Secure Networked Control Systems Against Replay Attacks Without Injecting Authentication Noise

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September 19, 2014

Outline

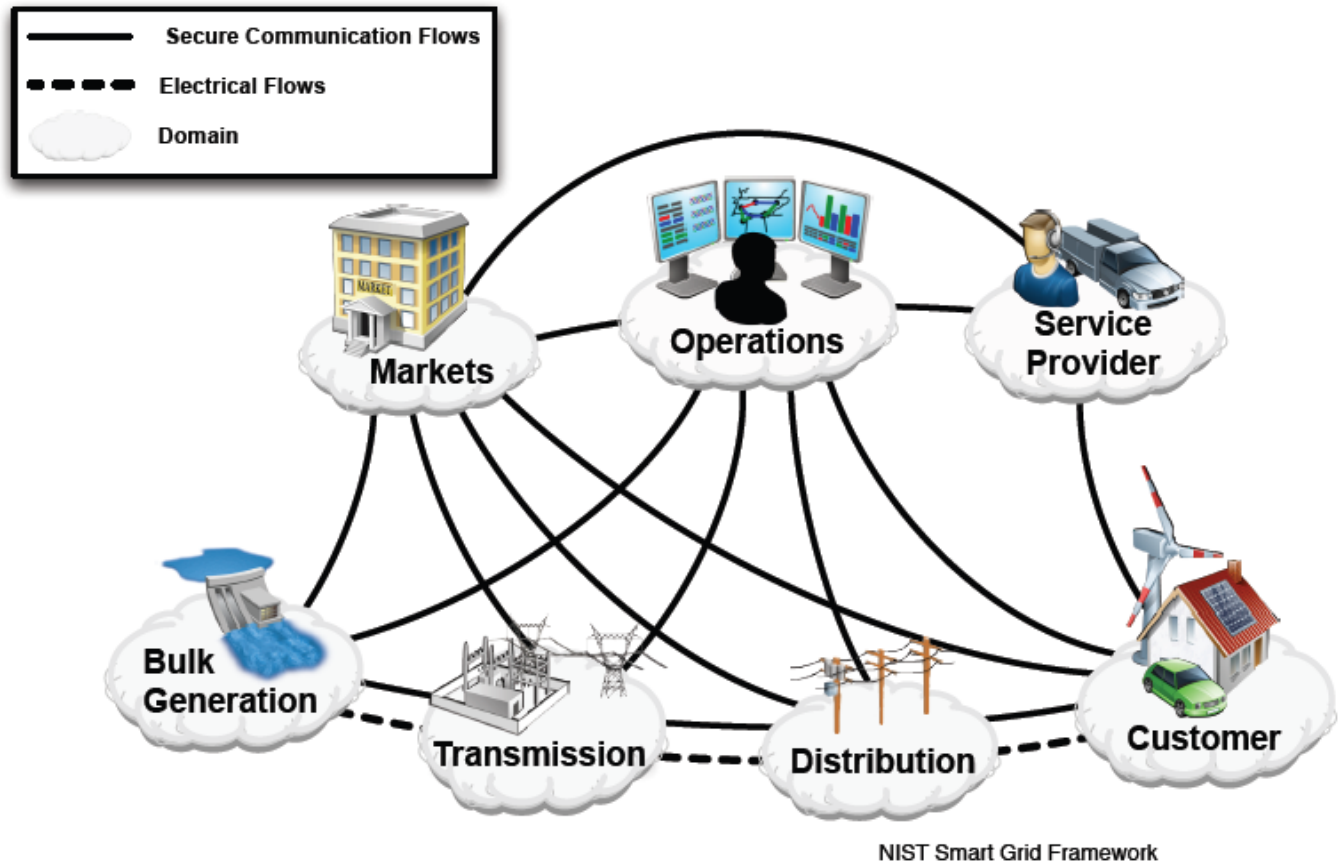
Smart Grid

Modern Power Grids

- Distributed generation units and loads contribute to unpredictable power fluctuations.
- Smart Grid technology (specifically SCADA and SDX service) facilitates the collection of power measurements.

