Practical and Secure Machine-to-Machine Data Collection Protocol in Smart Grid

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TCIPG

TRUSTWORTHY CYBER INFRASTRUCTURE FOR THE POWER GRID

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(M2MSec'14)

Outline

- Background
  - TCIPG
  - Smart Grid
  - Smart Grid and M2M Communications
- Data collection model (PO, DC, MD)
- Related work
- Protocol Overview and System Parameters
- Shared Key Generation
- Data Collection
- Preliminary Experimental Results
- Conclusion

TCIPG -- ACknowledgement

- Trustworthy Cyber Infrastructure for the Power Grid (TCIPG)
- Takes on the challenges of making the electric power infrastructure continuously functioning
  - While enhancing security, reliability, and safety
- U. of Illinois at Urbana-Champaign, Dartmouth College, WA State U., UC-Davis
- Funded by the US Department of Energy and Department of Homeland Security

Smart Grid Background

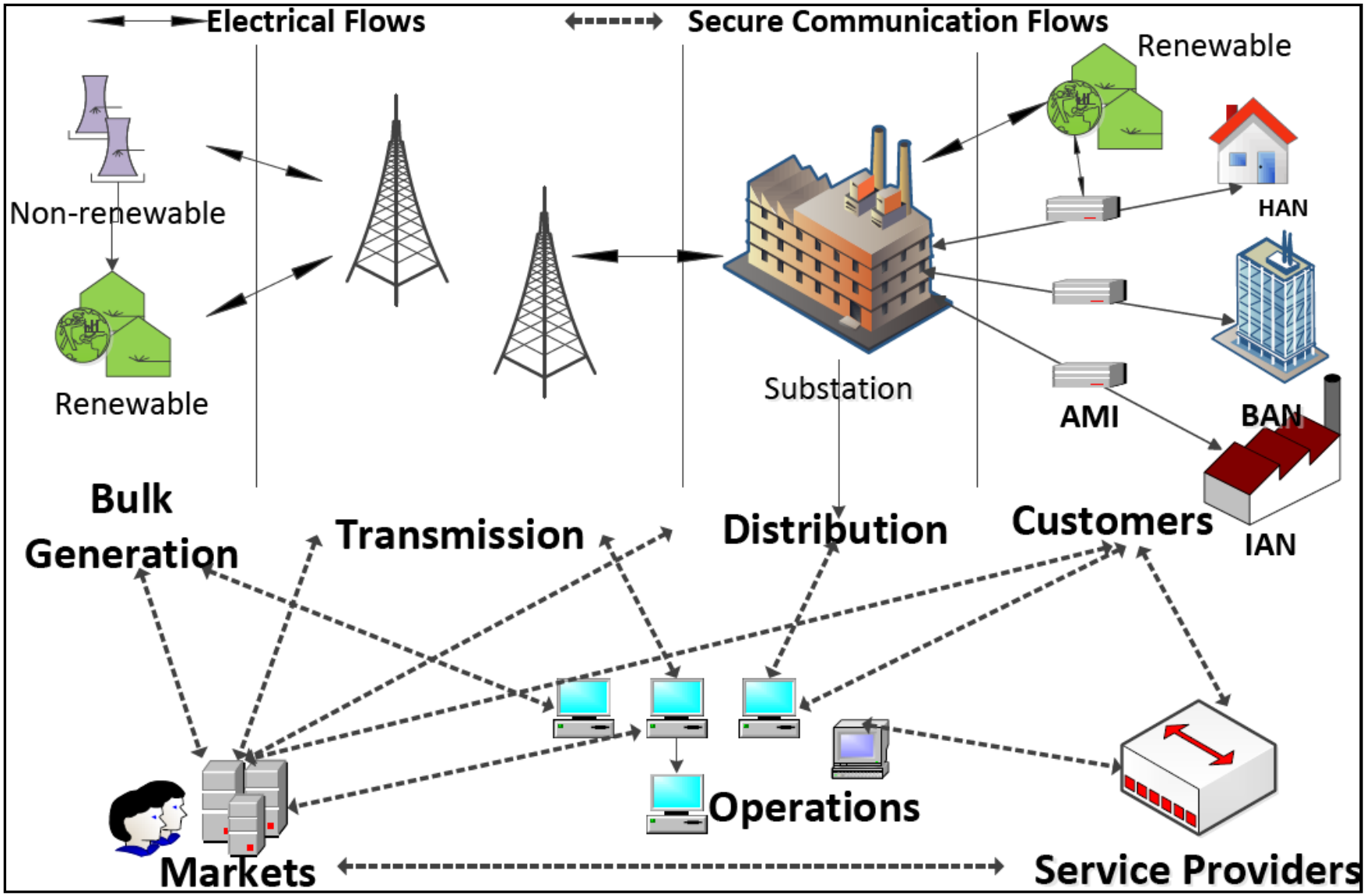
- Power Grid
  - Largest machine in the world
  - Centralized generation and control
  - Unidirectional power flow (from the grid)
  - Limited info flow (from the edge)
- Paradigm shift in energy production, transmission, distribution, consumption
- Key facilitator → **Smart Grid**

A Rough SG Definition

- Smart Grid (SG) is a vision, and a system of systems
- More specifically, the SG can be regarded as an electric system that uses information, two-way cyber-secure communication technologies, and computational intelligence in an integrated fashion across electricity generation, transmission, substations, distribution and consumption to achieve a system that is clean, safe, secure, reliable, resilient, efficient, and sustainable.

