A First Step Towards Leveraging Commodity Trusted Execution Environments for Network Applications

Seongmin Kim Youjung Shin Jaehyung Ha

Taesoo Kim* **Dongsu Han**

KAIST * Georgia Tech

Trend 1: Security and Privacy Critical Factors in Technology Adoption

- Demands for "security" and "privacy" are increasing
  - Widespread use of Transport Layer Security (TLS)
  - Popularity of anonymity networks (e.g., Tor)
  - Use of strong authentication/encryption in WiFi

- Expectation on security and privacy impacts design decisions:
  - Operating system (iOS, Android)
  - Apps/services (e.g., messenger, adblocker)
  - Network infrastructure (inter-domain SDN)

Trend 1: Security and Privacy

y Adoption

ANDY GREENBERG SECURITY 10.29.15 5:30 PM

WIRED

TOR JUST LAUNCHED THE
EASIEST API
ANONYMOUS

LINE, the WhatsApp of Japan, Is Adding Some Pretty Serious Encryption

October 13, 2015 // 10:23 AM EST

Snapchat Prompts Privacy Concerns As Terms Allow Company To 'Publicly Display' Content

The Huffington Post UK | By Nitya Rajan

Posted: 30/10/2015 12:40 GMT | Updated: 30/10/2015 12:59 GMT

BlackBerry's Android Priv Phone Targets High-End Privacy Needs

Posted October 23, 2015

Trend 2: Commoditization of Trusted Execution Environment

- Trusted Execution Environment (TEE)
  - Isolated execution: integrity of code, confidentiality
  - Remote attestation

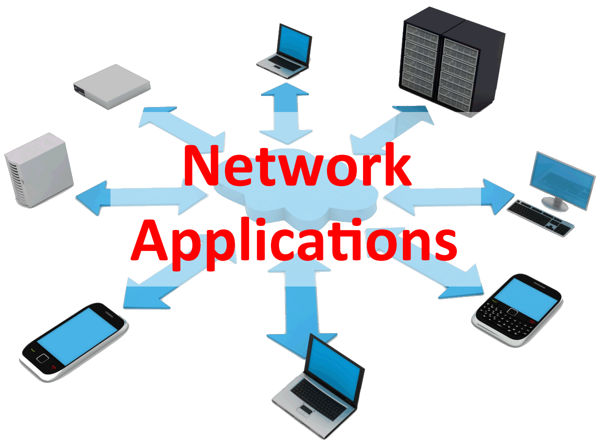
- Commoditization of TEE

The commoditization of TEE brings new opportunities for network applications.

2. Compatibility with x86

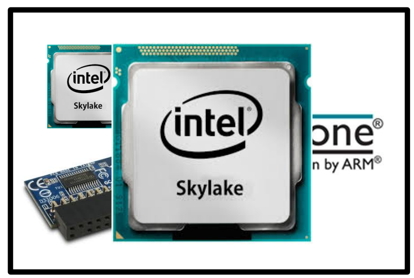
Network Applications + TEE = ?

- What impact does TEE have on networking?



+

TEE



Intel SGX

=

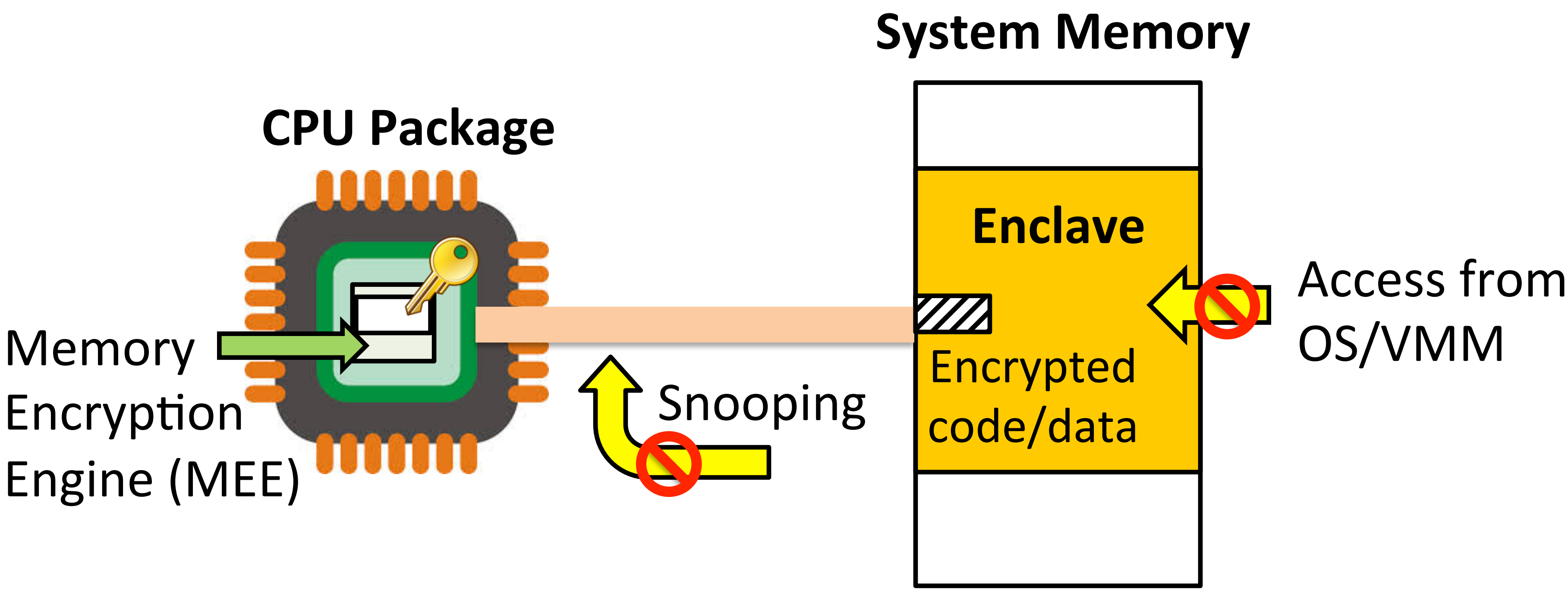
Enhanced security

New design space

New functionality

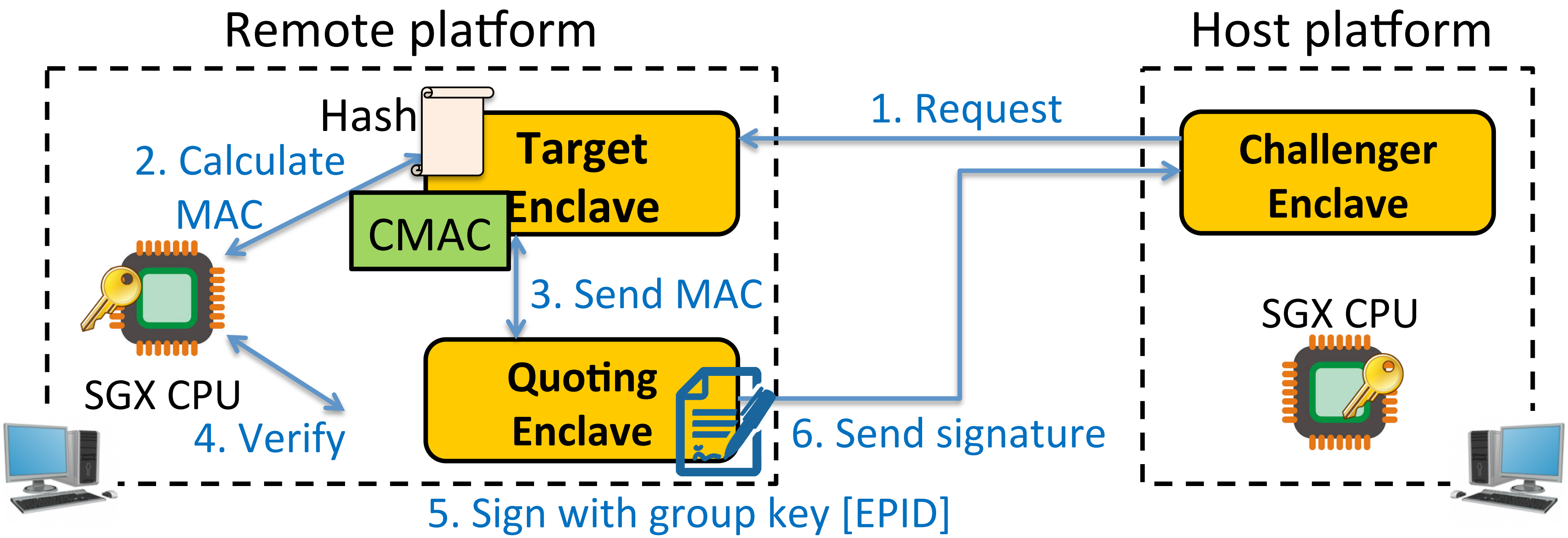
- Previous efforts: Adopting TEE to cloud platform
  - Haven [OSDI'14] : Protects applications from an untrusted cloud
  - VC3 [S&P'15] : Trustworthy data analytics in the cloud