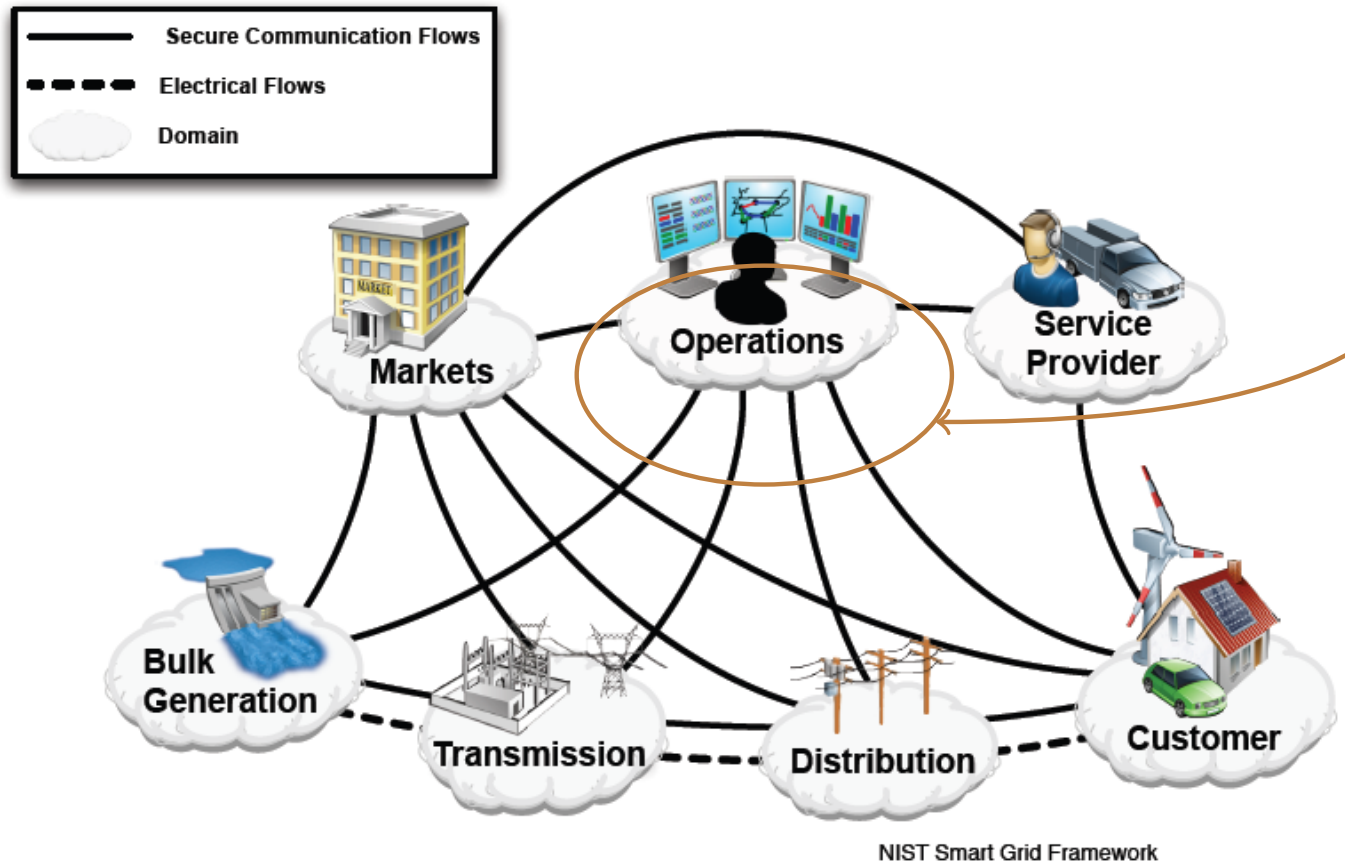
Outline

NIST Conceptual Model



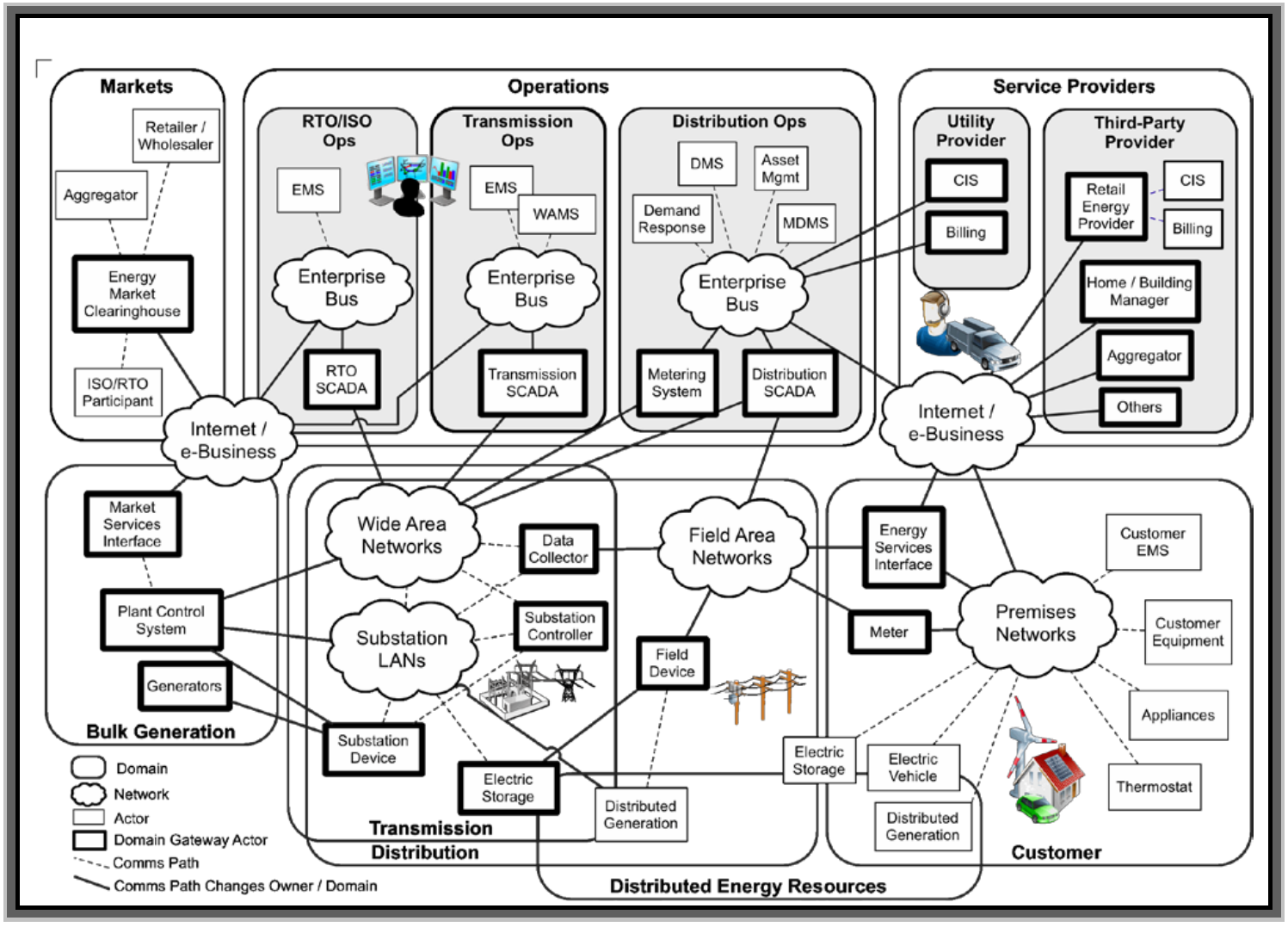
NIST Smart Grid Framework

NIST Conceptual Model



Smart Grid Security

NIST Conceptual Model Detail



Smart Grid Security

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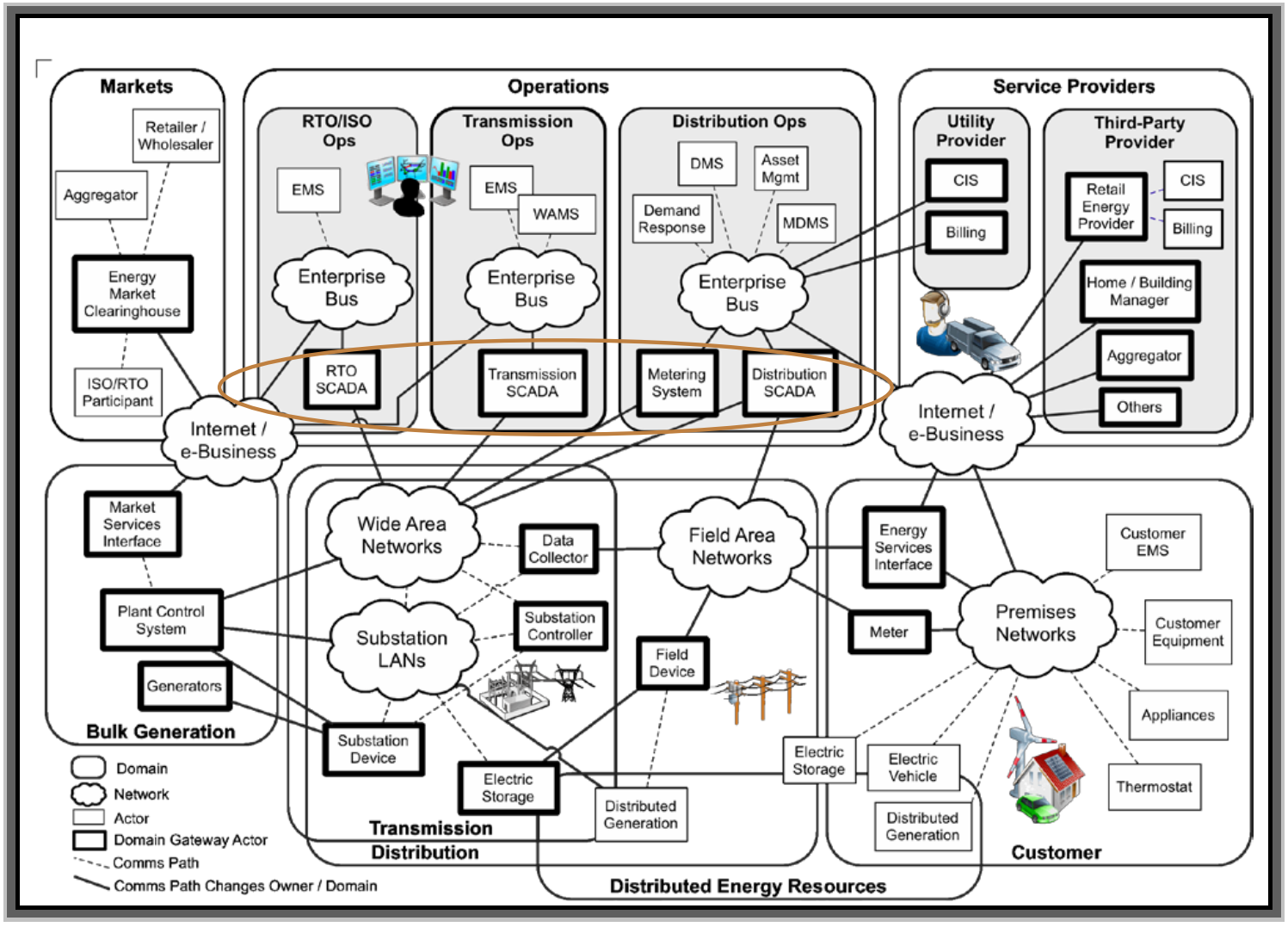

Smart Grid Security

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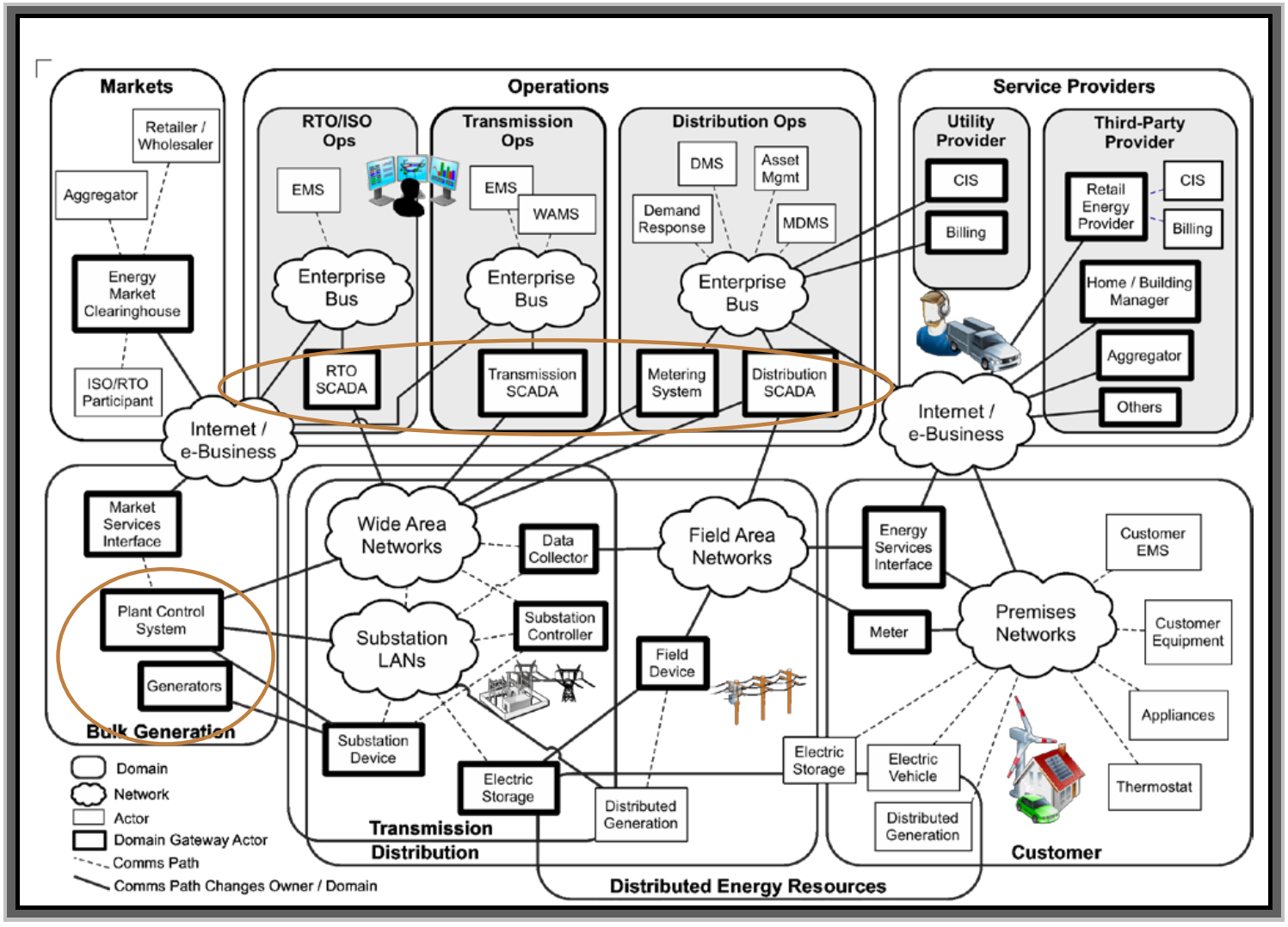