Source: Fang et al. Smart Grid Survey, 2011, IEEE Comm. Surveys and Tutorials

NIST Smart Grid Conceptual Model



Based on http://www.oncor.com/images/content/pathwaytopower.gif

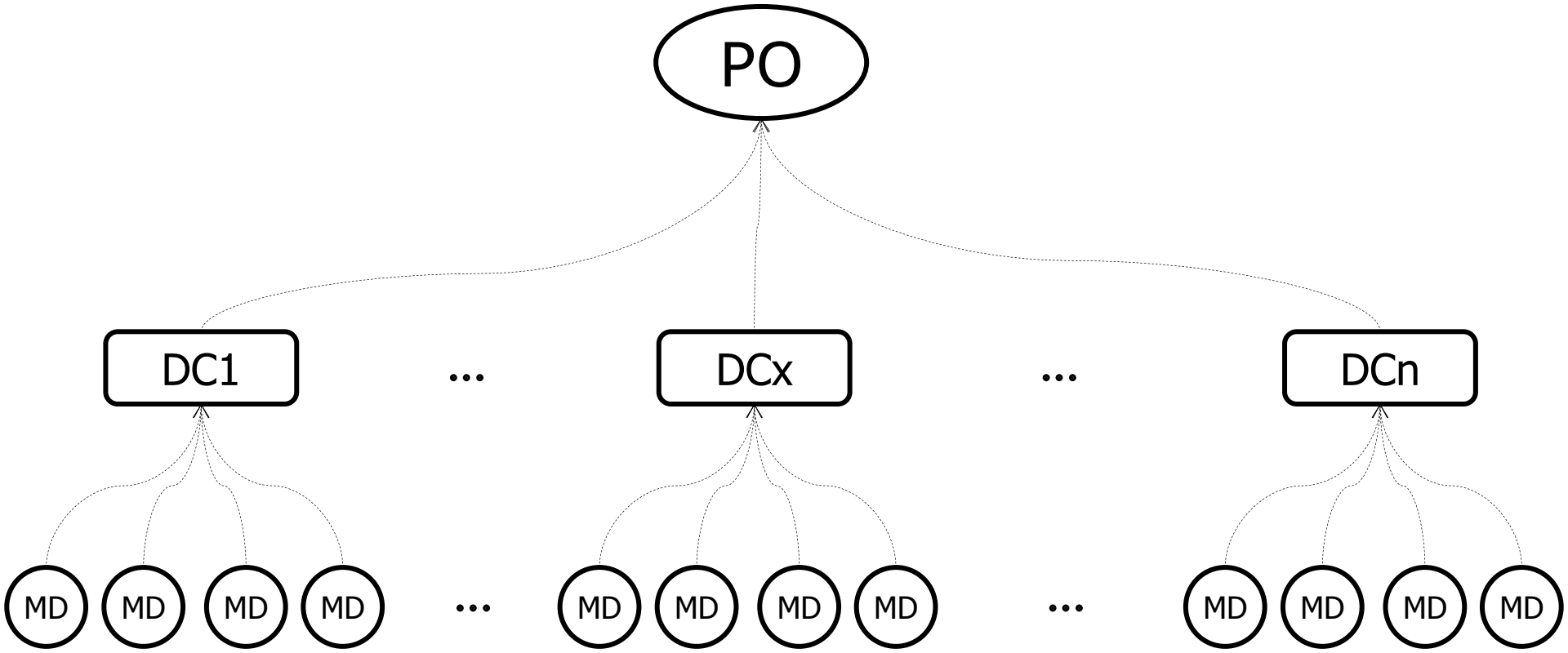
Smart Grid and M2M Communications

- Machine-to-Machine → a building block for SG
  - Especially for the wide-scale monitoring and control infrastructure
- SG → one of the most promising growth areas M2M adoption
  - Smart Cities, Smart Buildings, Vehicle-to-Grid (V2G), Grid-to-Vehicle (G2V) communications , Plug-in Hybrid Electric Vehicles (PHEV)
- Evolution of power distribution networks calling for sophisticated **Energy Management Systems (EMS)** for improved efficiency

Smart Grid M2M Applications

- Optimal line controls & loss minimization
- Fault-detection and management
- Load balancing
- Real-time state estimation
  - Phasor management units (PMU)
- AMI (Advanced Metering Infrastructure)
  - Smart meters
- Facilitate integration of distributed and/or renewable sources
- Distribution Automation (DA)
- Various other sensors, measurement devices, pole-top devices, etc.

