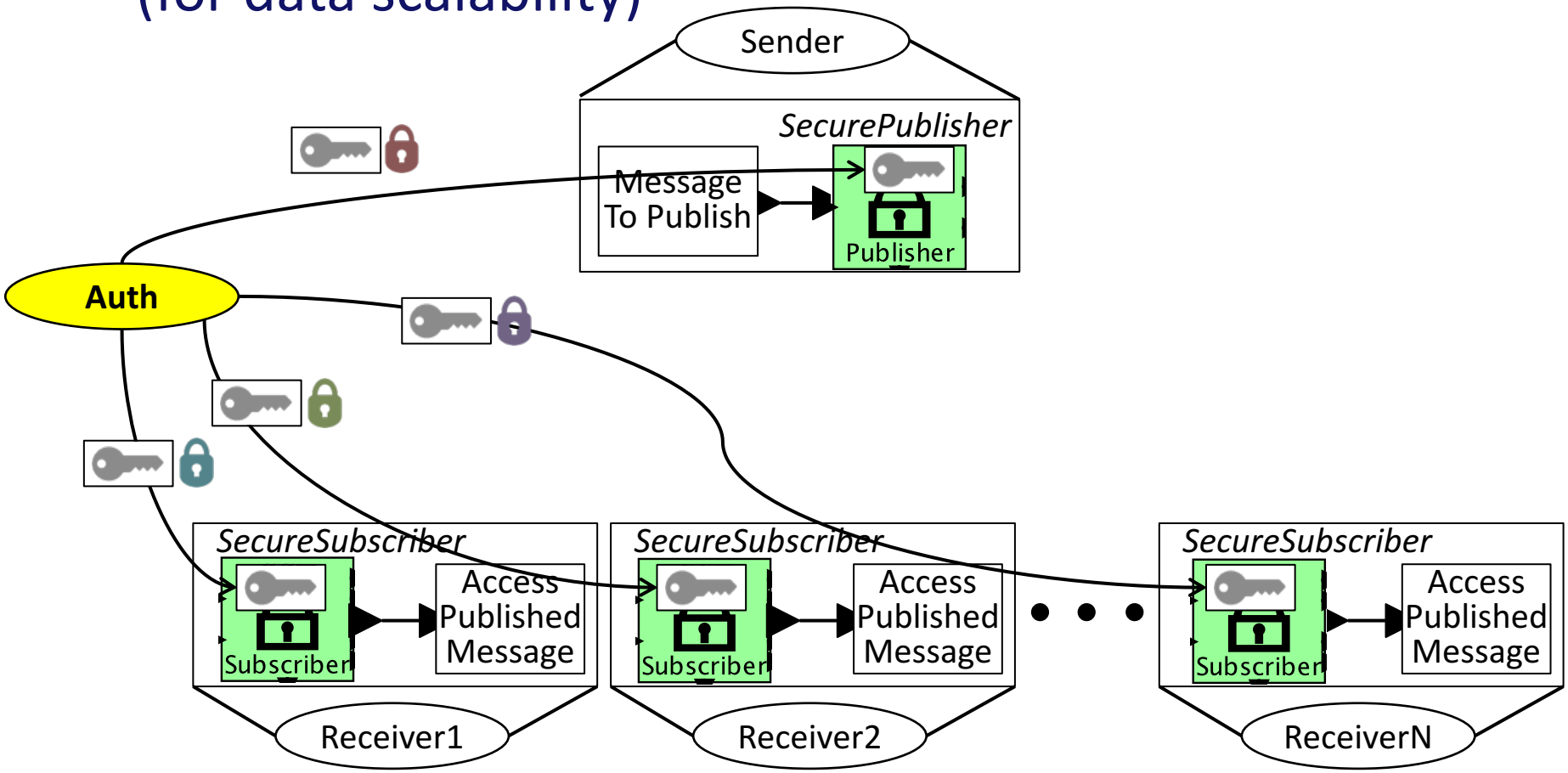
- Shared key support for one-to-many communication (for data scalability)