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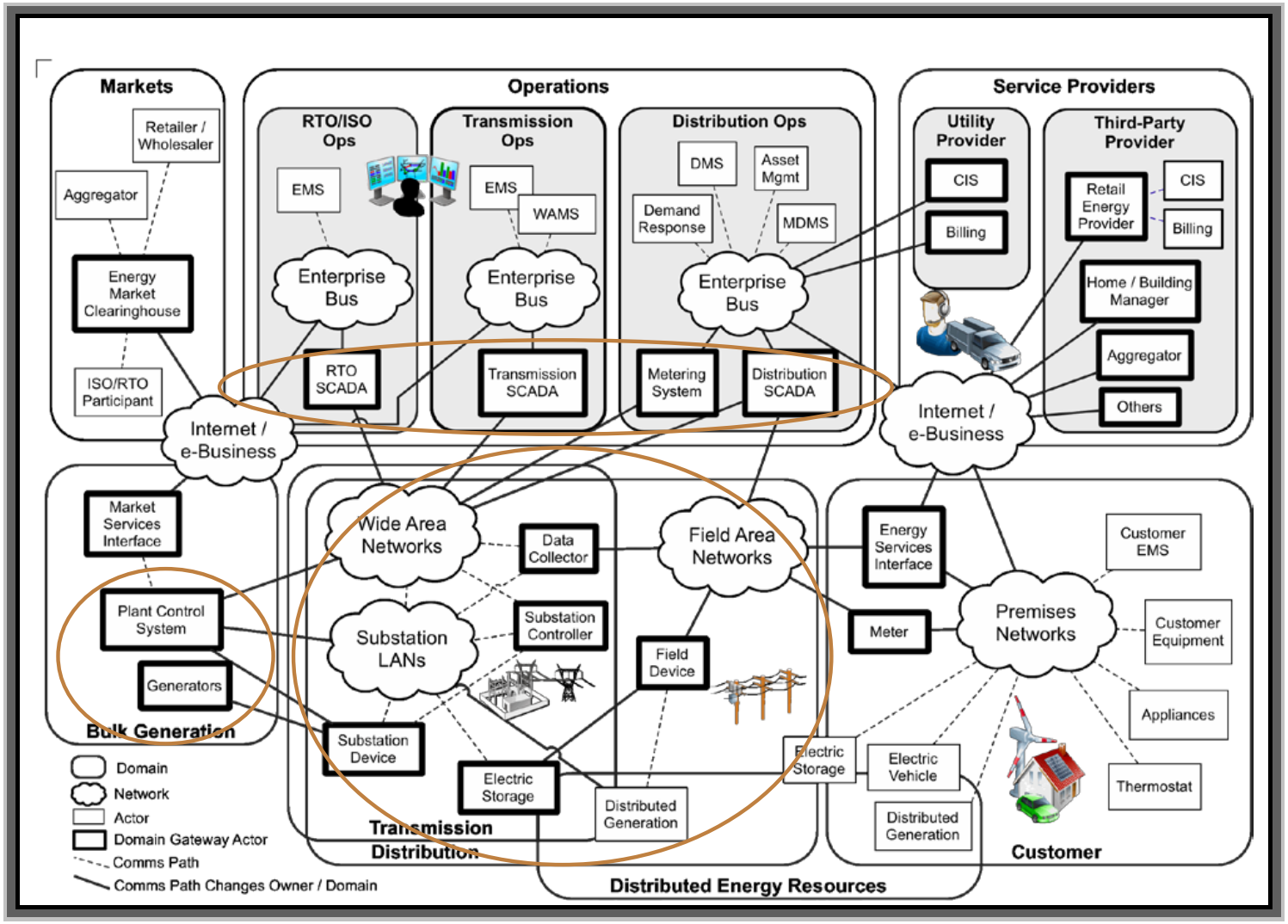

Replay Attacks

- "At a global scale, pretty much every single industrial or military facility that uses industrial control systems ... is dependent on its network of contractors, many of which are very good at narrowly defined engineering tasks, but lousy at cybersecurity."
- "[conventional hackers] are also much more likely to go after civilian critical infrastructure. Not only are these systems more accessible, but they're standardized ... all modern plants operate with standard industrial control system architectures and products from just a handful of vendors per industry .... "

R. Langner, cyberdefense consultant.


The New York Times

Middle East

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Israeli Test on Worm Called Crucial in Iran Nuclear Delay

By WILLIAM J. BROAD, JOHN MARKOFF and DAVID E. SANGER
Published: January 15, 2011

*This article is by **William J. Broad, John Markoff** and **David E. Sanger**.*

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Nicholas Roberts for The New York Times

Ralph Langner, an independent computer security expert, solved Stuxnet.

Multimedia

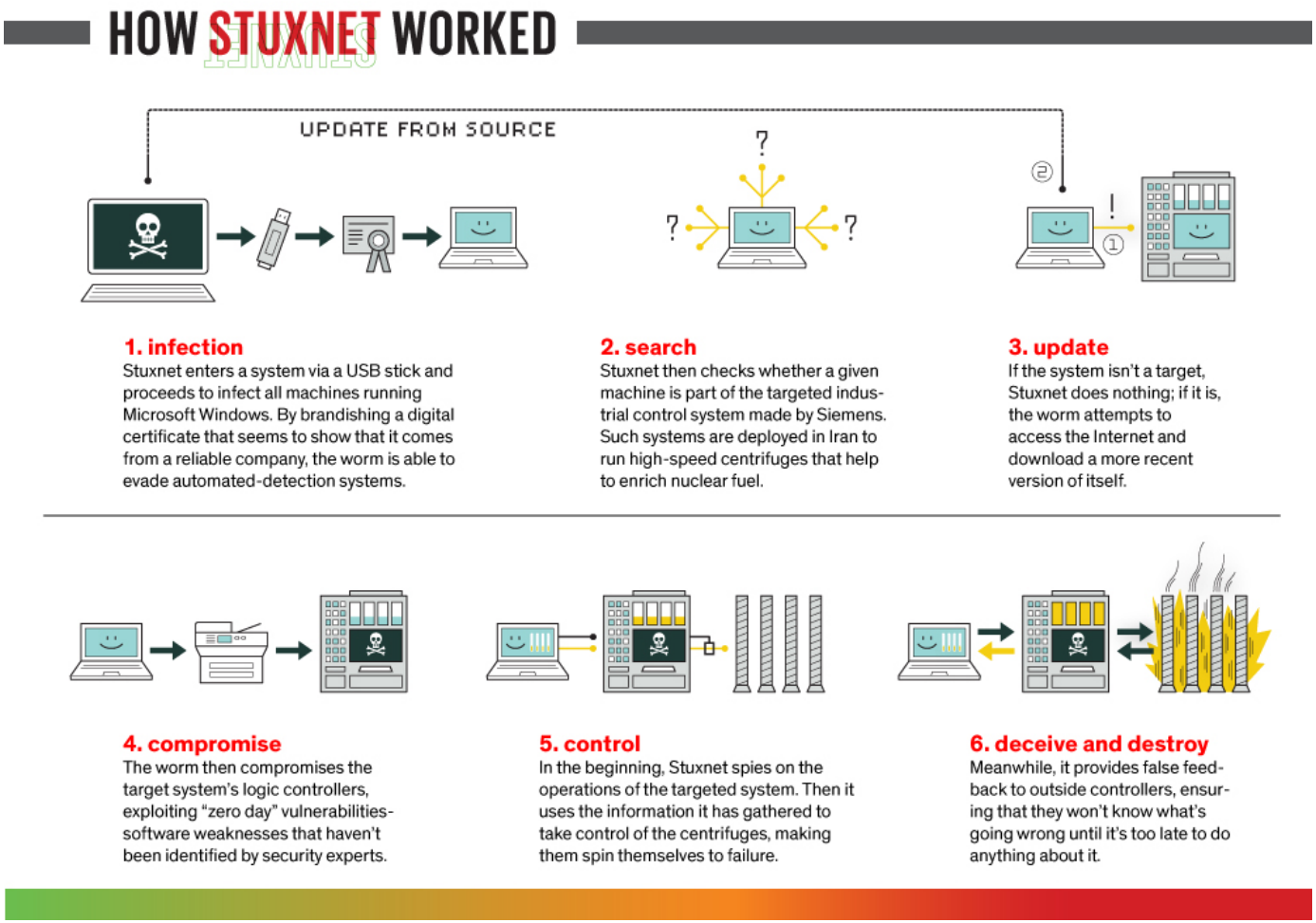
The Dimona complex in the Negev desert is famous as the heavily guarded heart of Israel's never-acknowledged nuclear arms program, where neat rows of factories make atomic fuel for the arsenal.