SGX : Isolated Execution



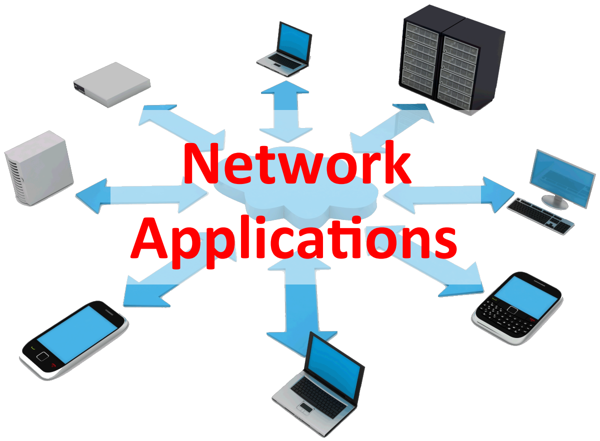
- Application keeps its data/code inside the "enclave"
  - Smallest attack surface by reducing TCB (App + processor)
  - Protect app's secret from untrusted privilege software (e.g., OS, VMM)

SGX : Remote Attestation



- Attest an application on remote platform
- Check the identity of enclave (**hash of code/data pages**)
- Can establish a "**secure channel**" between enclaves

Case Studies: Three Applications



+

TEE

Intel SGX

=

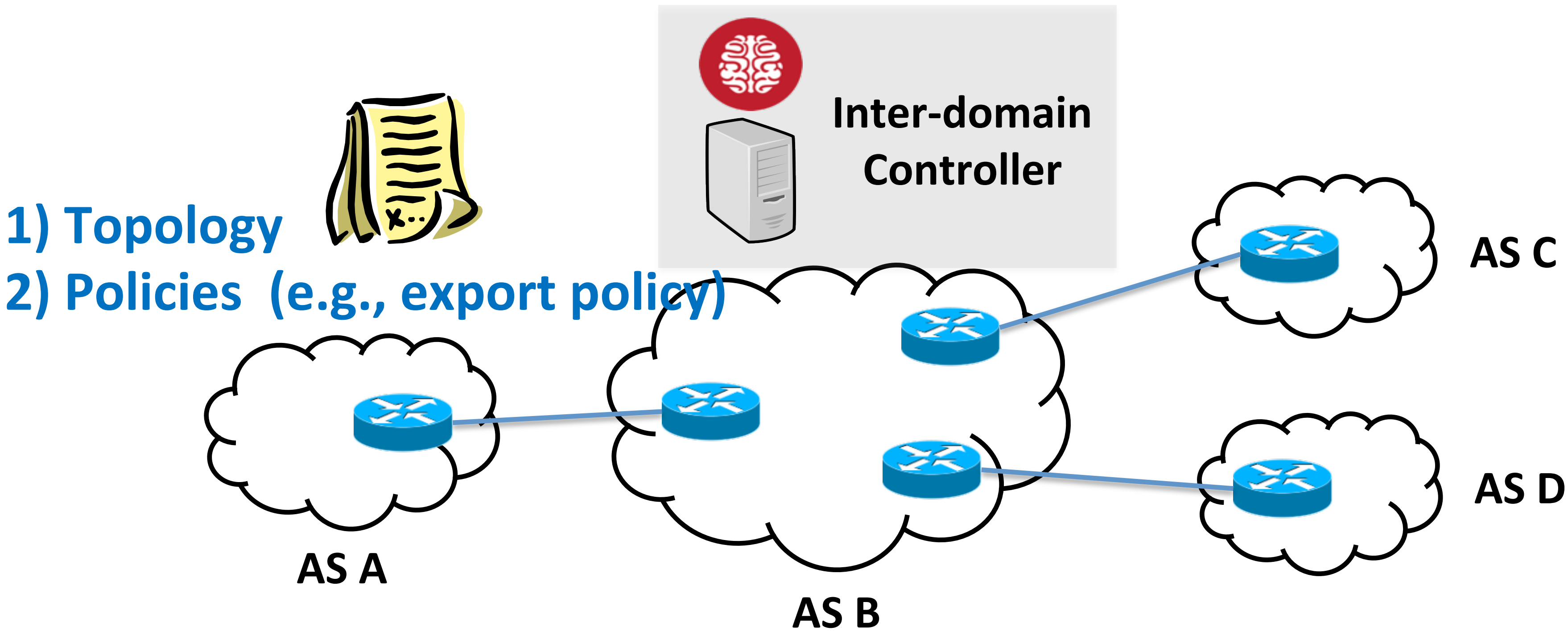
Enhanced security

New design space

New functionality

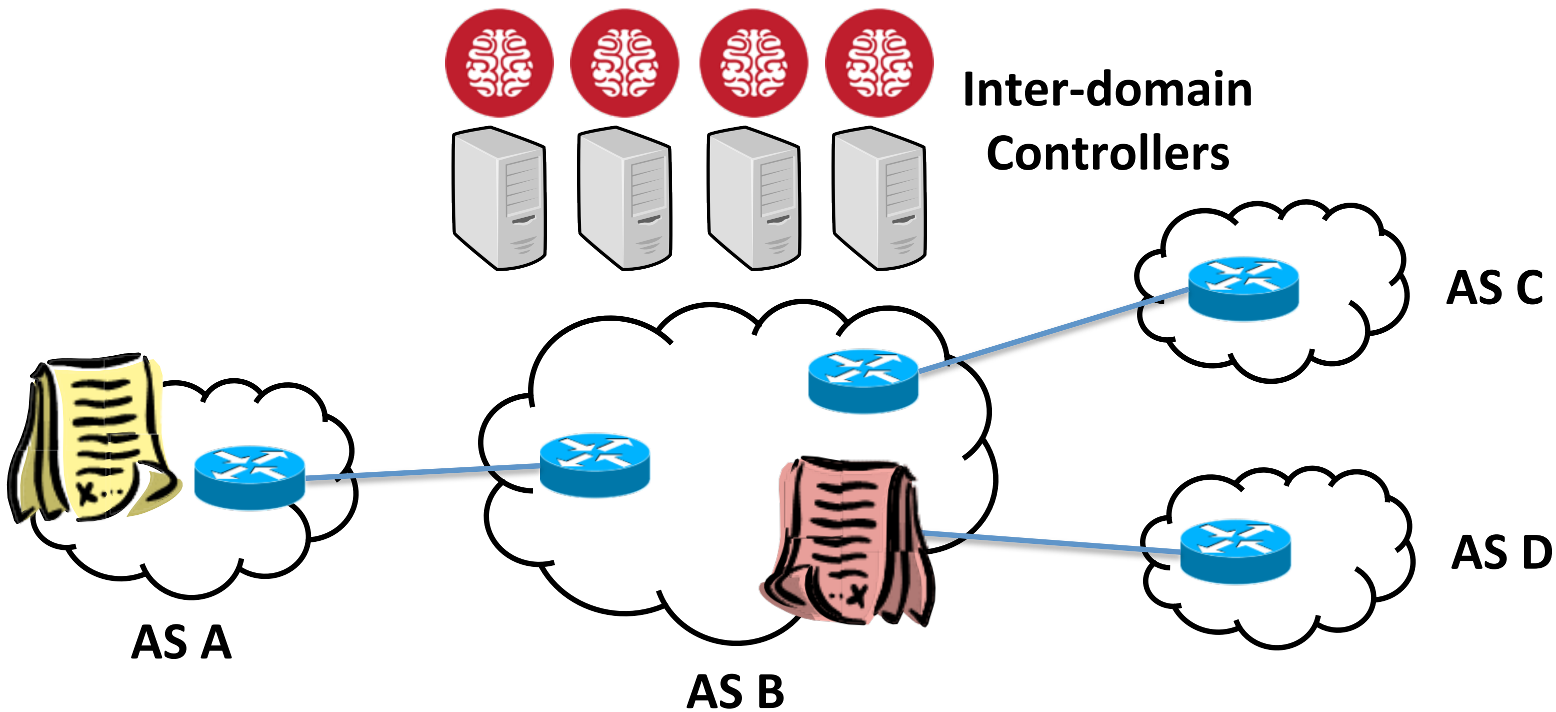
1. **Network infrastructure**: Software-defined inter-domain routing
2. **Peer-to-peer systems**: Tor anonymity network
3. **Middlebox**: TLS and "secure" middleboxes