SST for Scalability

Heterogeneity
Open Env.
Scalability

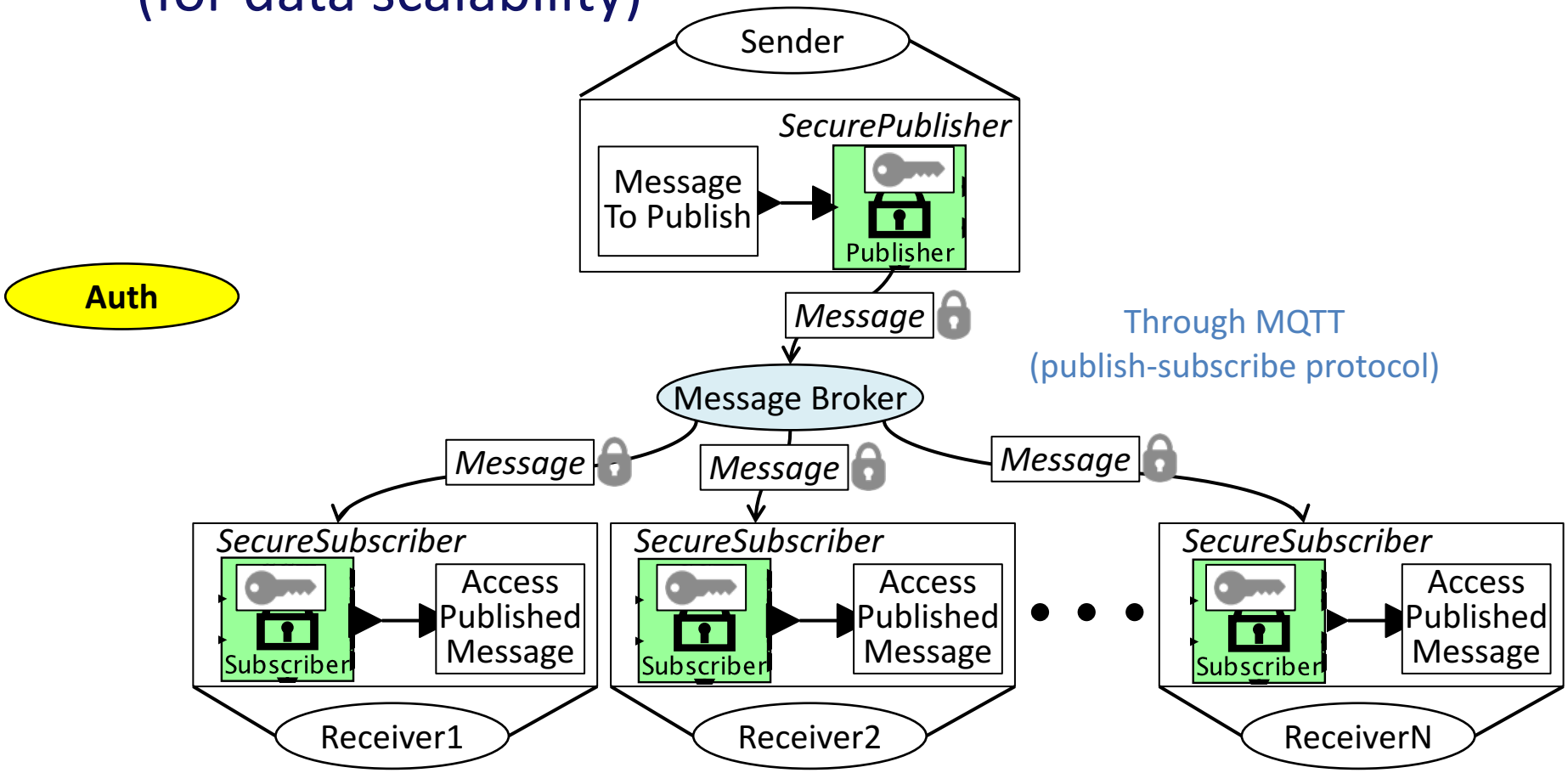
- Shared key support for one-to-many communication (for data scalability)