Over the past two years, according to intelligence and military experts familiar with its operations, Dimona has taken on a new, equally secret role — as a critical testing ground in a joint American and Israeli effort to undermine Iran's efforts to make a bomb of its own.

- As of 2010, more than 50,000 Windows computers infected.

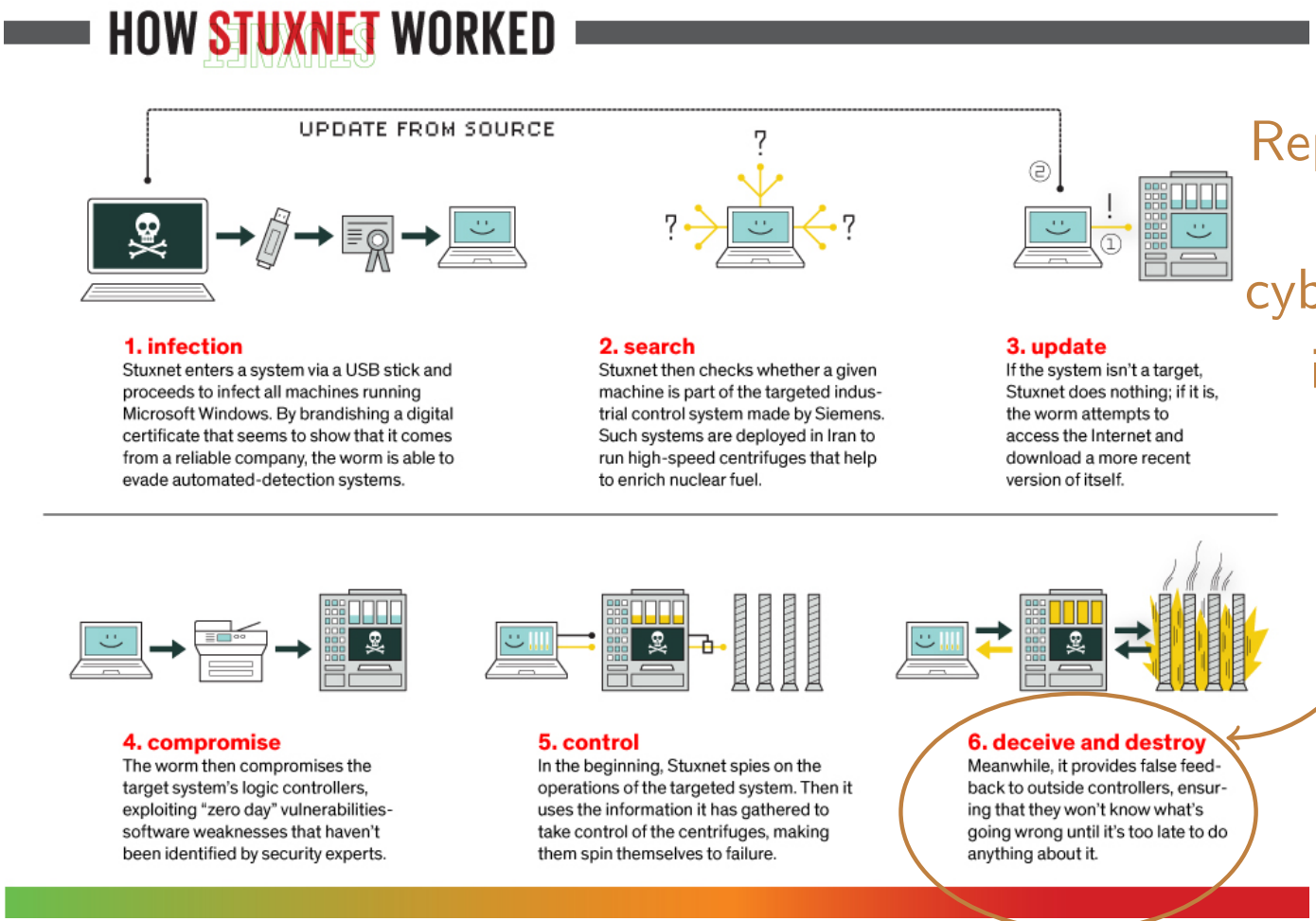
Replay Attacks

Stuxnet Worm



Replay Attacks

Stuxnet Worm



Replay attack at the cyber-physical interface

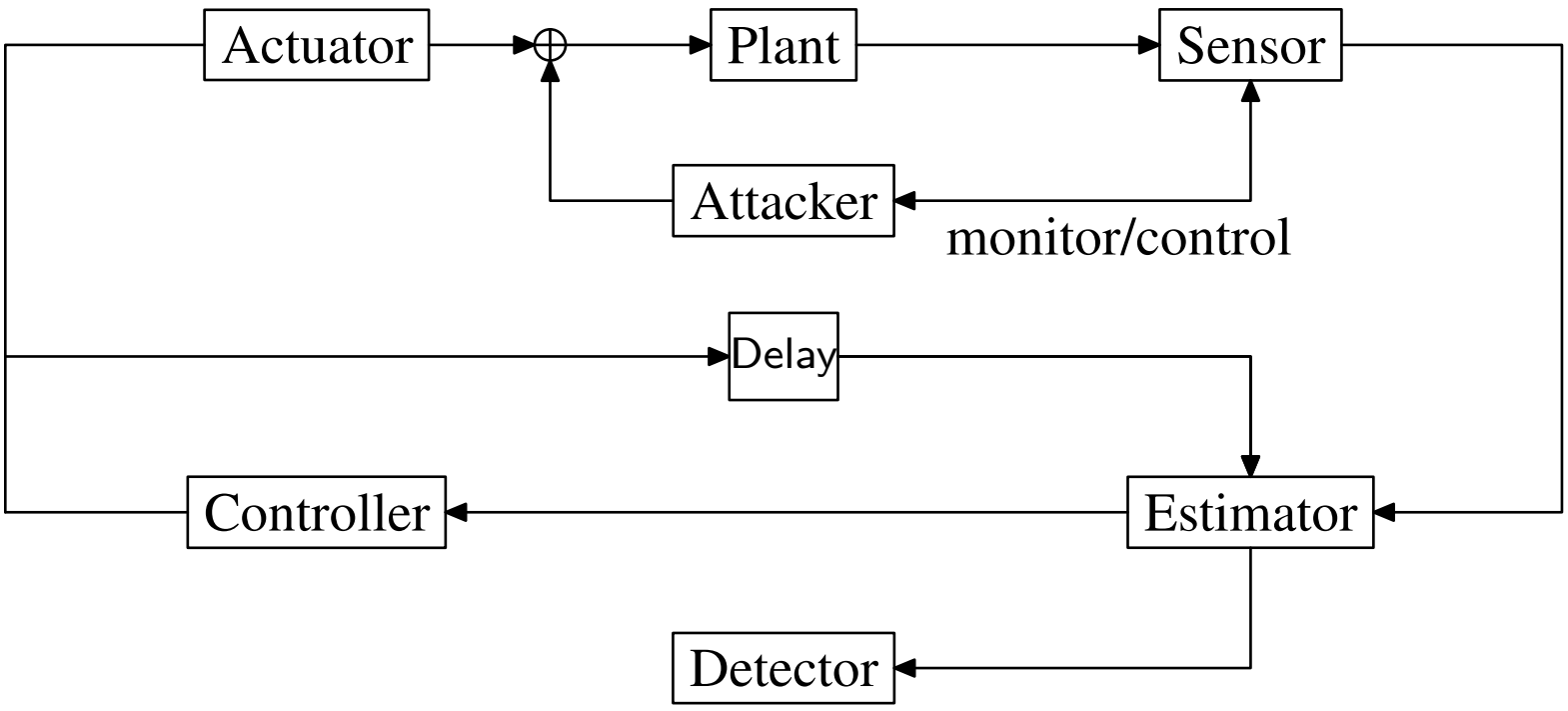
Replay Attacks

Small sample of existing work

- Y. Mo, T. Kim, K. Brancik, D. Dickinson, H. Lee, A. Perrig, and B. Sinopoli, "Cyberphysical security of a smart grid infrastructure," *Proceedings of the IEEE*
- T. Tran, O. Shin, and J. Lee, "Detection of replay attacks in smart grid systems", *IEEE 2013 International Conference ComManTel*
- F. Miao, M. Pajic, and G.J. Pappas, "Stochastic game approach for replay attack detection," *2013 IEEE Annual Conference on Decision and Control*
- A.A. Cárdenas, S. Amin, and S. Sastry, "Secure control: Towards survivable cyber-physical systems," *28th International Conference on Distributed Computing Systems Workshops*
- Y. Mo, R. Chabukswar, and B. Sinopoli, "Detecting Integrity Attacks on SCADA Systems",*IEEE Transactions on Control Systems Technology*