Data Collection Model



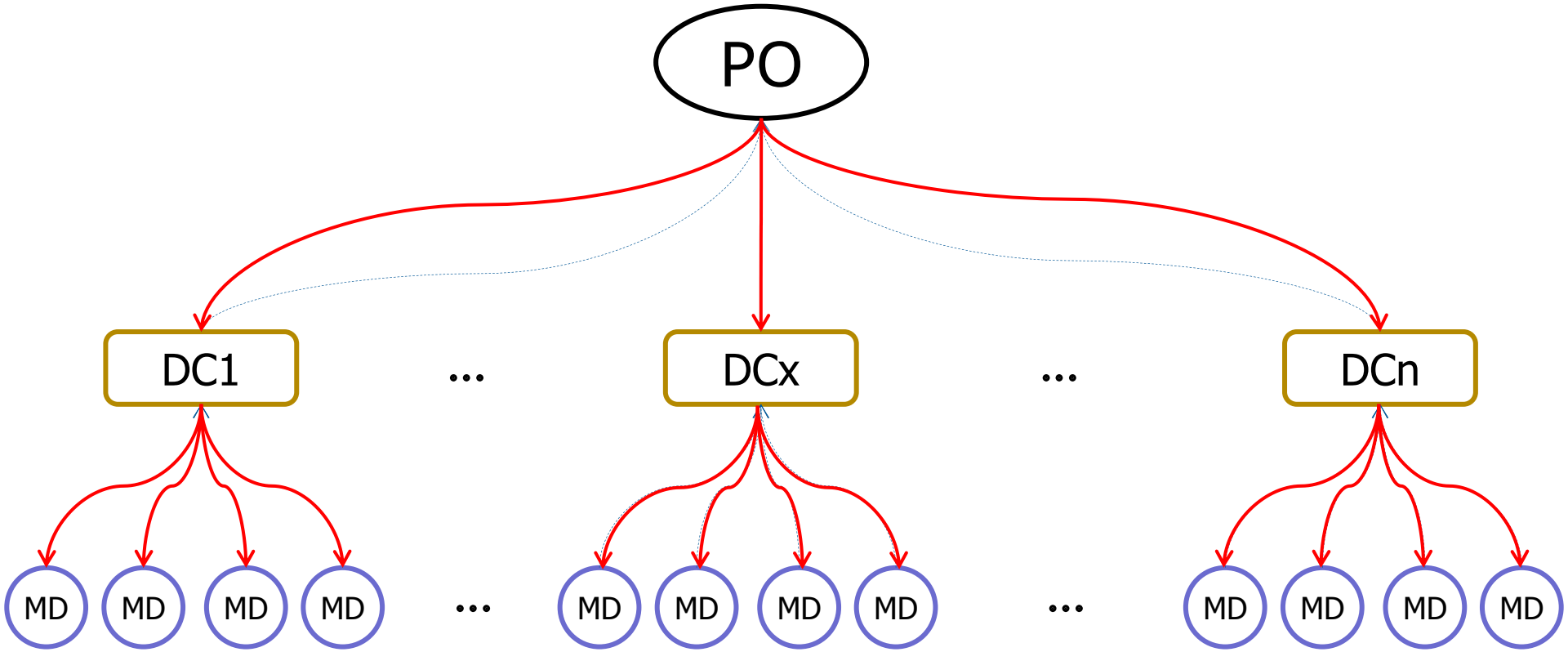
- Measurement Devices (MD)
- Data Collectors (DC)
- Power Operator (PO)

Related Work

- End-to-End data protection studied extensively for the Internet
  - TLS/SSL assume abundant power/memory
- Distributed Network Protocol 3 (DNP3) for SCADA
  - Assumes operating a security perimeter of the operator
- IEC 61850 does not have such a secure provisioning
- Overall existing protocols cannot address a hierarchical data collection model where PO and MDs cannot establish direct connection

System & Protocol Overview

- PO initiates the data collection process periodically or otherwise



Protocol specs

- Goal is to protect against
  - Eavesdropping
  - Impersonation
  - Message tampering
- PO → Always trustworthy
- DCs → Honest-but-curious
- MDs :
  - Trustworthy at the time of installation
  - Can then be attacked
- Our protocol cannot identify whether data is legit if a legit key is used
  - But, MDs cannot impersonate other MDs