SST for Scalability

Heterogeneity
Open Env.
Scalability

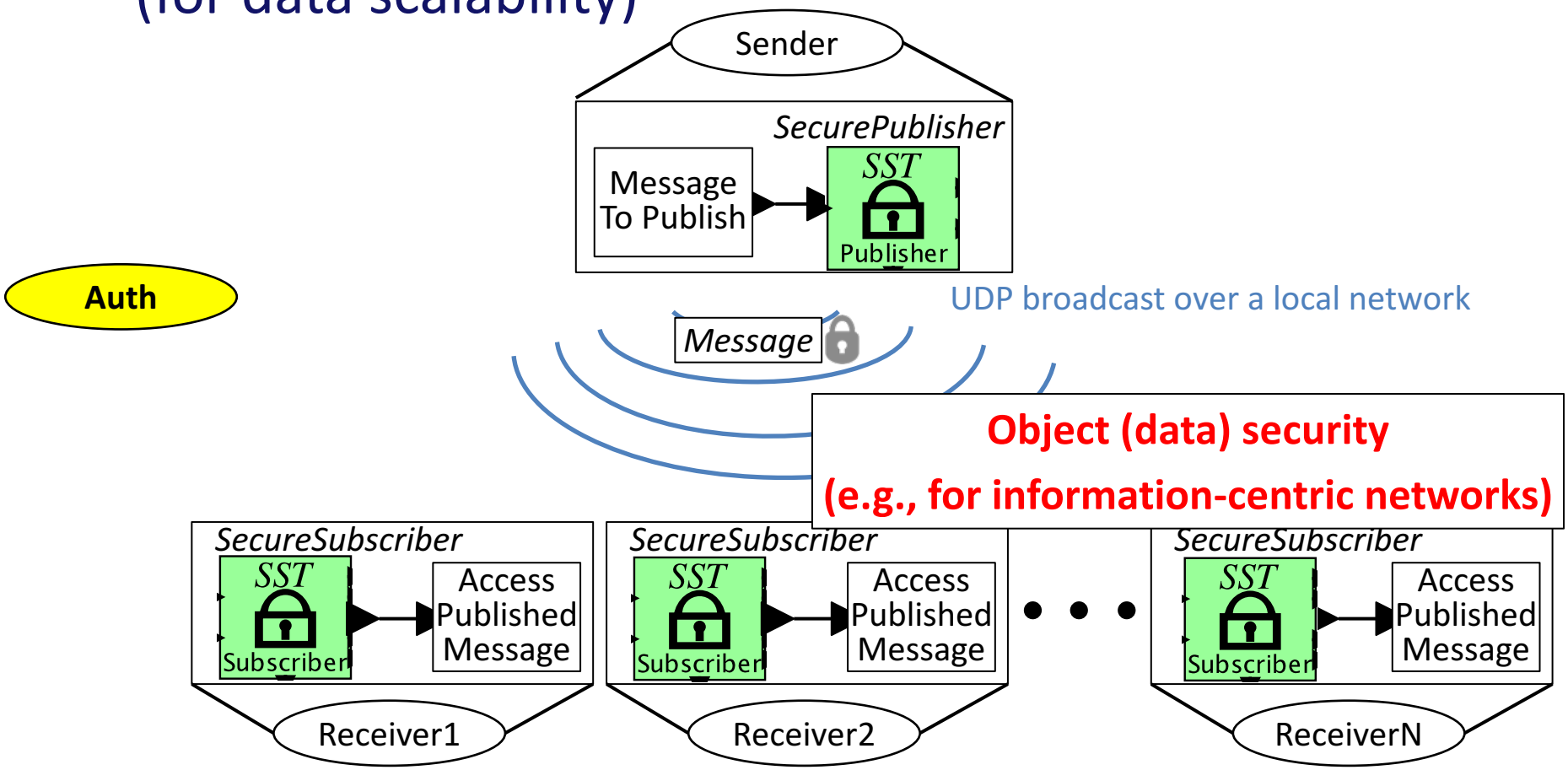
- Shared key support for one-to-many communication (for data scalability)