Replay Attacks on SCADA Systems

(Mo, Chabukswar, and Sinopoli): LQG+χ^2 Detector



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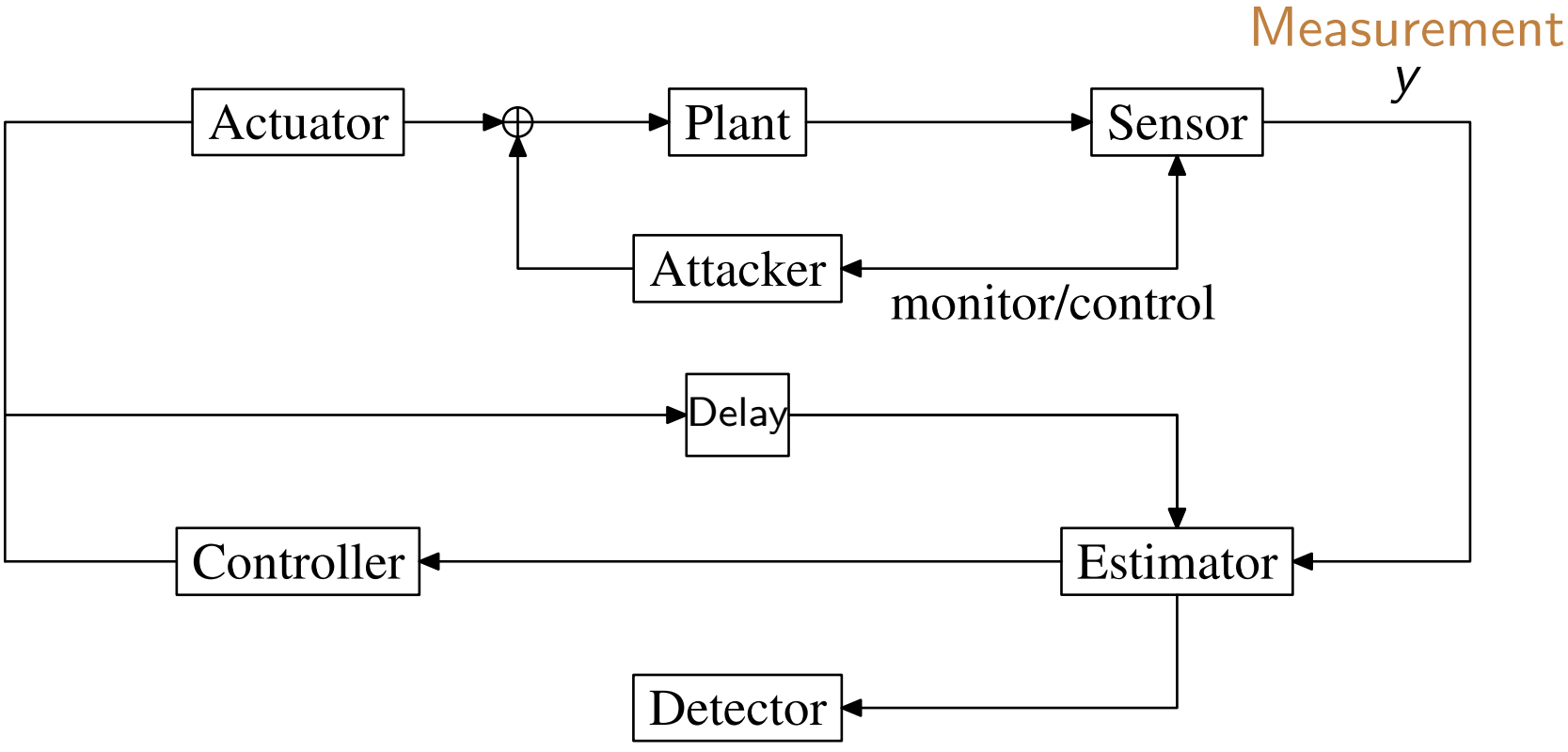

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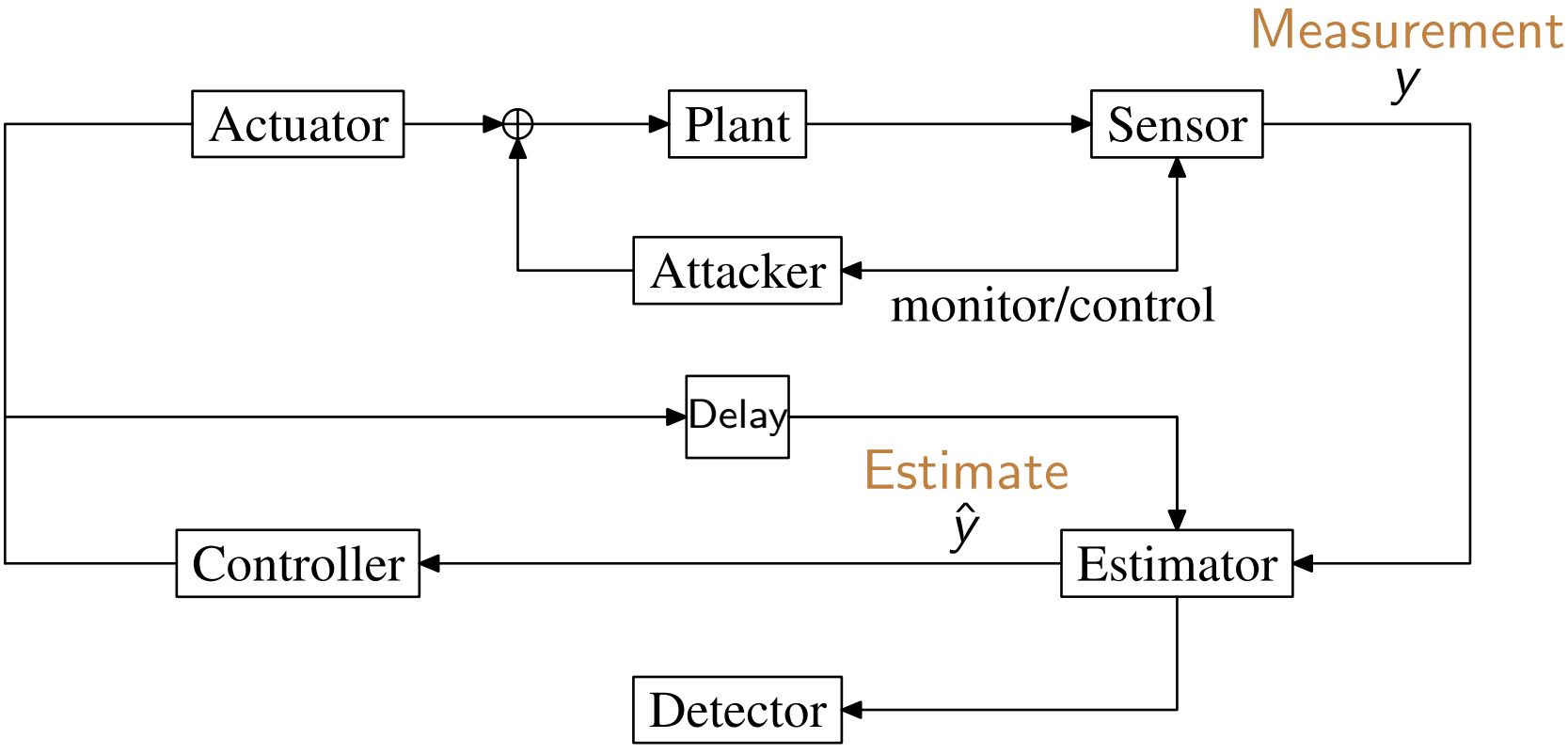