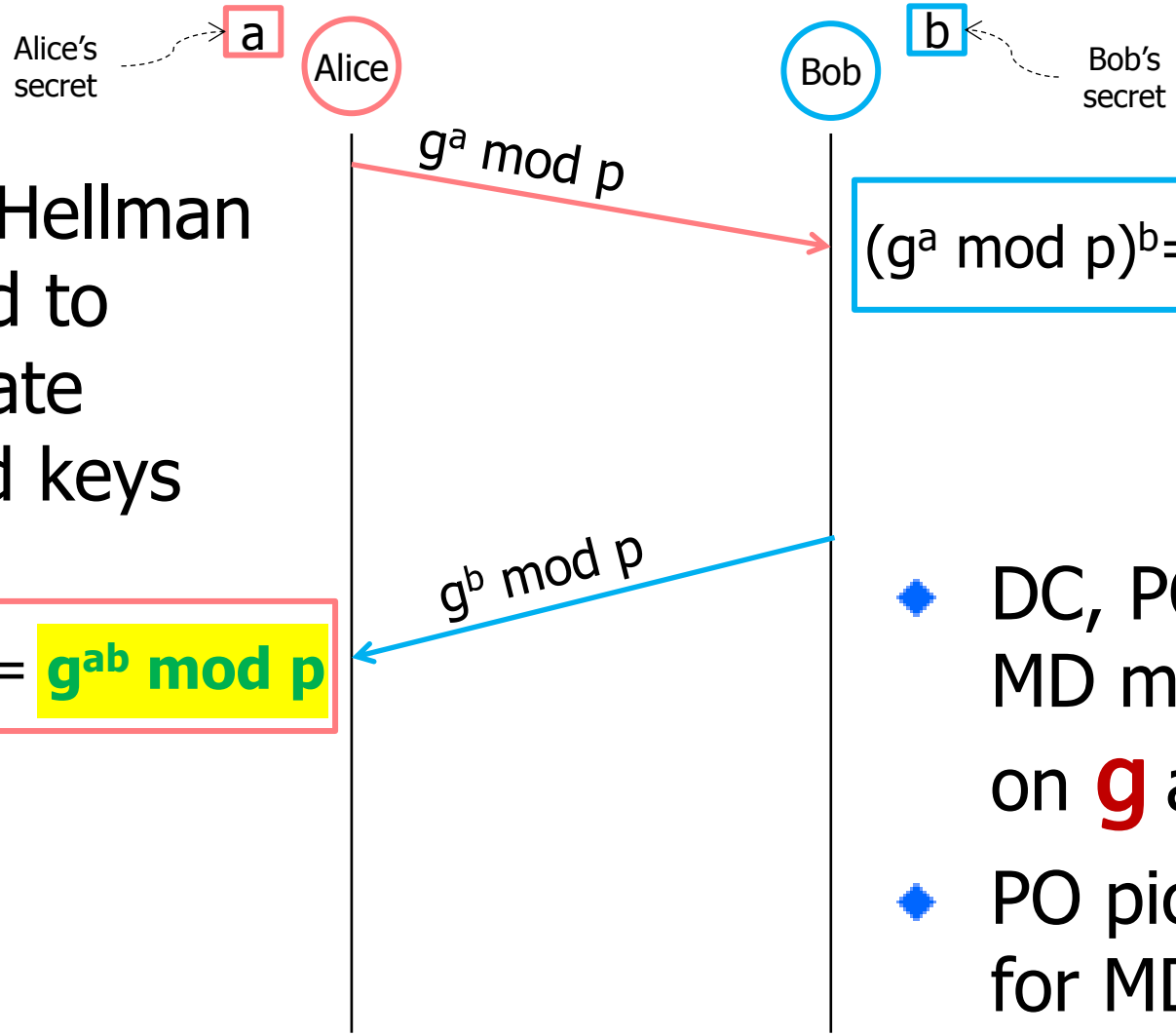
System Parameters

- PO, DCs, and MDs are assumed to have been equipped in advance with
  1. Long-term secrets,
  2. A set of system parameters, and
  3. The required cryptographic functions.
- A DC or MD should have all parameters and functions configured before it is deployed/installed in the field
- Notation:
  - Public key of node **A** → $\mathbf{A}^{+}$
  - Private key of node **A** → $\mathbf{A}^{-}$

1. Long-Term Secrets

- Key server generates private/public keys for all
  - Burned into DCs/MDs before installations
- PO keeps own as well as keys of all the MDs/DCs
  - PO does not make any keys available to outside
  - Our protocol is secure even if the public keys are known