SST for Scalability

Heterogeneity
Open Env.
Scalability

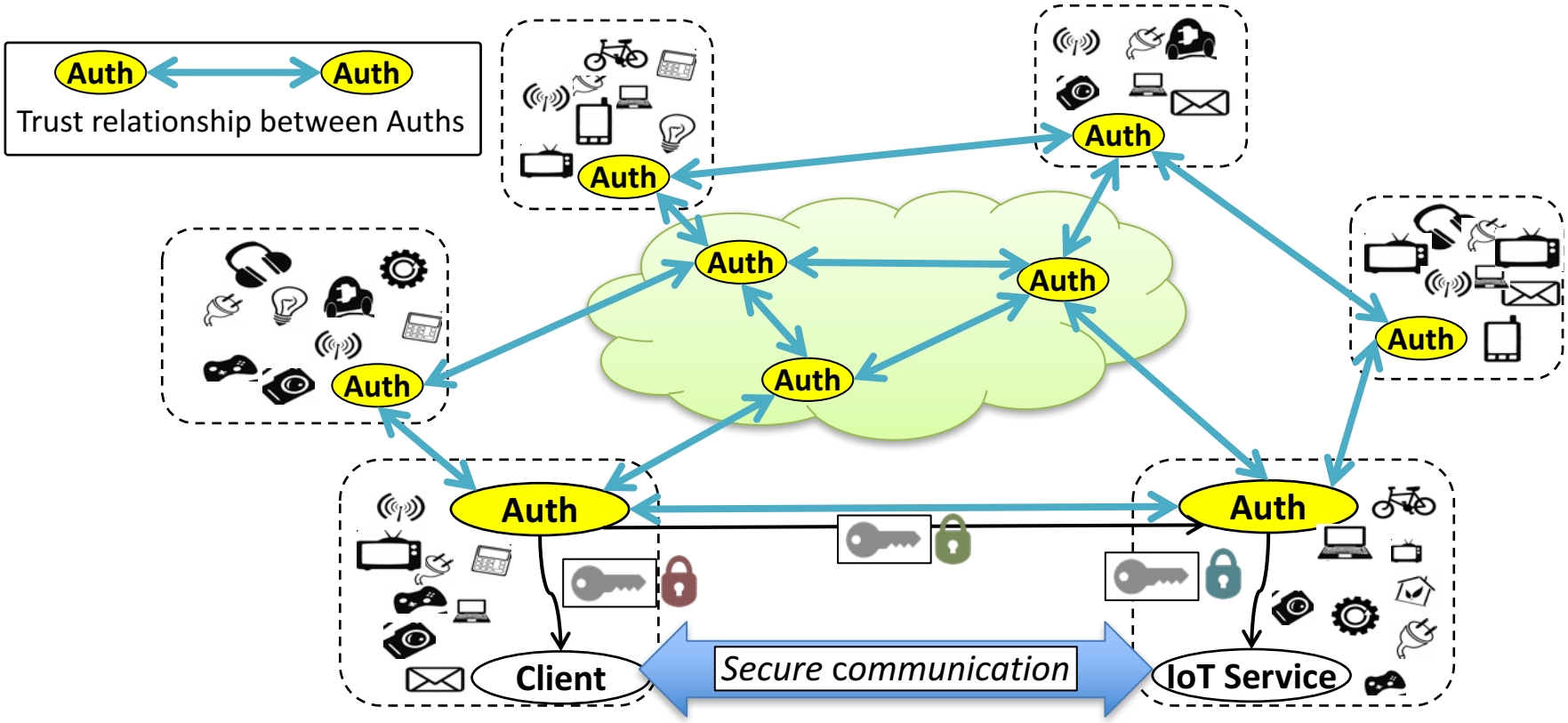
- Shared key support for one-to-many communication (for data scalability)



SST for Scalability (cont'd)

Heterogeneity
Open Env.
Scalability

- Globally distributed Auths (to scale with # IoT devices)
  - Trust relationships without a centralized authority