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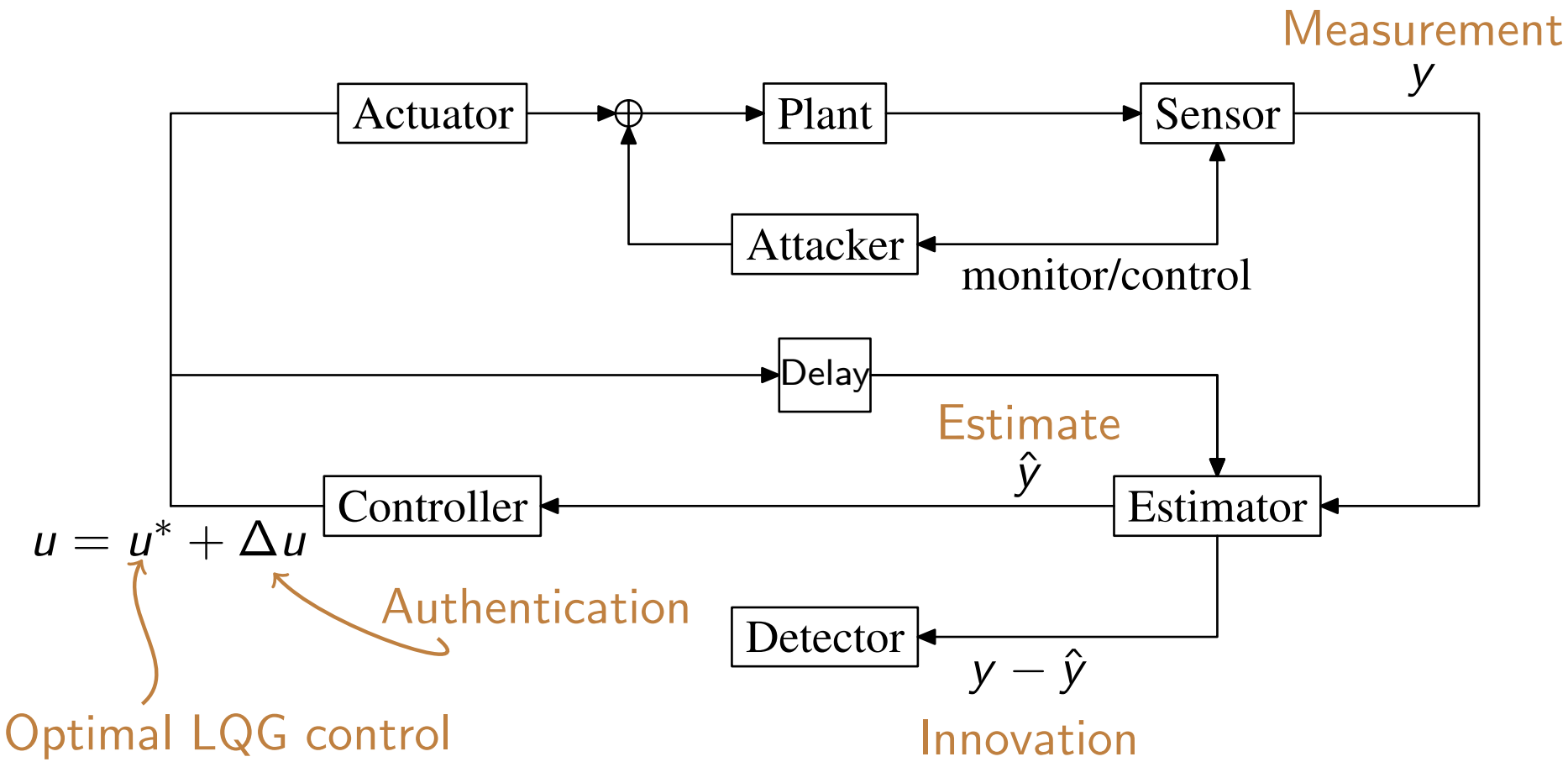


Replay Attacks on SCADA Systems

Plant: $x(t+1) = Ax(t) + Bu(t) + w(t)$

$$y(t) = Cx(t) + v(t)$$

Control Signal: $u(t) = u^*(t) + \Delta u(t)$

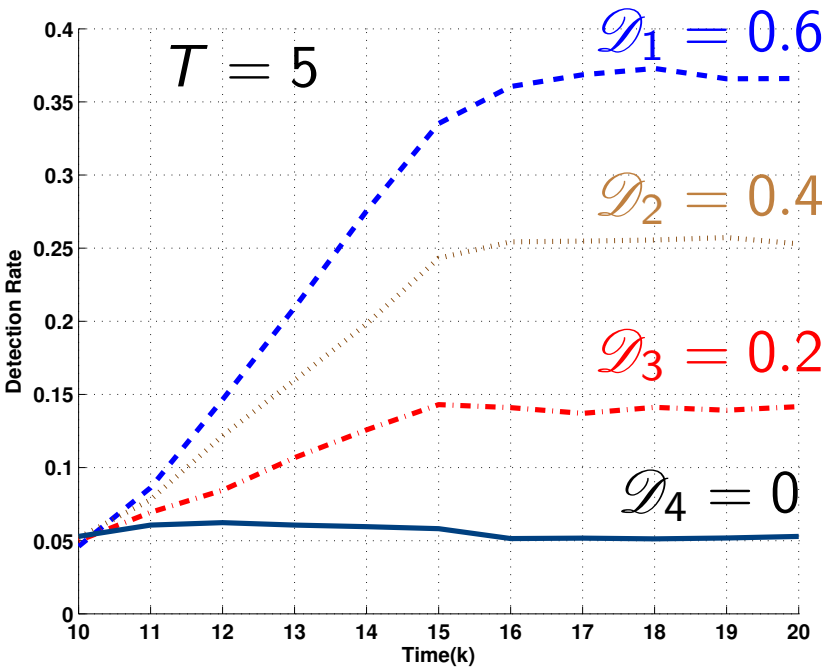
$u^*(t)$: LQG optimal control signal.

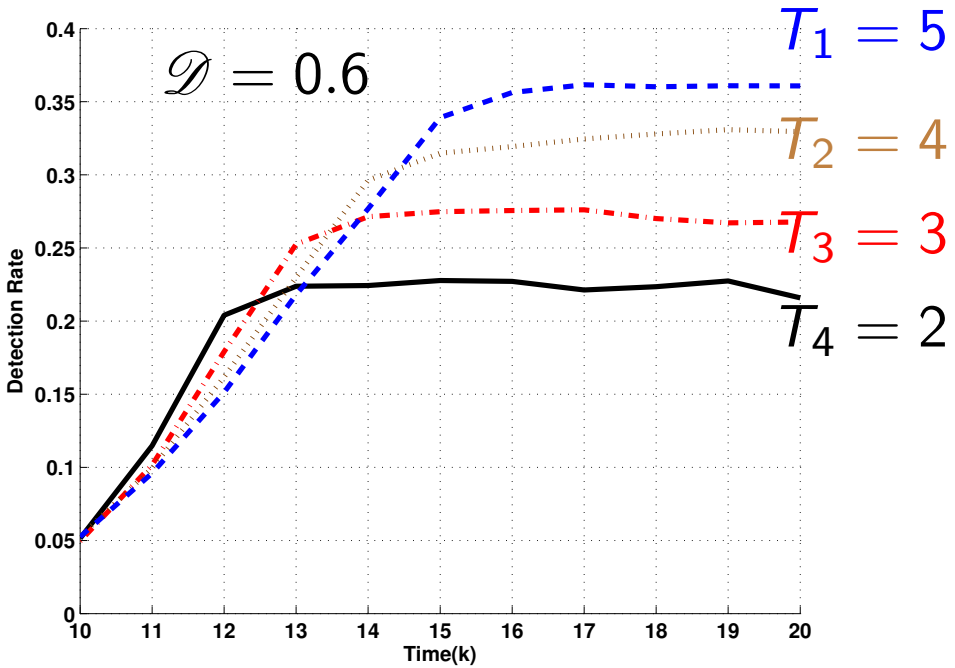
$\Delta u(t)$: Authentication signal with mean zero and covariance $\mathscr{D}$.

LQG Performance: $J = J_{LQG} + \mathrm{trace}\{(U + B'SB)\mathscr{D}\}$

Detector: $\sum_{t=k-T+1}^{k}(y(t) - \hat{y}(t))'P^{-1}(y(t) - \hat{y}(t)) \leqslant \text{threshold}$

Replay Attacks on SCADA Systems

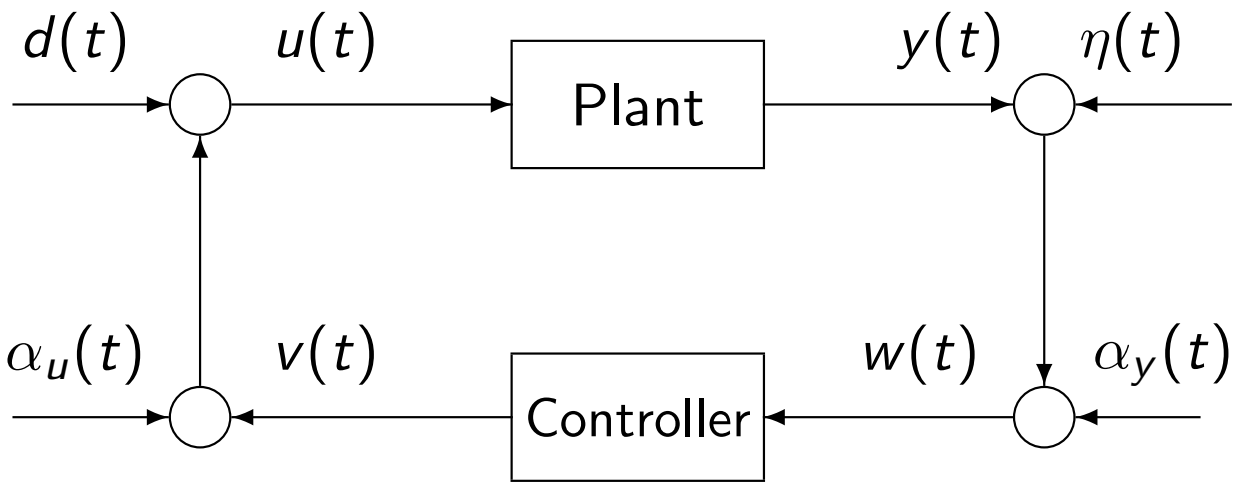




Tradeoff between detection rate and control performance for a temperature control system.