2. System Params. (Diffie-Hellman)



- Diffie-Hellman is used to generate shared keys

- DC, PO, and MD must agree on **g** and **p**
- PO picks these for MDs/DCs

3. Cryptographic Functions

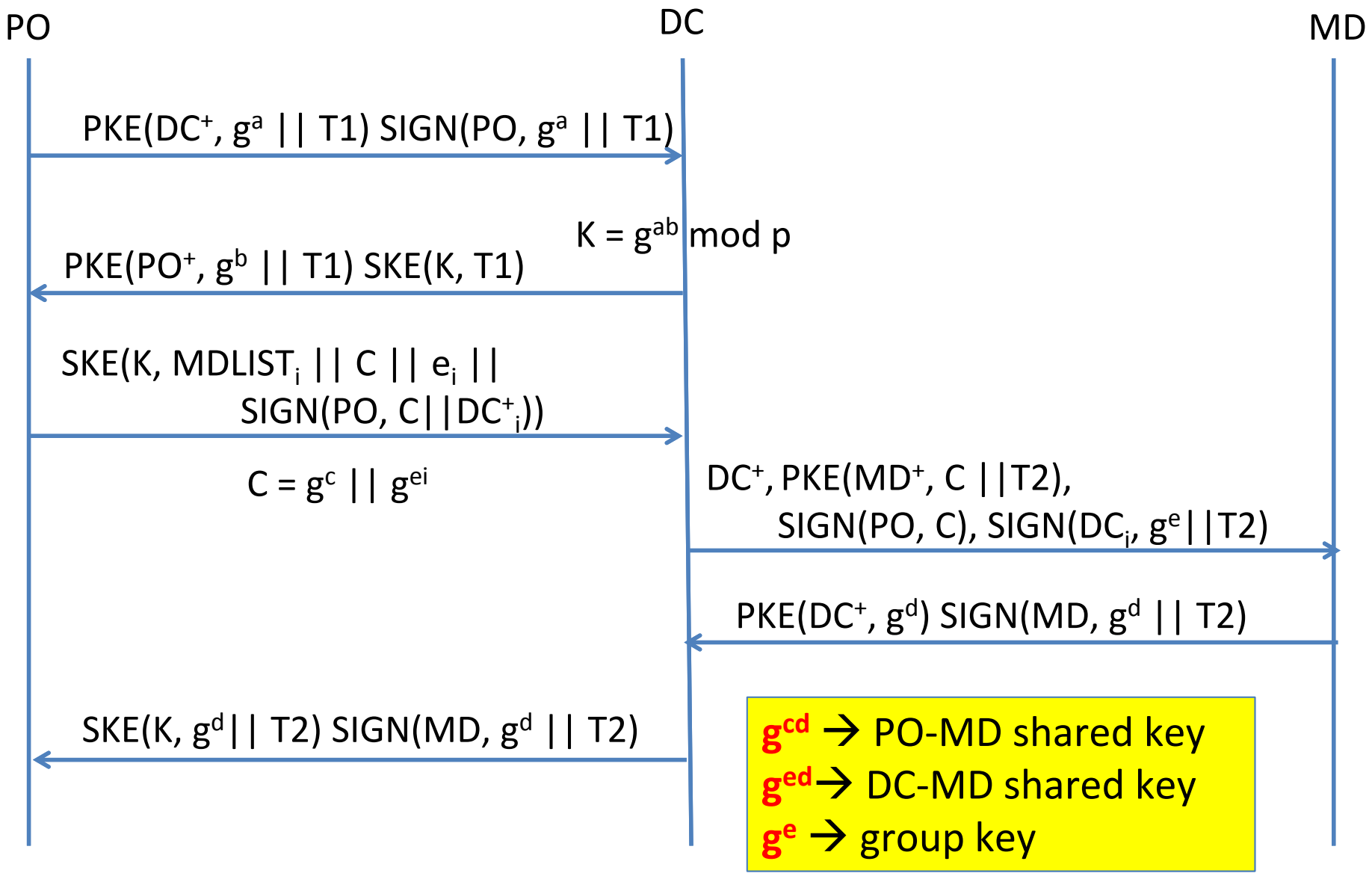
- Encryption, hashing, or signing
  - Needed for authentication, confidentiality, integrity
- PO selects appropriate cryptographic functions to be pre-installed in DCs/MDs

Name	Description
PKE(K,M)	apply public key encryption on M using K
SKE(K,M)	apply symmetric key encryption on M using K
SIGN(A,M)	The signature of M by A (created using A^-)
HASH(K,M)	compute the keyed-hash of M using key K
GENKEY(X,Y)	generate a key based on X and Y