Evaluation: Security Analysis

Desired Security Properties

- Confidentiality (of data)
- Message authenticity
- Data integrity

Threat Model

- Network attackers
  - Eavesdrop or inject packets
- Compromised IoT Entities
  - Try to break security of others
- No compromised Auths

Formal Security Model of SST[1]

- Modeled in Alloy[2] (Model checking tool & language)
- Includes models for Auths, entities and communication messages

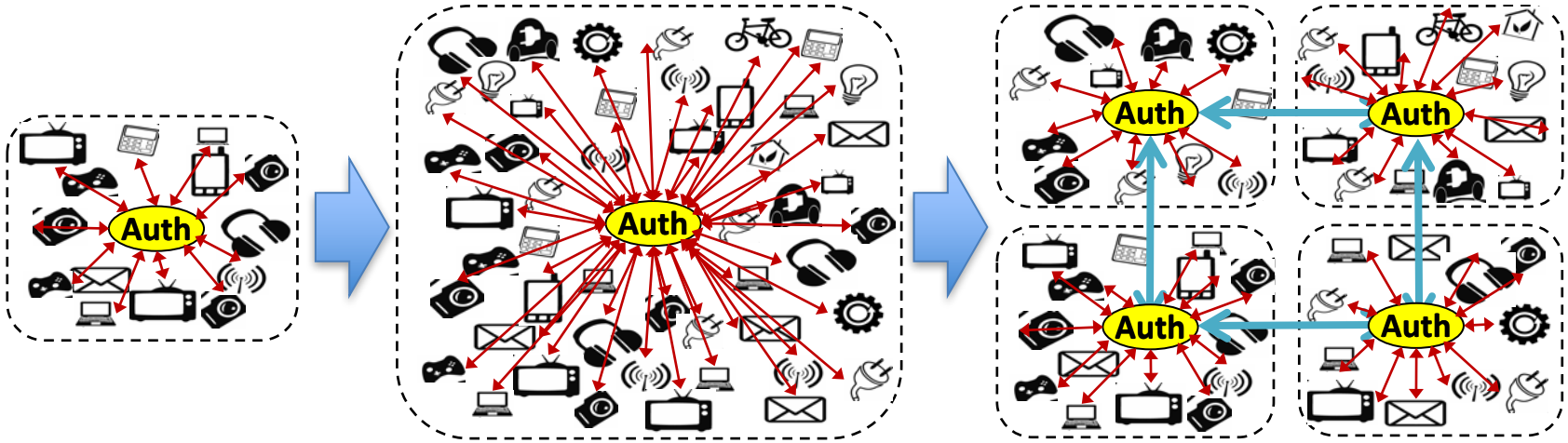
Result: Formally proven to satisfy the security properties!

[1] https://github.com/iotauth/security_analysis
[2] http://alloy.mit.edu/alloy/

Evaluation: Scalability Analysis

- Auth's authorization tasks include
  - Communication with IoT entities and Auths
  - Cryptographic operations
  - Accessing Auth's database (keys, access policy, etc.)

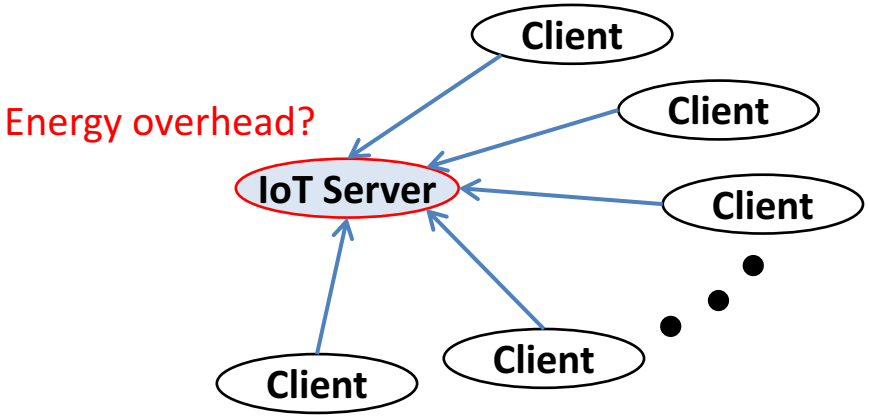
Number of IoT entities ↑
Access activity per entity ↑
Authorization workload ↑