Replay Attacks

A Novel Approach



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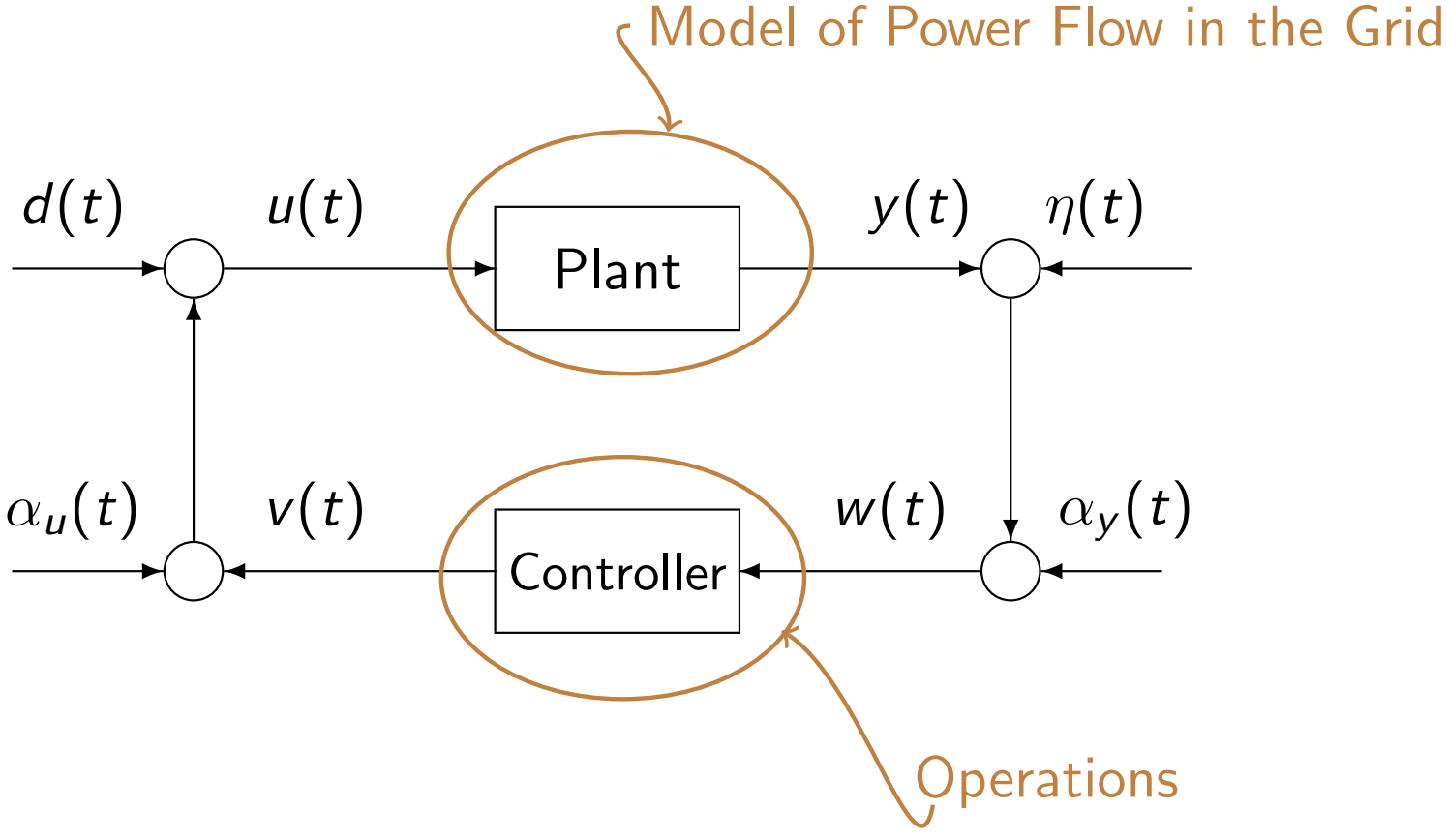

Replay Attacks

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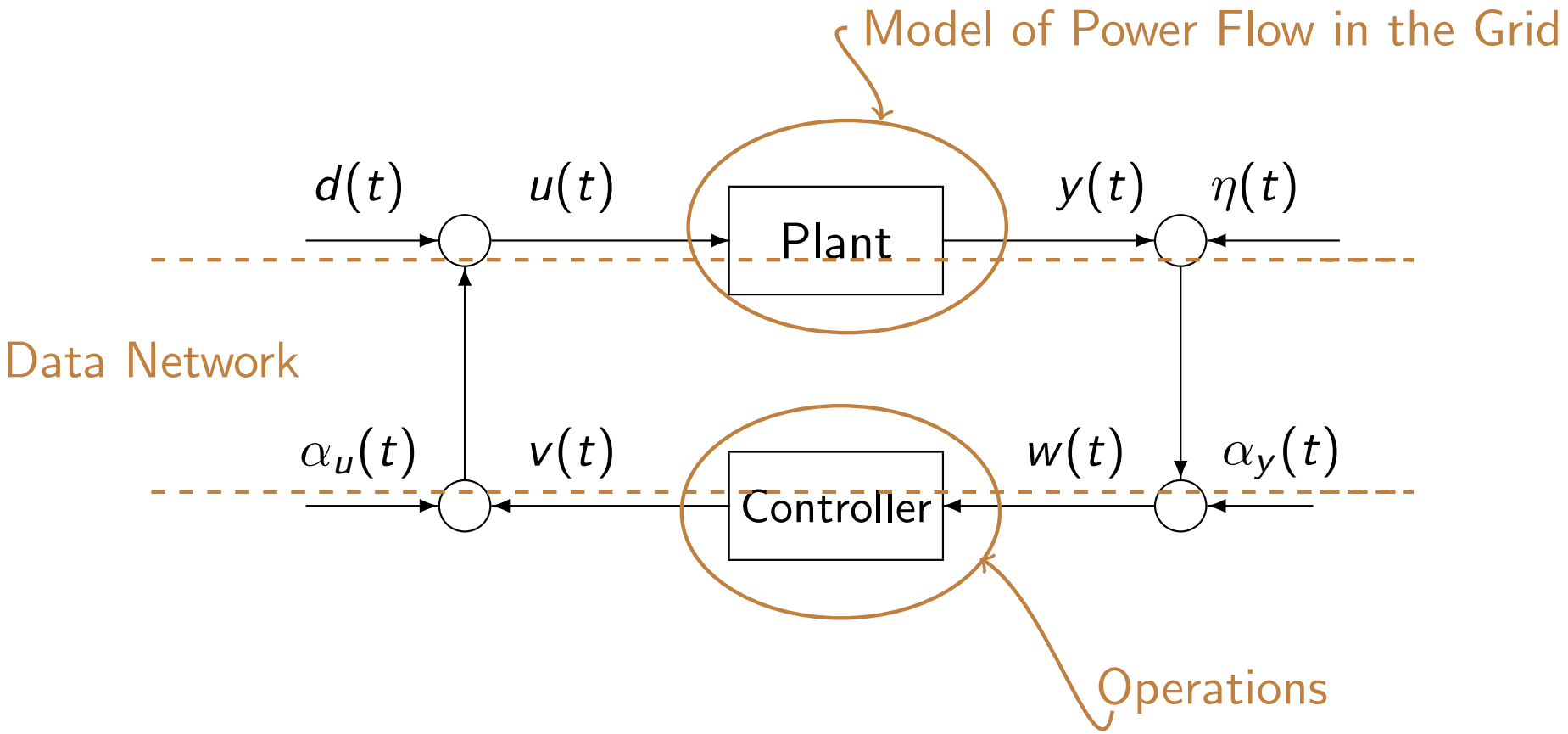