Protocol Overview

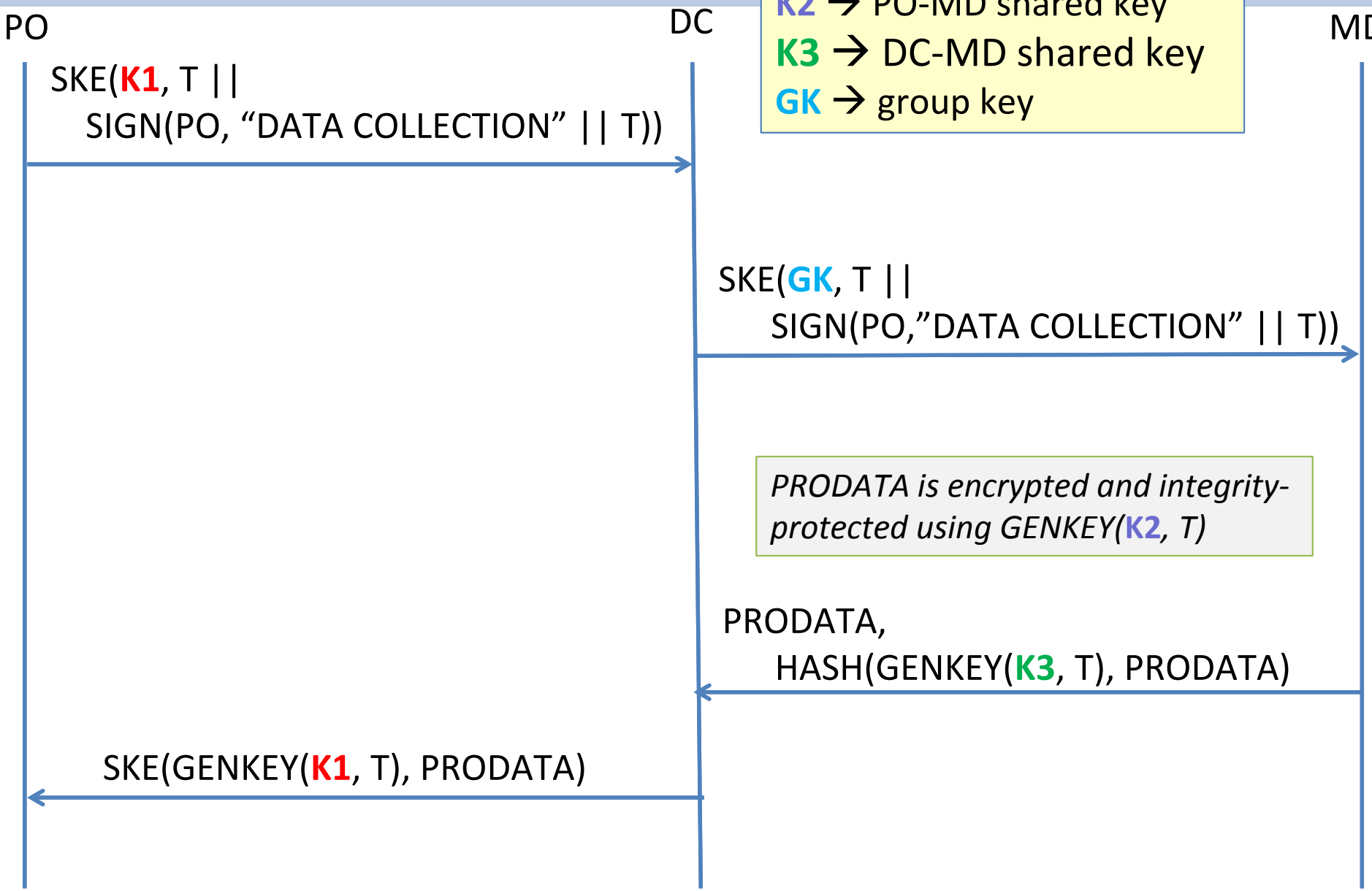
- Public-key infrastructure is NOT used for data
  - Expensive and not a good practice
- PO, DC, and MD use long-term secrets to establish shared keys
  - **Pairwise shared key**: A key only known by two parties
    1. PO-MD pairwise shared key for data
    2. DC-MD pairwise shared key (also known by PO)
    3. Group Keys among the PO, a certain DC and its MDs
- PO initiates the process to generate shared keys using the Diffie-Hellman exchange
  - DH half keys are authenticated using the long-term keys to prevent man-in-the-middle attacks
  - DH is expensive, so timestamps are used to avoid it every time