SDN-based Inter-domain Routing



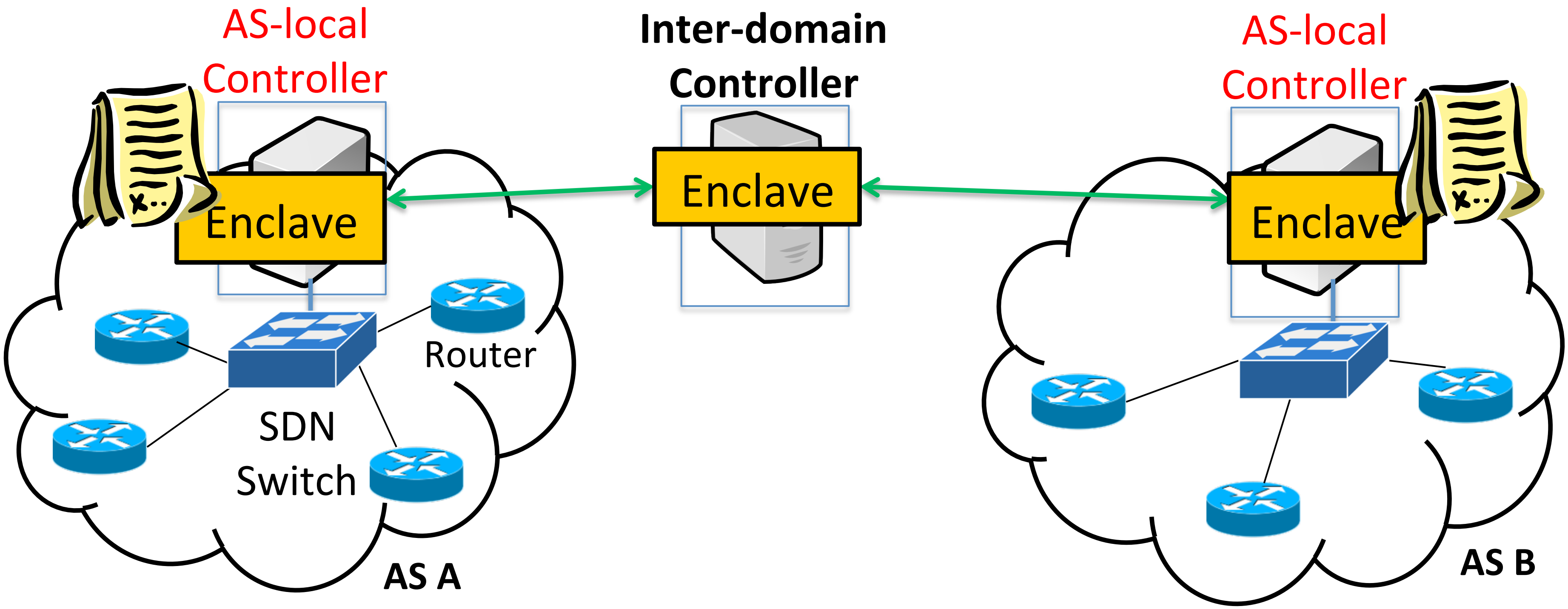
- Offers new properties
  - Fast convergence, application-specific peering, flexibility, what-if analysis [hotnets2011]
- Reveals private information: topology and policy

SDN-based Inter-domain Routing



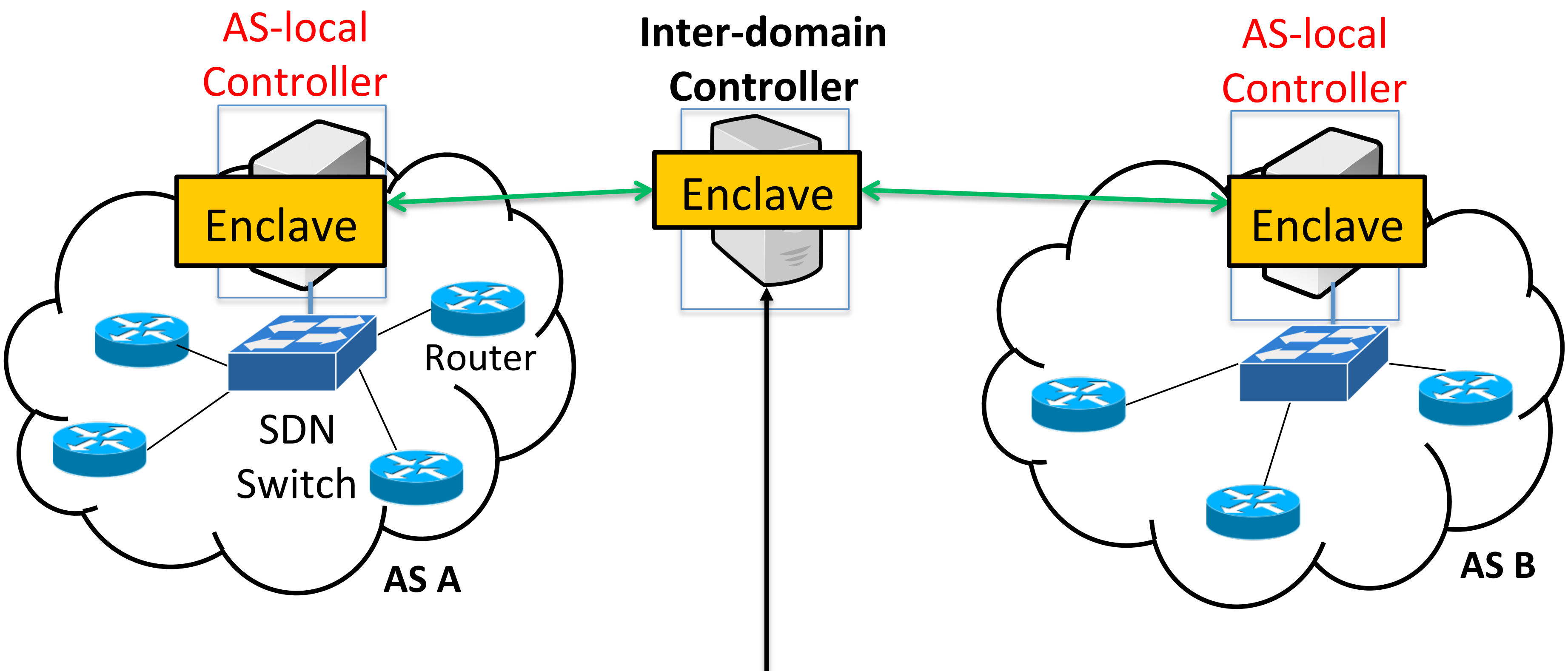
Prior work [hotnets2011] uses Secure Multi-Party Computation (SMPC) to solve this, but the computational complexity is prohibitive.