- Scalability analysis result:
  - Each Auth's workload is a linear function of "number of entities per Auth", *not* "total number of entities in the system", assuming access activity per entity is fixed
  - In theory, we can always scale with increasing entities by adding Auths accordingly

Experiments & Results

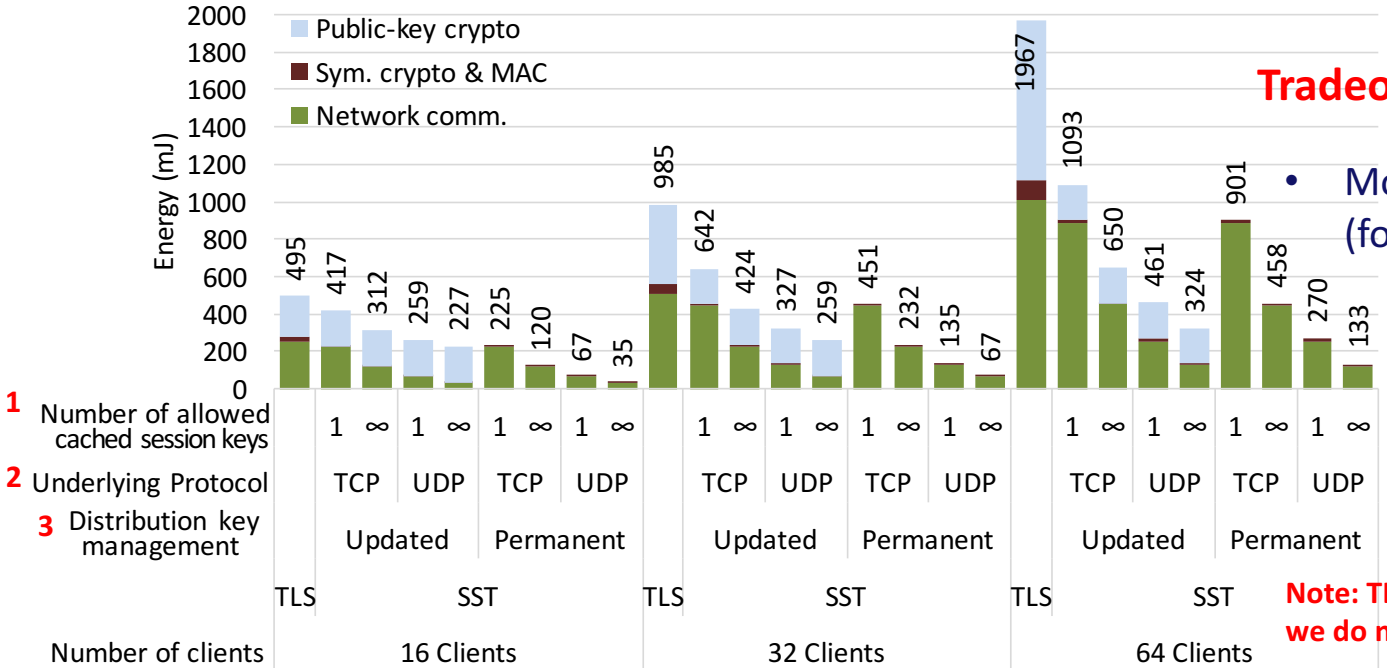
- Effect of various configuration alternatives
  - Estimated energy consumption for setting up secure connections between IoT clients & IoT servers
    - Logged crypto operations and captured packets
    - Used energy numbers from UAB[1] and SICS[2]



[1] UAB (Universitat Autònoma de Barcelona), Rifà-Pous and Herrera-Joancomartî. 2011
[2] SICS (Swedish Institute of Computer Science), Feeney and Nilsson. 2001