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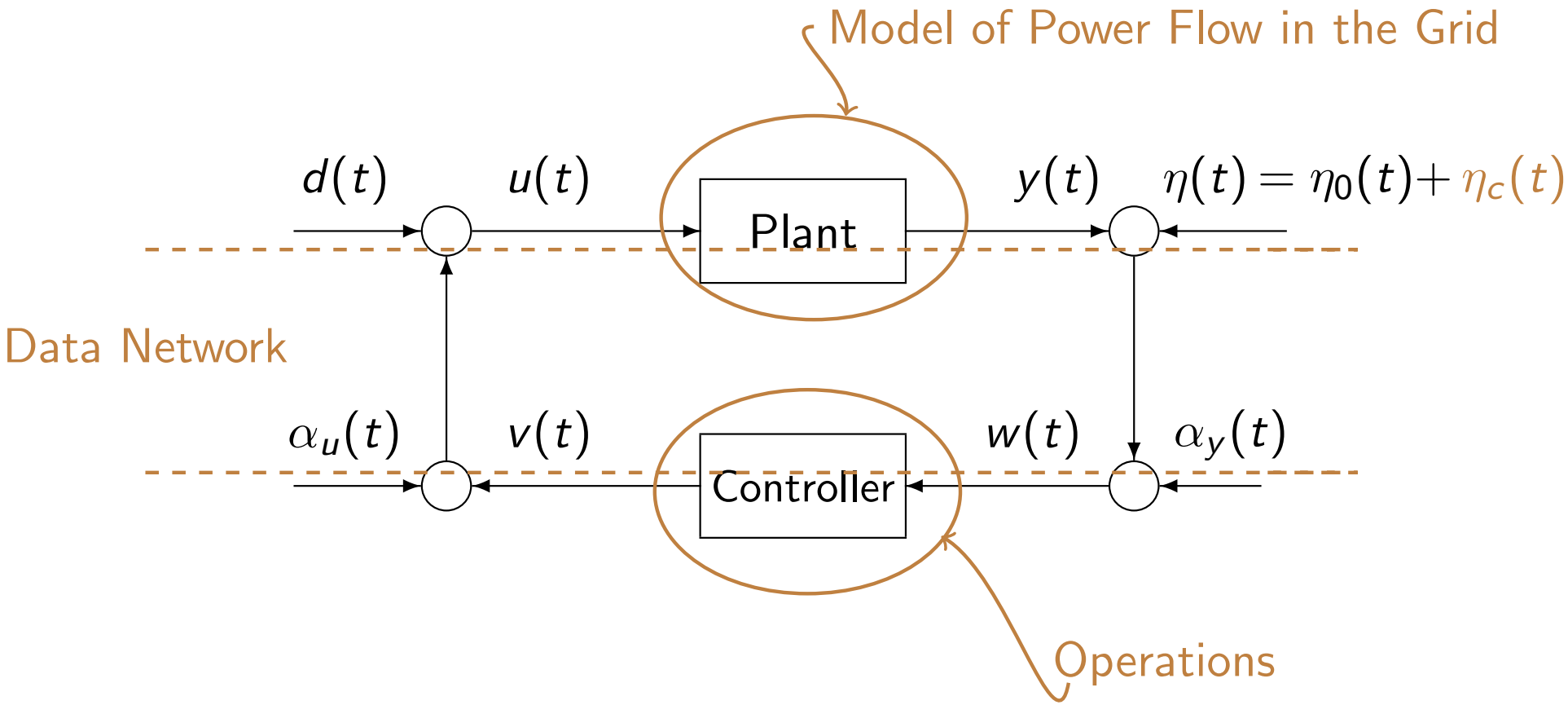
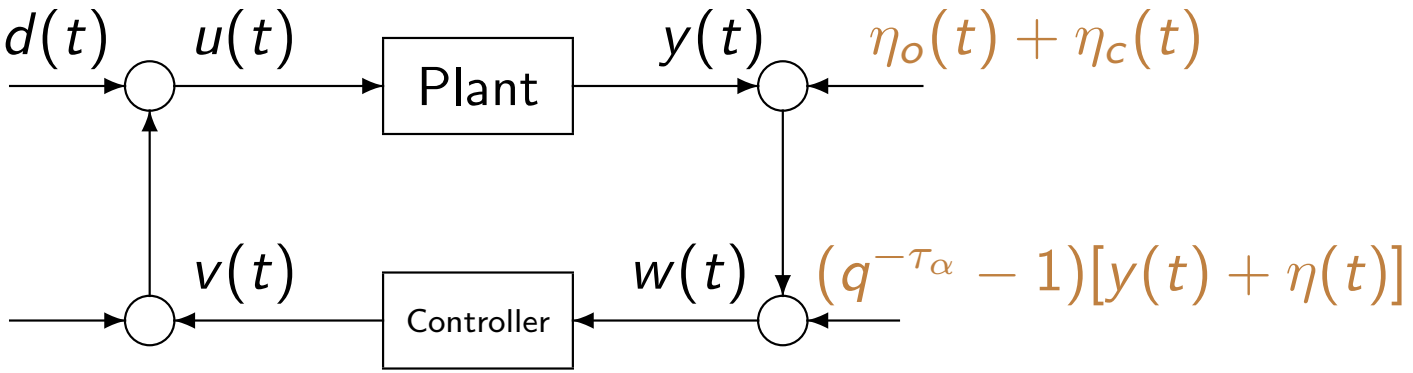


Replay Attacks



Plant: $P(z) = \tilde{M}(z)^{-1}\tilde{N}(z) = N(z)M(z)^{-1}$

Controller: $K(z) = U_{\mathrm{n}}(z)V_{\mathrm{n}}(z)^{-1}$

Attack: $w(t) = y(t - \tau_\alpha) + \eta(t - \tau_\alpha)$

Detector: $s = V_n(q)^{-1}w(t)$

$|\Phi_s(\omega) - I| \lesseqgtr$ threshold OR Is the PSD of $s(t)$ white?

Replay Attacks

Refining the Detector

Large deviation of $\|\Phi_s(\omega) - I\|$ in most of the frequency range does not hold in engineering practice.

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Replay Attacks

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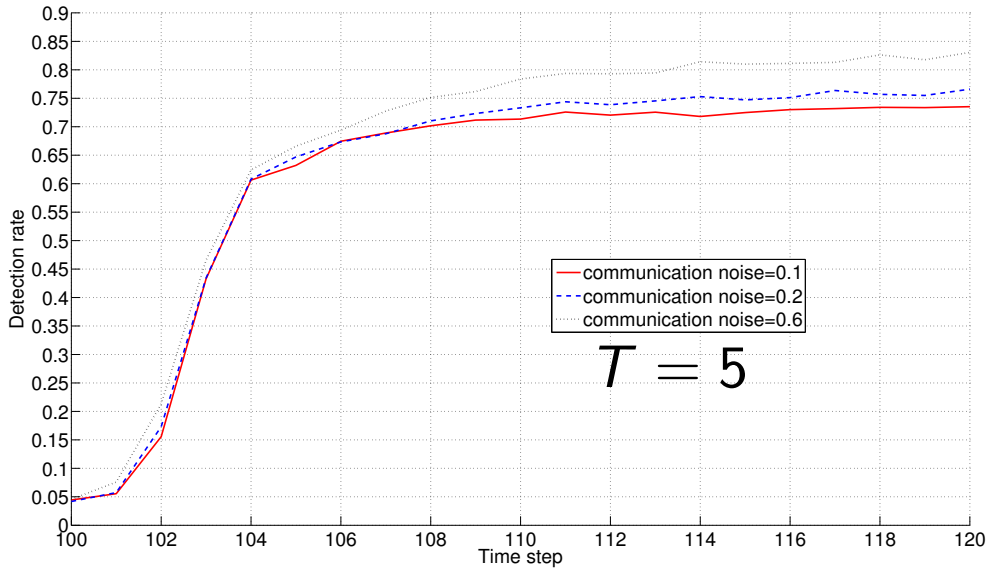
Therefore focus on a particular frequency $\omega = \omega_h$.(Where the gain of the loop transfer function is high)

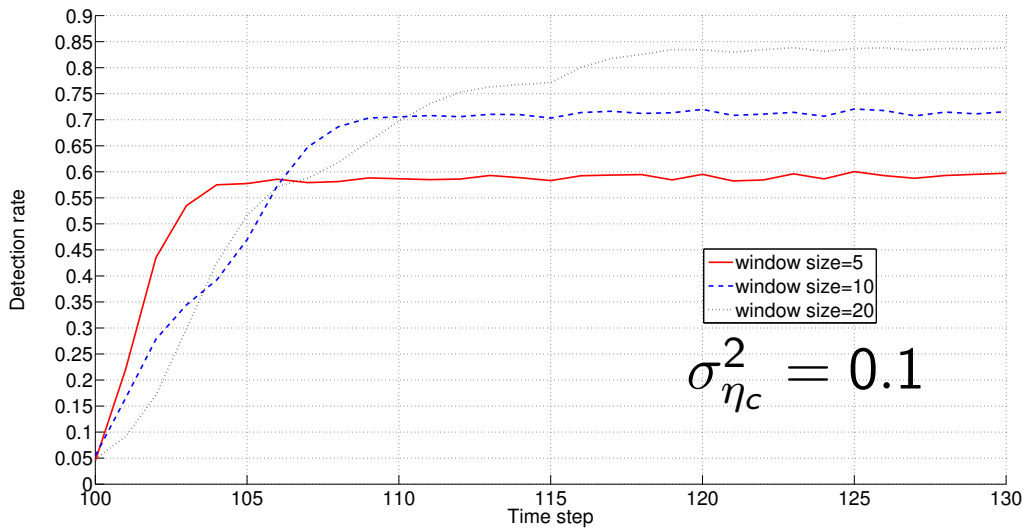
Refined Detector:

$$\Phi_s(\omega_h) = \begin{cases} \sigma_d^2, & \text{if no replay attack,} \\ \sigma_d^2 + 2\sigma_c^2 |V(e^{j\omega_h})|^{-2}, & \text{if replay attack is present} \end{cases}$$

Several methods available to obtain estimate of the PSD of $s(t)$.

Replay Attacks





Detection rate performance for a temperature control system.

Comparison

Novel Approach

- Control signal is not limited to LQG control, any controller that can be represented by a coprime factorization may be used.
- No need to inject authenticating noise to control signal which could affect performance.

LQG + χ^2 Detector

- Control signal is limited to LQG control.
- Control performance is sacrificed, although appropriate choice of $\mathscr{D}$ may reduce loss in performance.

Outline

Conclusion

- We use the communication noise that exists in networked control systems for detecting the replay attack.
- A spectral estimation method is developed to estimate the spectrum of the received signal at the controller site at a specific frequency point.
- Its value or its filtered value differ between the presence and absence of the replay attack.

Outline

References

- Figure in slide 3 from `http://solutions.3m.com/wps/portal/3M/en_EU/SmartGrid/EU-Smart-Grid/`
- Figure in slides 5-6 from `NIST Special Publication 1108R2`
- Figure in slide 7 from `http://spectrum.ieee.org/telecom/security/the-real-story-of-stuxnet`
- Y. Mo and B. Sinopoli, "Secure control against replay attacks," *Proceedings of 47th Annual Allerton Conference*,UIUC, IL, pp. 911-918, Sept 30 - Oct. 2, 2009.

Outline

Questions?

Thank you for your attention!