SDN-based Inter-domain Routing



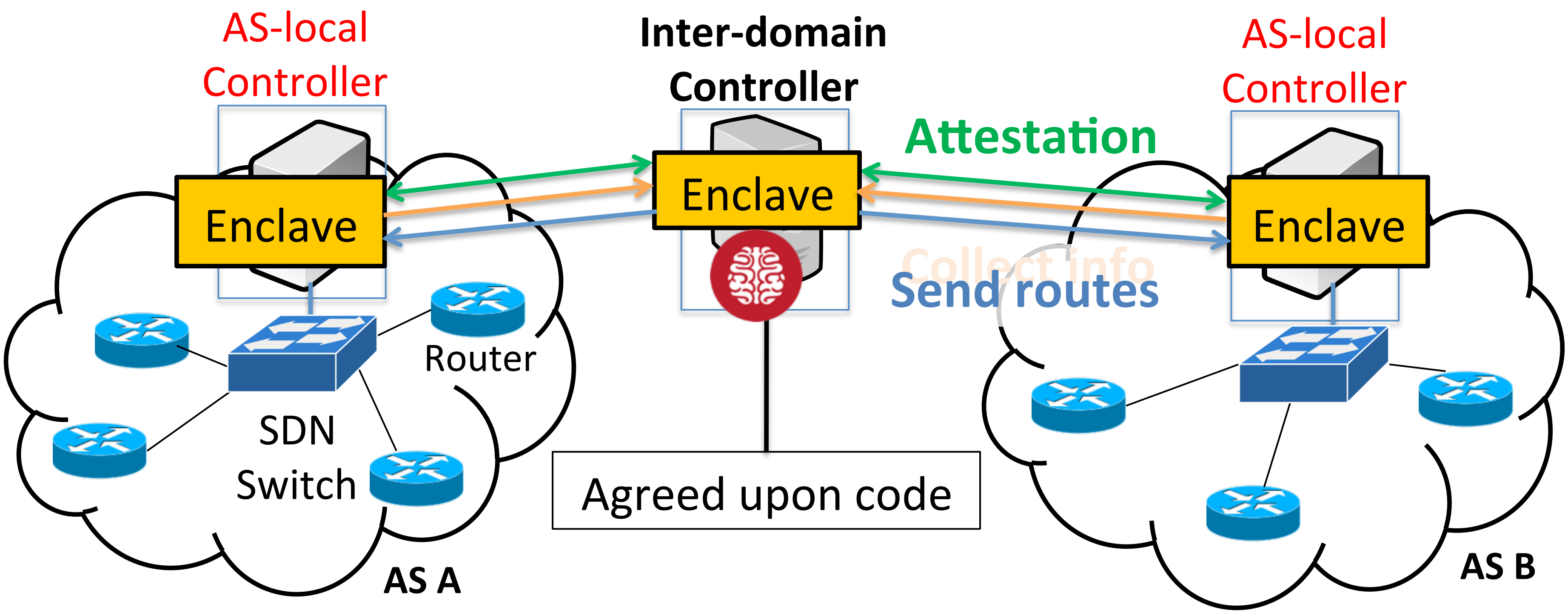
- Enclose private information inside the enclave
- Communication through a secure channel after attestation

SDN-based Inter-domain Routing



ASes agree upon a common code base.
Makes sure that it does not leak private information [Moat].
It becomes the TCB of the inter-domain routing infrastructure.

SDN-based Inter-domain Routing



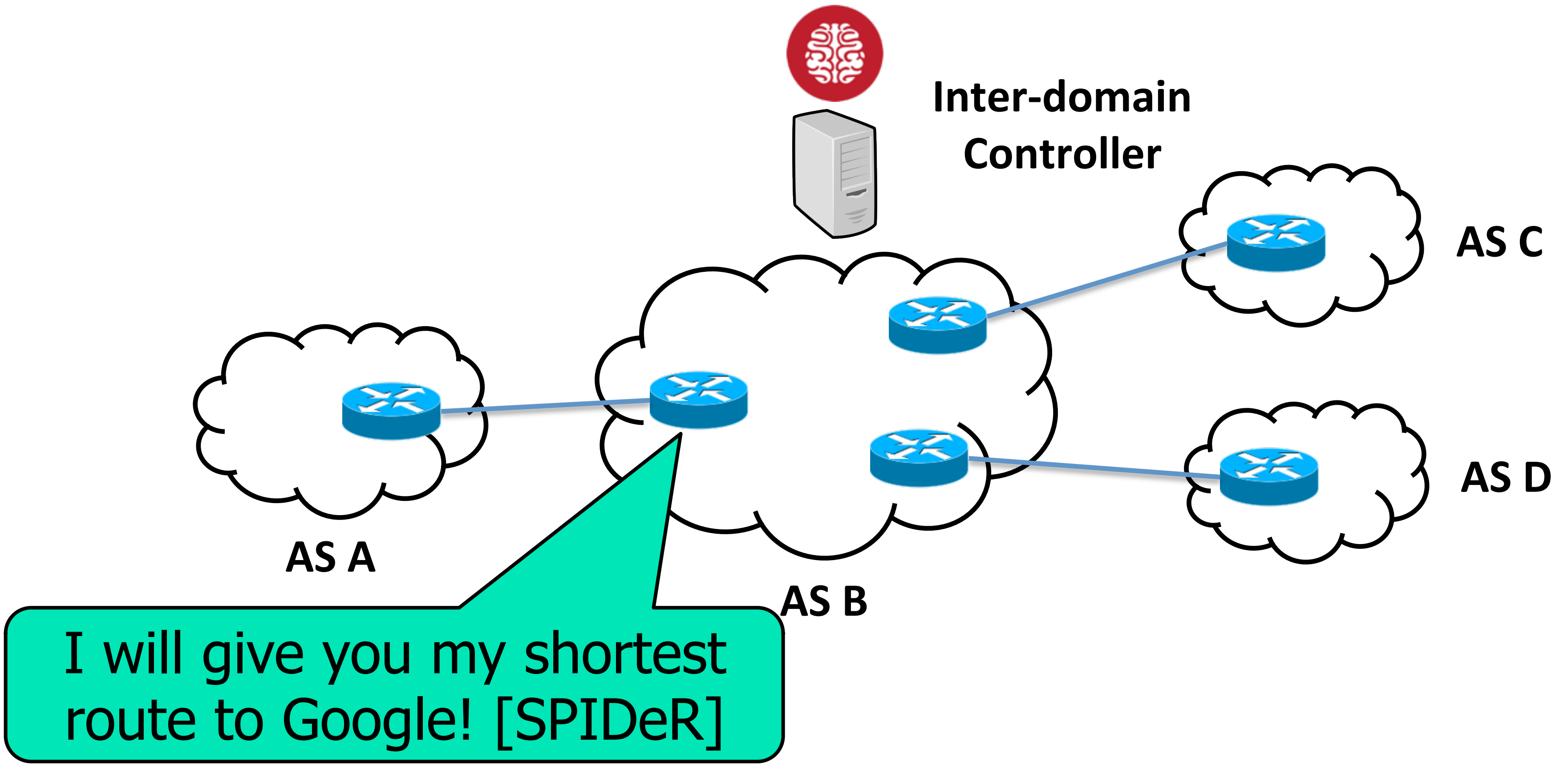
1. Mutually attest/authenticate using remote attestation

2. Collect policy and topology through a secure channel

3. Main controller computes routing path

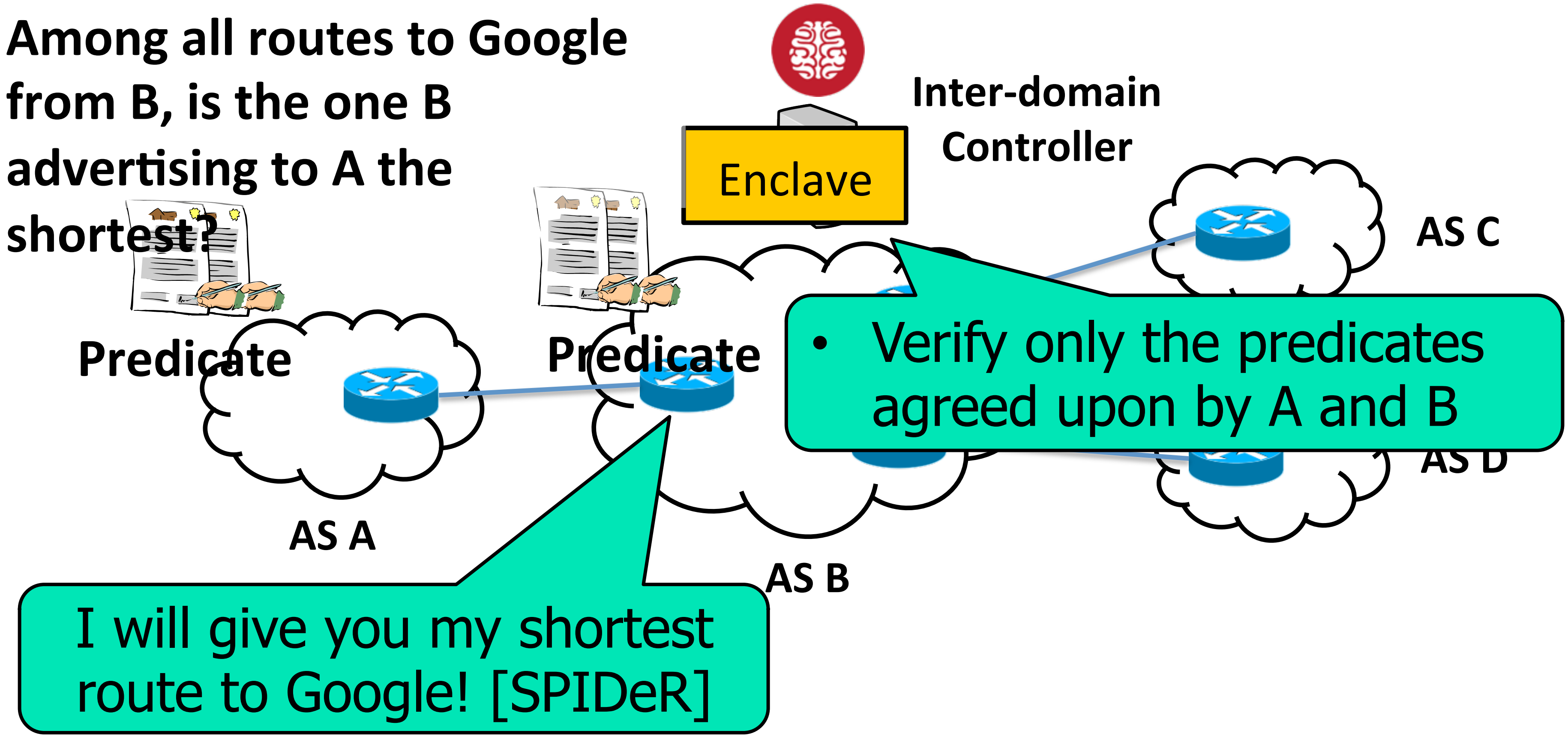
4. Sends routes for each AS through a secure channel