Experiments & Results (cont'd)

Estimated energy for an IoT server connected by 16, 32, and 64 clients

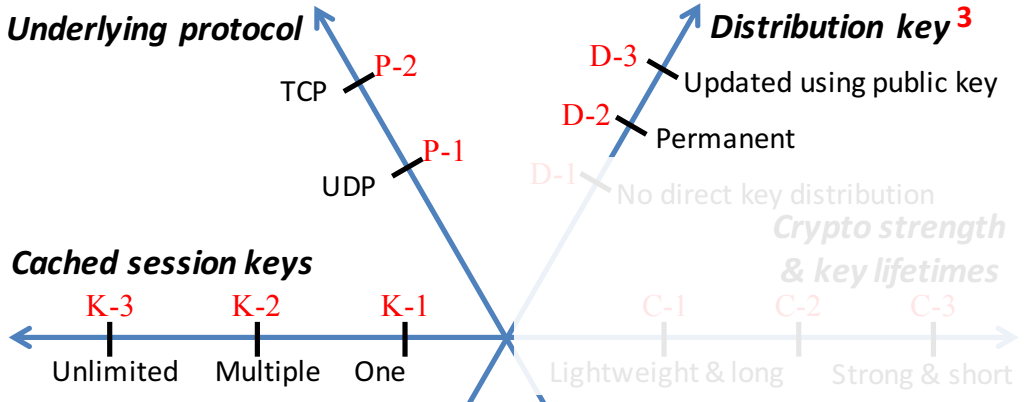


Tradeoffs for heterogeneity!

- More results in our paper! (for IoT clients)

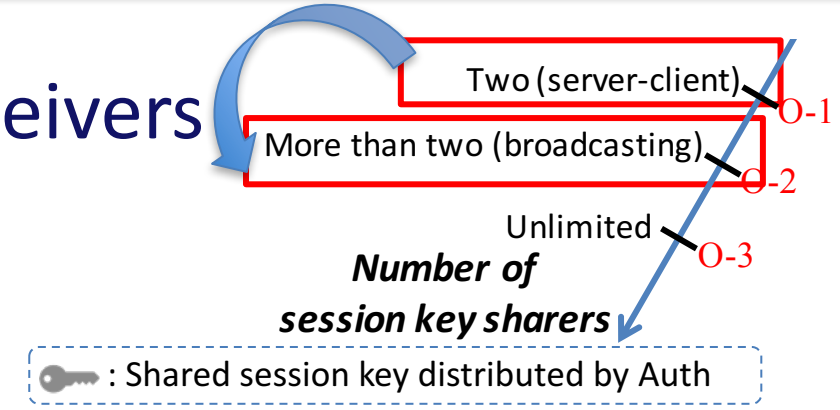
Note: TLS was used as a reference and we do not claim that SST is better than TLS

Less energy overhead — **More security guarantees**

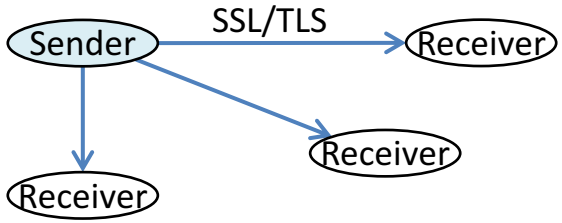


Experiments & Results (cont'd)

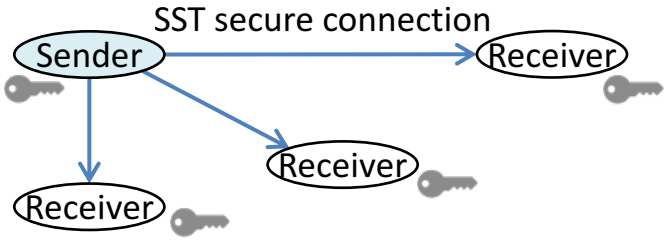
- A sender and multiple receivers with different settings