Shared Key Generation



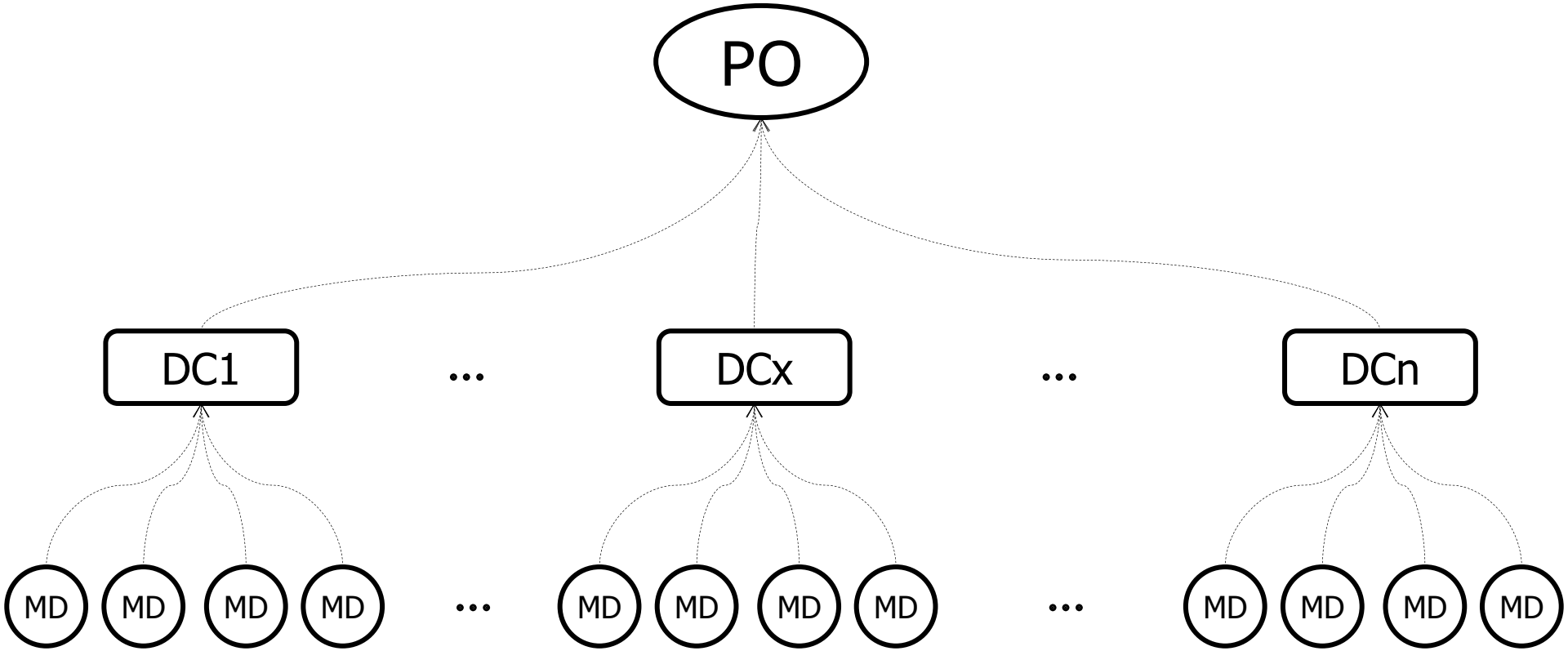
Data Collection

K1 → PO-DC shared key
K2 → PO-MD shared key
K3 → DC-MD shared key
GK → group key



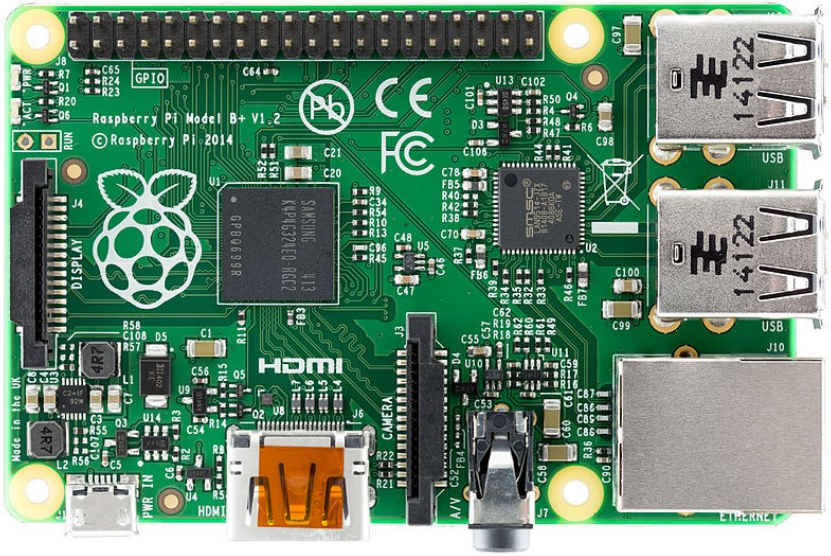
Preliminary Experimental Results

- Since the bottleneck of the protocol is on MD side, our focus is on MD-DC part
  - Message generation, communication, and message processing



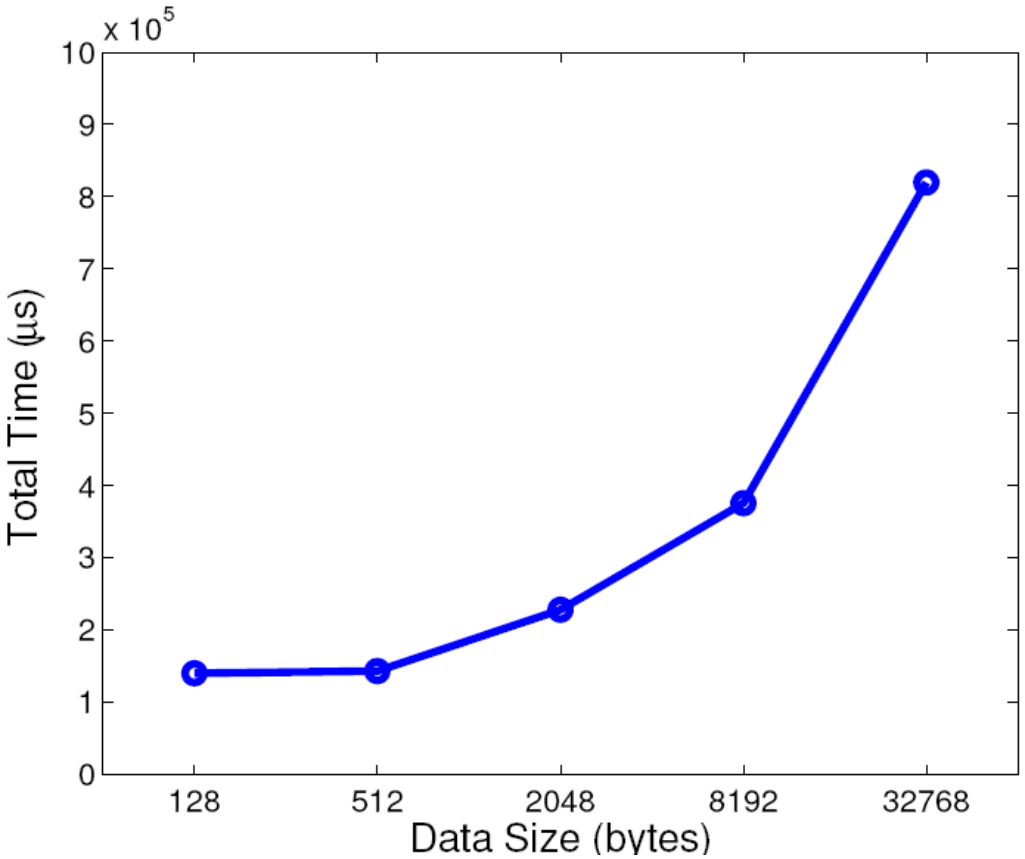
Preliminary Experimental Results

- A small testbed of data collection
- Resource-constrained MDs → by Raspberry Pi
  - Raspberry Pi: Credit-card sized, inexpensive, single-board computers