Extending Features: Policy verification



- Enabling verification on routing decisions
  - Want to verify whether the promise is being kept [SPIDeR]

Extending Features: Policy verification



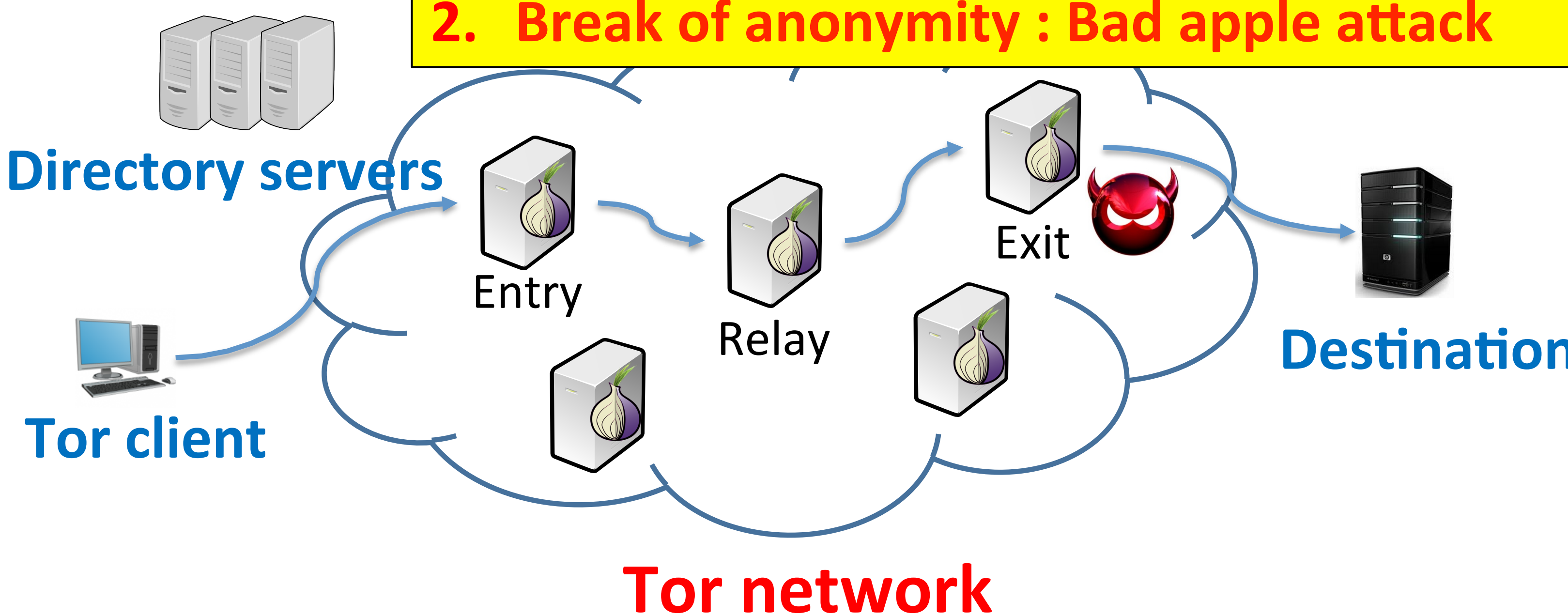
- Enabling verification on routing decisions
  - Want to verify whether the promise is being kept [SPIDeR]

Tor: Anonymity Network

- Tor network : uses 3-hop onion routing
  - Directory servers : Advertise available onion routers (ORs) vote for bad
  - Relies on vol

When exit node is compromised,
(unless end-to-end encryption is used)

1. **Snooping or tampering of the plain-text**
2. **Break of anonymity : Bad apple attack**

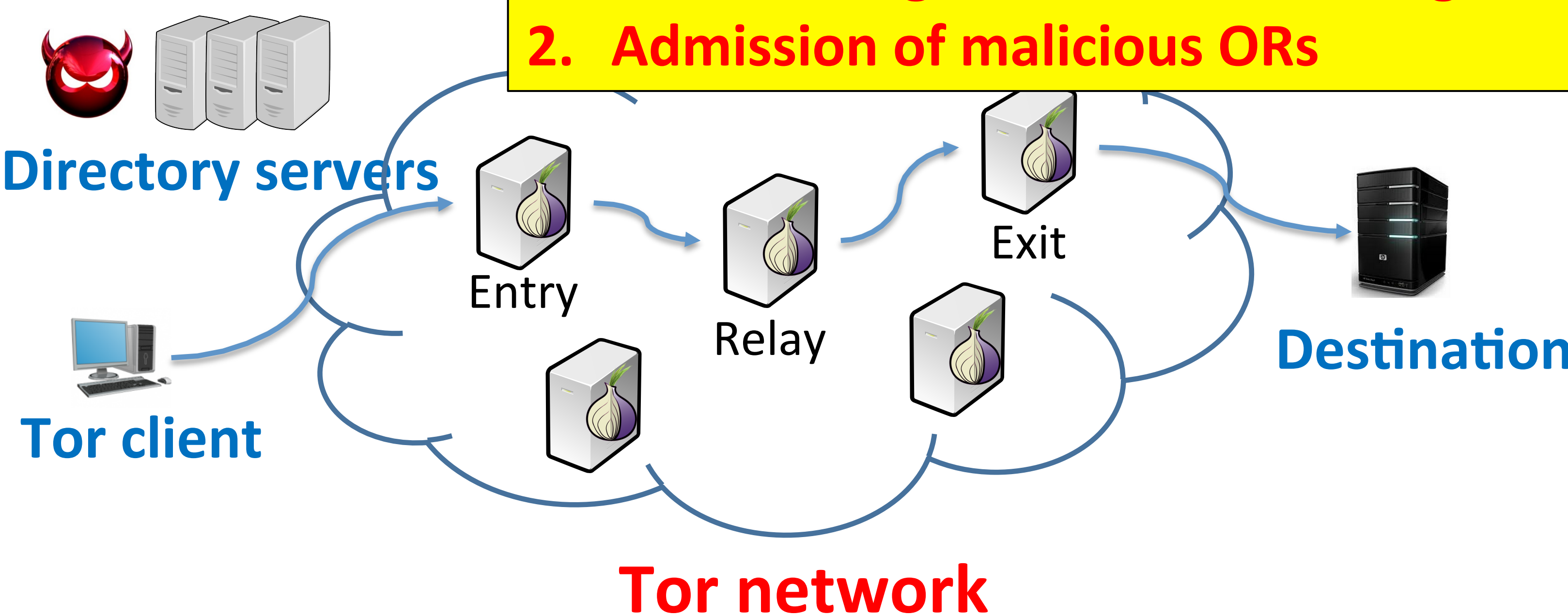


Tor: Anonymity Network

- Tor network : uses 3-hop onion routing
  - Directory servers : Advertise available onion routers, vote for bad exit nodes
  - Relies on volunte