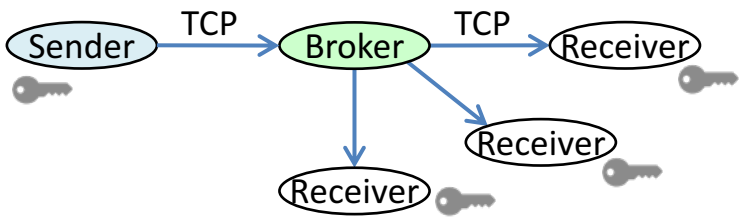
(1) Connections with SSL/TLS



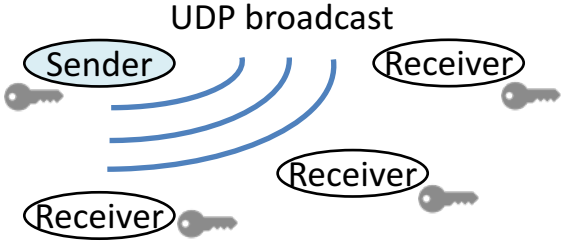
(2) Shared Key + secure connections by SST



(3) Shared key + MQTT message broker

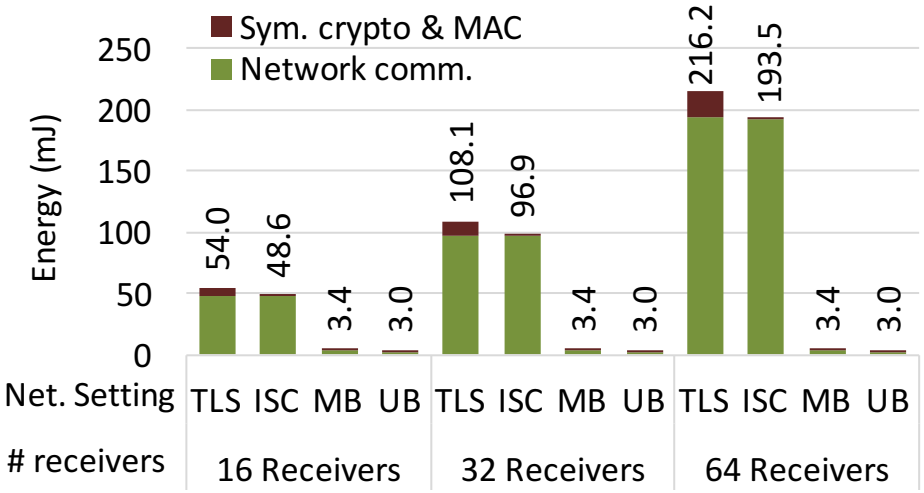


(4) Shared key + UDP broadcast



Experiments & Results (cont'd)

Estimated energy for a sender to send a 1KB-message to receivers



TLS: (1) SSL/TLS

ISC: (2) Individual SST Connections + shared key

MB: (3) MQTT Message broker

UB: (4) UDP broadcast

- More results in our paper! (for sender initialization)

Tradeoff example

A sensor node (500mAh/1.5V battery) sending 1KB per minute to 64 receivers

Expected battery life

<10 days with ISC (secure connections by SST)

625 days with UB (UDP broadcast)

Image: DevDuino Sensor Node V1.3

Conclusions

- Benefits of SST: Secure Swarm Toolkit
  - Authorization for a wide range of IoT from sensor nodes to safety-critical systems
  - Enable Internet-scale deployment with increasing connected devices and traffic
  - Help deployment of IoT security solutions by system designers with moderate knowledge in security
  - Possible integration with other IoT-related efforts (e.g., securing CoAP[1])

[1] Shelby et al., 2014. "The Constrained Application Protocol (CoAP)". RFC 6347

Conclusions (cont'd)

- Future work
  - Mitigation against availability attacks (e.g., Denial-of-Service attacks)
  - Detection of malicious behavior of compromised IoT entities or Auth
  - Further studies on usability of SST
  - Efficient initial setup of SST (e.g., registering IoT devices with Auth)
- For further information
  - https://github.com/iotauth