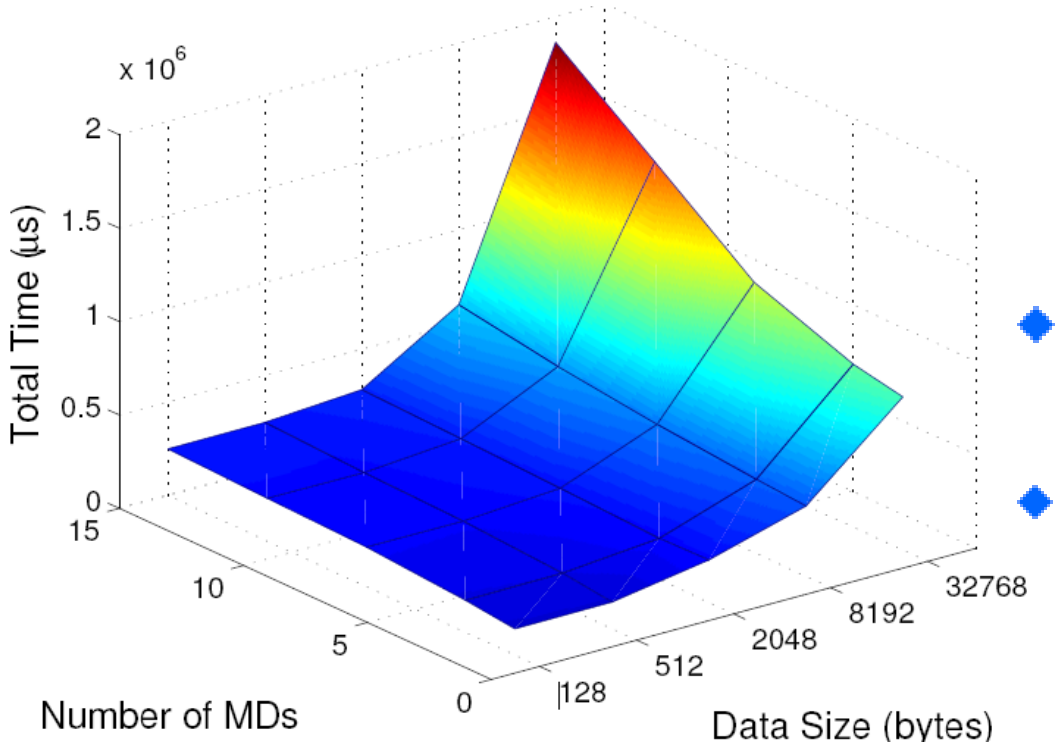
  - 700MHz Broadcom System-on-a-Chip (SoC)
    - Equivalent to late 1990s Pentium CPUs
  - 256/512 MB RAM
- 15 MDs
- DC → laptop

Time for data collection



- Total time
  - DC msg generation and transmission to MD
  - MD processing and transmission time
  - DC final processing time
- DH key size : 1024 bits
- RSA key size: 3072 bits
- AES key size: 256 bits

Collection Time, Size, # of MDs



- Total data collection time by one DC
  - DH key size : 1024 bits
  - RSA key size: 3072 bits
  - AES key size: 256 bits
- Total time rises with more MDs and data size
- Association of MDs with DCs emerges as a critical problem, which we will be studying as part of our future work.

Conclusion

- Data collection is critical for the success of the Smart Grid.
- Vastly increased data calls for mechanisms with security, reliability, and privacy
  - Automation becomes inevitable and thus M2M
- Proposed: a secure communications protocol data collection in a practical, scalable, and efficient manner under a hierarchical model
- 3rd party service providers enabled as envisioned by NIST's Smart Grid Conceptual Model

Thank You!

Questions

or

Comments?

Backup Slides…

Renewable Sources – Strong Push

- President Obama's **25by25** goal : 25% renewable sources (Wind turbines, solar panel, etc.) by 2025
  - Now < 5%.
- European Union's ambitious climate and energy targets for 2020
  - These targets, known as the "**20-20-20**" targets, set three key objectives for 2020:
    - A 20% reduction in EU greenhouse gas emissions from 1990 levels;
    - Raising the share of EU energy consumption produced from renewable resources to 20%;
    - A 20% improvement in the EU's energy efficiency.

SG and M2M Communications???

Advanced Metering Infrastructure

- ??????
- Example scenarios (AMI, sensors measurement devices)