When directory servers are compromised,

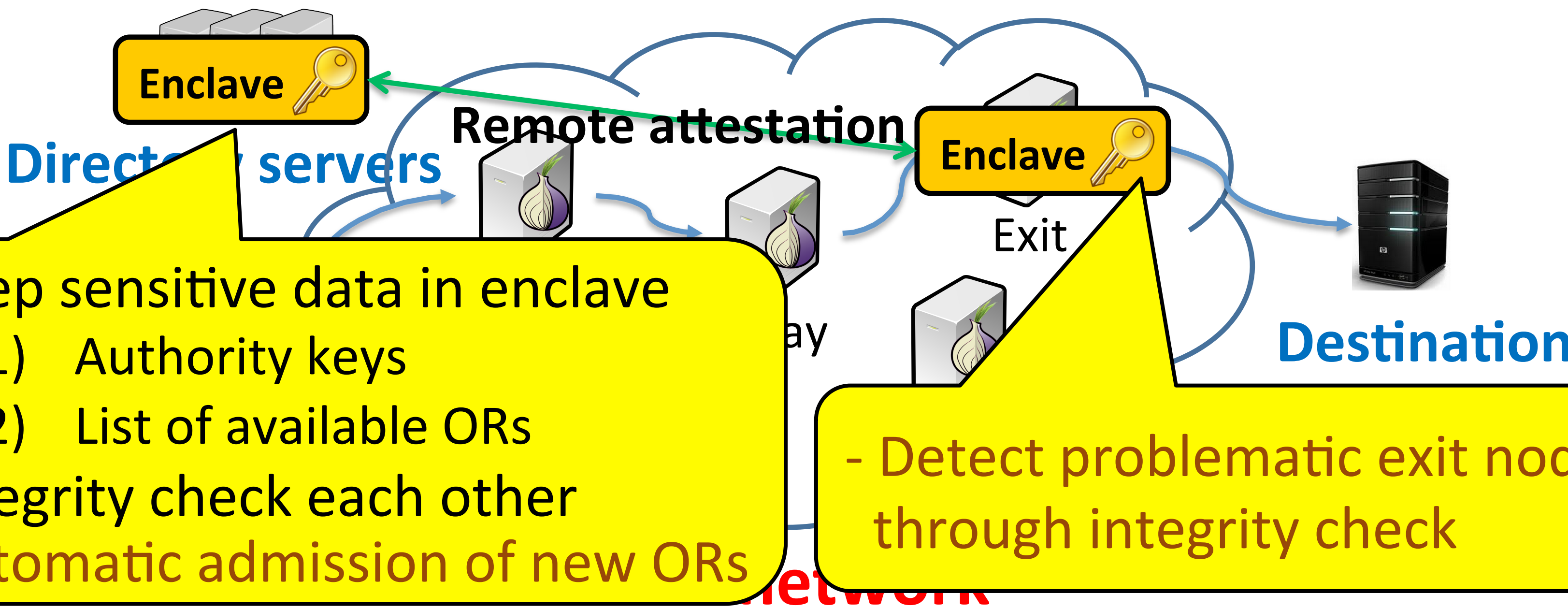
1. **Tie-breaking attacks while voting**
2. **Admission of malicious ORs**



Application of TEE to Tor

1) SGX-enabled directory servers

2) SGX-enabled directory servers & ORs



- Keep sensitive data in enclave
  1) Authority keys
  2) List of available ORs
- Integrity check each other
- Automatic admission of new ORs

- Detect problematic exit nodes through integrity check

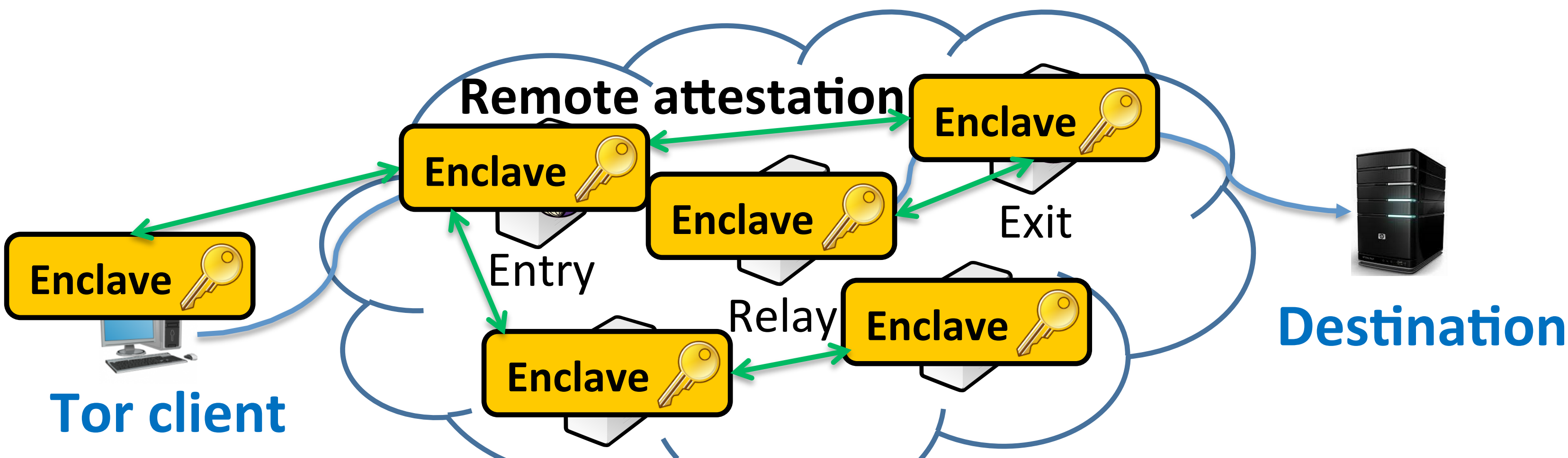
Application of TEE to Tor

1) SGX-enabled directory servers

2) SGX-enabled directory servers & ORs

3) Fully SGX-enabled setting

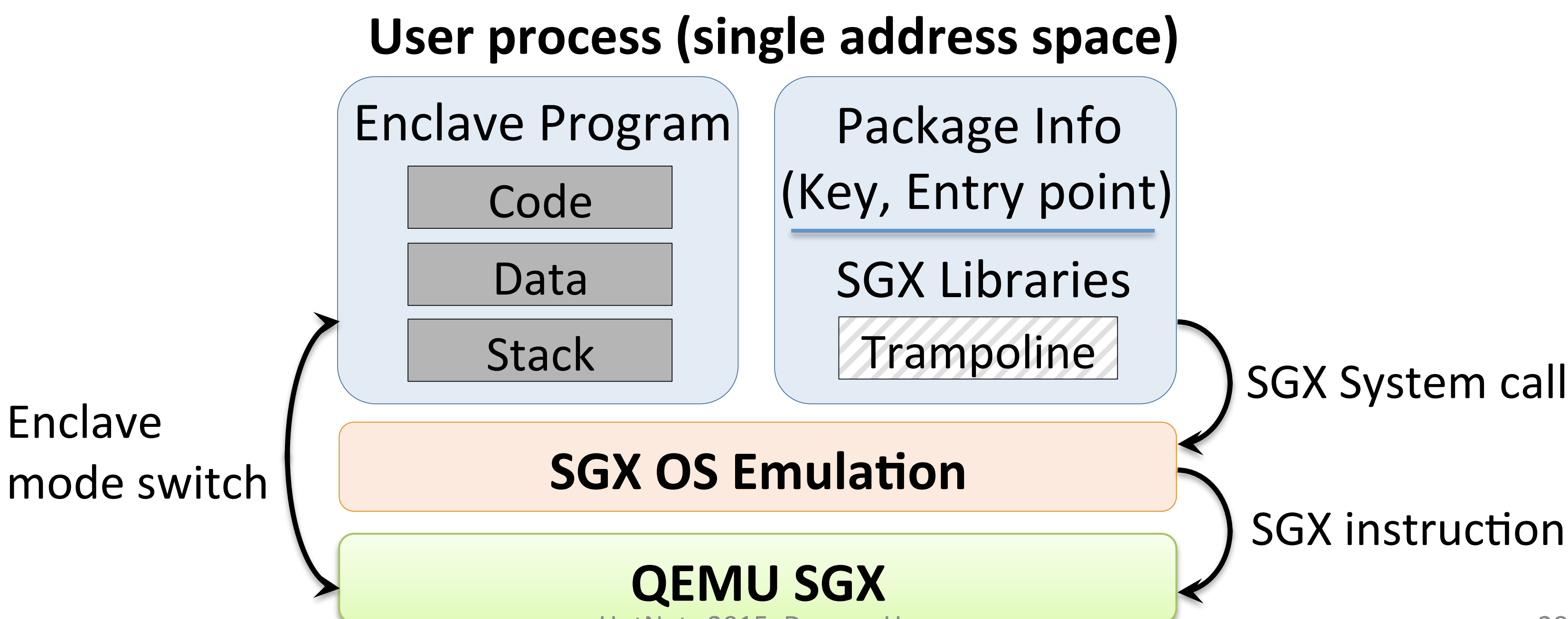
→ Eliminate directory servers altogether



Each Tor components can check the integrity of target program (Tor binary)

Implementation

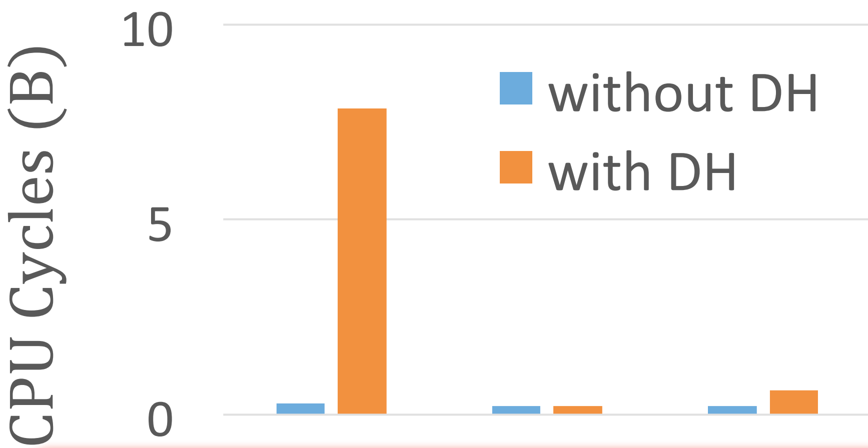
- OpenSGX [NDSS'16] : Open source SGX emulator
  - Fully functional, instruction-compatible emulator of SGX build on top of QEMU
  - Emulates system software and provide SGX libraries



Preliminary Evaluation: Overhead

- Estimate the overhead in terms of additional CPU cycles
  - *Each SGX instruction = 10 k cycles* [Haven]

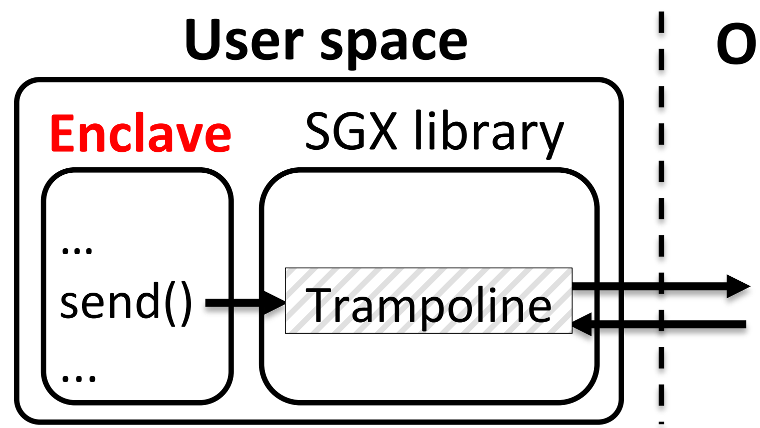
<Cost of remote attestation>



Cost of remote attestation:

3% of 1024-bit Diffie-Hellman

<Cost of packet transmission>



For each I/O operations,

2 Mode switches

+ SGX library calls

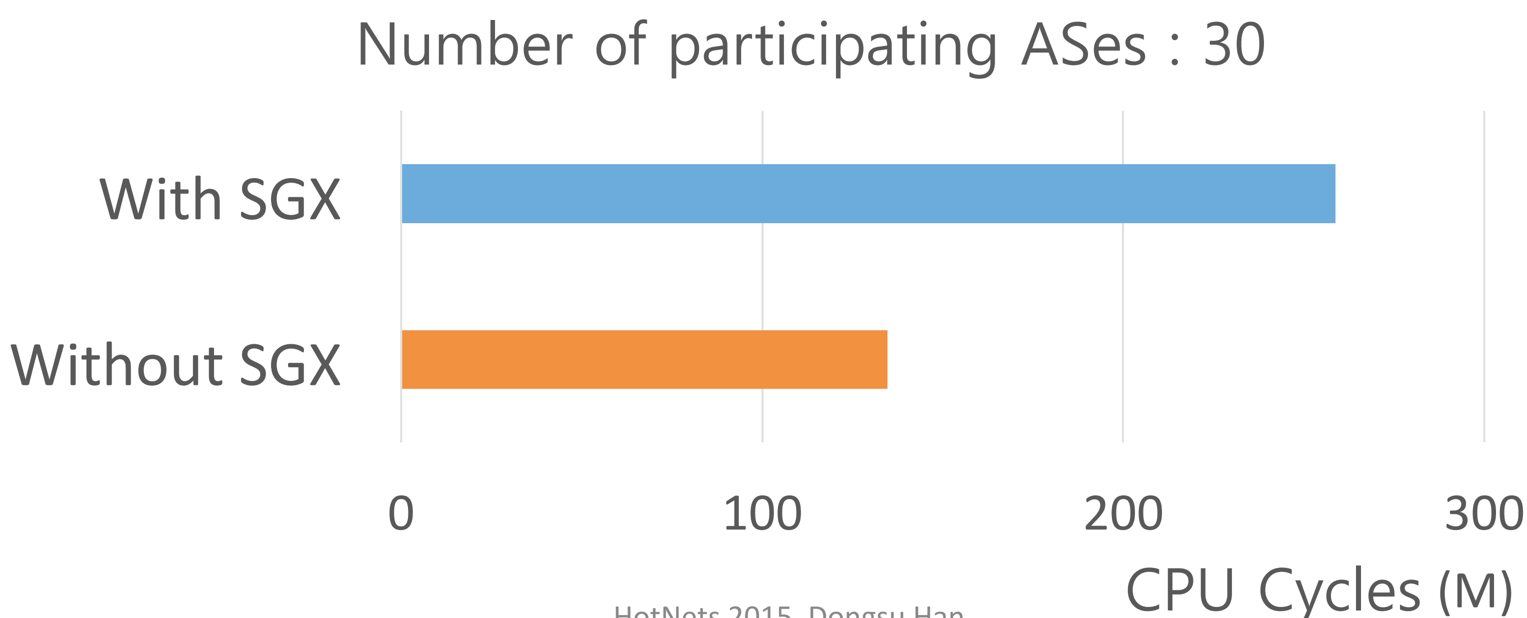
SDN-based inter-domain routing

– 30 ASes with the centralized inter-domain controller

– Inter-domain controller : 90% more CPU cycles

– AS-local controllers : 70% more CPU cycles

<# of CPU cycles consumed in the inter-domain controller>



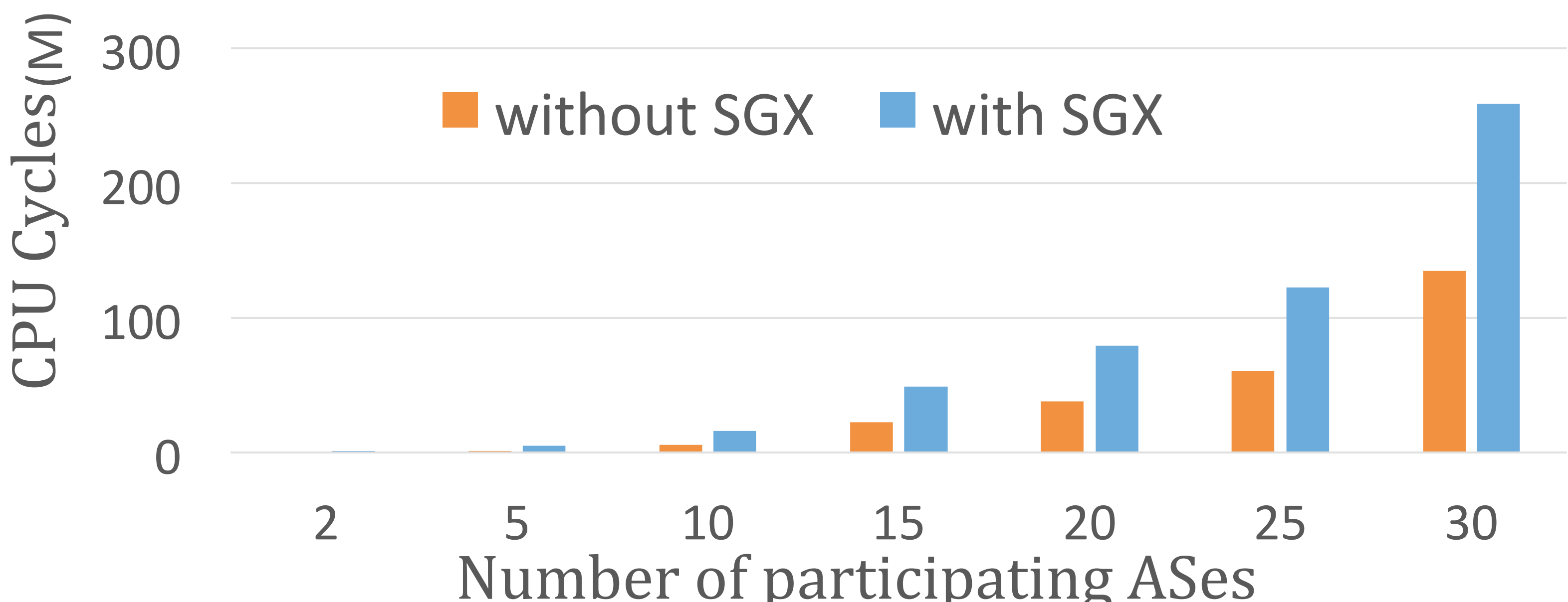
Conclusion

- Commoditization of TEE brings new opportunities for network applications
- Cases studies show wide range of impact:
  - Policy privacy of SDN-based inter-domain routing
  - New design space of Tor anonymity network
  - Secure in-network functions
- SDN-based inter-domain routing:
  - Characterize and measure the overhead of using SGX
  - Consumes 70-90% more CPU cycles

SDN-based inter-domain routing

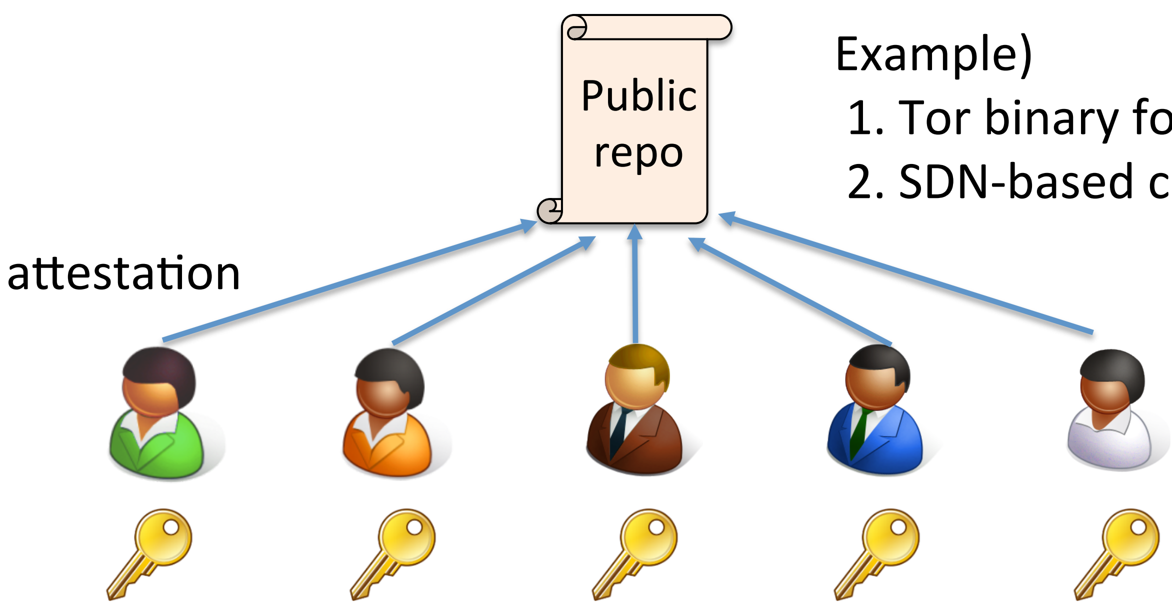
- 30 ASes with the centralized inter-domain controller
- Inter-domain controller : 90% more CPU cycles
- AS-local controllers : 70% more CPU cycles

<# of CPU cycles consumed in the inter-domain controller>



Secure Multi-party Execution

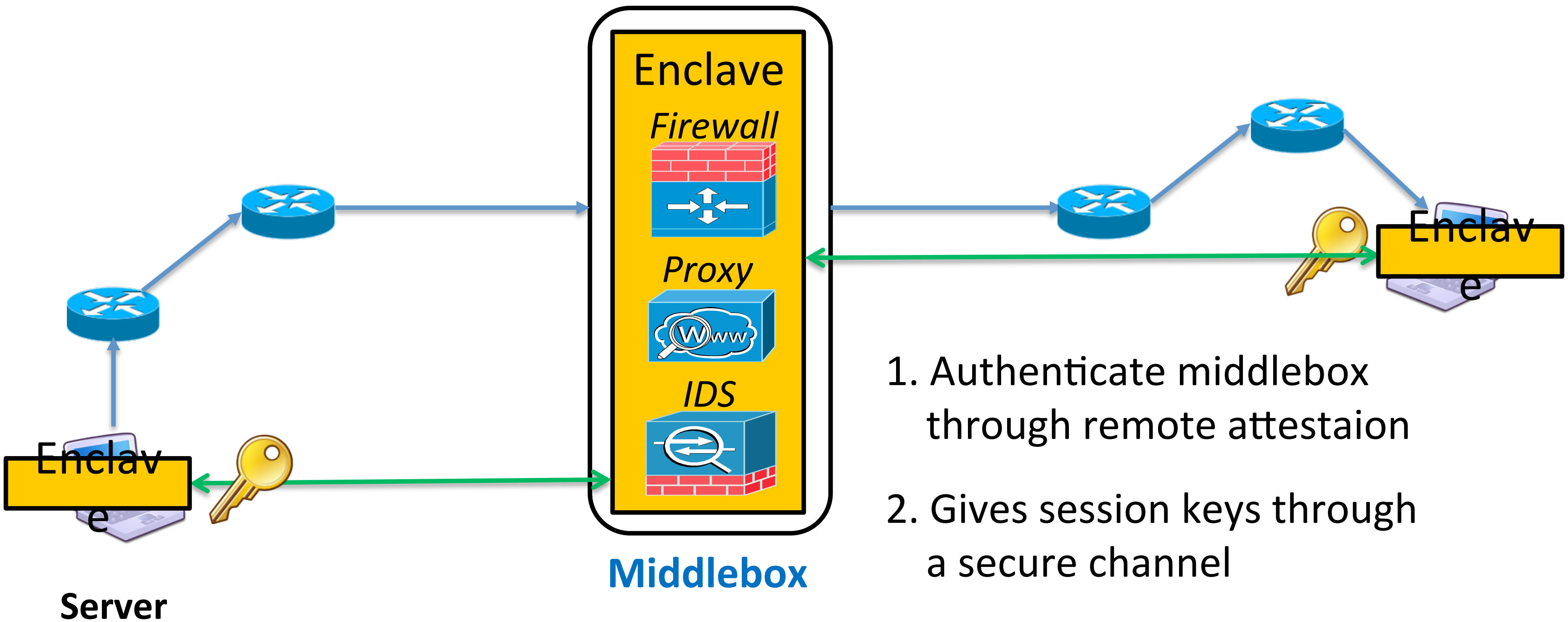
- SGX Program owner can remotely verify the integrity of code
- Publicly available programs (e.g., git) can validate the integrity of project by sharing the private key for the attestation
- Creates signature of program through shared private key



Example)
1. Tor binary for OR
2. SDN-based controller program

In-network Functions (Middleboxes)

- Use of TLS protocol disrupts in-network processing
  → Only endpoints of communication can access the plain-text
- SGX enables opportunity for secure in-network functions



1. Authenticate middlebox through remote attestaion
2. Gives session keys through a secure channel

Can be done unilaterally or bilaterally.

Trend 2: Commoditization of Trusted Execution Environment

- Trusted Execution Environment (TEE)
  - Isolated execution: integrity of code, confidentiality
  - Remote attestation
- Commoditization of TEE

The commoditization of TEE brings new opportunities for network applications.

2. Compatibility with x86