A Synergy of the Wireless Sensor Network and the Data Center System

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Data Center vs. Sensornet

- Both distributed, dense, scalable
  - 300 nodes in VigilNet, hundreds in GreenOrbs, 1000+ in ExScal
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  – Thousands of compute servers organized in racks [Google, Microsoft Quincy]
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• Low-end and high-end of computation
  – Limited computing resource on each sensor node
  – Abundant computing resources on rack servers
Related Work

• Sensornet in data centers
  – “Cool” scheduling [USENIX ‘05]
  – RACNet [SenSys ‘09]
  – Thermocast [KDD ‘11]

• The combined computational and networking capability of a sensornet enables it to interact with compute clusters in a more sophisticated way
Cluster-Area Sensor Network

• CASN as a complementary solution
  – To improve the cluster management
  – To enhance the operational security

• Cluster-wide command dissemination

• Verification of server’s physical presence
Management in Data Centers

• Software reprogramming on compute servers
  – System settings, configuration files, software upgrade
  – Usually performed on a management station
  – Require certain manual operations

• Why not wirelessly broadcast commands and small files via a sensornet?
  – Wireless as a convenient and flexible broadcast medium
Security Hints

Two-step verification adds an extra layer of protection to your account. Whenever you sign in to the Dropbox website or link a new device, you'll need to enter both your password and a security code sent to your mobile phone.
Security in Data Centers

• Existing cryptologic methods do not entirely ensure the operational security of data centers
  – User account leakage at Yahoo!, Sony PlayStation Network and Qriocity
  – Need additional measures for security monitoring

• New security hint: servers’ physical presence
  – Servers in data centers usually serve different roles (i.e. management, web agent, mail agent, storage)
  – Alarm triggered upon request from strange roles
Access Path Verification
Access Path Verification
CASN Architecture

• System components
  – Sensor network
  – Compute servers

• Three types of motes
  – Control motes
  – Anchor motes
  – Server motes
Prototype Implementation

A prototype of CASN consisting of 1 control mote and 4 anchor motes (Telos B) in a research cluster
Prototype Implementation

motors attached to servers via USB interfaces
Prototype Implementation

motes attached to servers via USB interfaces
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Command Dissemination

- Workflow of command dissemination
  - Issued from the management station
  - Forwarded to the control mote
  - Broadcasted via sensornet
  - Received by server motes
  - Executed on servers

- Command-line interface
Command Dissemination Delay

• To evaluate the round-trip delay of command dissemination to a number of servers across three racks

• Results
  – Scalable broadcast via sensornet
  – Stable delay
Cluster-Area Sensor Network

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Verification of Physical Presence

• Operations in data center are yet to be secure
  – Example: impersonating the management station

• Example: verify the physical location of a control mote
  – Before execution, server motes query anchor motes for the legitimacy of certain control mote
Localizing Control Motes

• Workflow of physical localization
  – Passive discovery: anchor motes periodically query the location of control motes
  – Active discovery: control mote initiates discovery upon its arrival
  – Anchor motes together localize a control mote to determine its legitimacy

• Suffice with 4 anchors
Radio-based Localization

• Coarse-grained radio-based localization
  – Suffice even at 5-meter precision
  – Inefficacy of RSSI-based ranging approach

\[ P(d) = P(d_0) - 10n \log\left(\frac{d}{d_0}\right) \]

• Necessity for empirical RSSI modeling in a data center environment
Empirical Localization Model

• Cope with the multipath effect by considering indirect signals

\[ P(d) = P(d_0) - 10n\log\left(\frac{\sum_{i=1}^{k} r_id_i}{d_0}\right) \]

- \( \mathbf{R} = [r_1 \ r_2 \ ... \ r_k] \) as the amplitude coefficients of signal components
- \( \mathbf{D} = [d_1 \ d_2 \ ... \ d_k] \) as discretized distances of signal components

• Rician distribution used to model amplitudes of indirect signals

\[ R(x|\gamma,\sigma) = \frac{x}{\sigma} e^{-\frac{(x^2+\sigma^2)}{2\sigma^2}} I_0\left(\frac{x\gamma}{\sigma^2}\right) \]
Probabilistic Ranging

• Solving $R$ in $R \times D = d_0 \times 10^{\frac{P(d_0) - P(d)}{10n}}$
  
  – Consider only the 5 shortest reflected signals
  
  – $d_{AB}$ as the distance between the transmitter A and receiver B (i.e. 2 meters)

\[
r_i = \begin{cases} 
0 & \text{if } d_i < d_{AB} \text{ or } d_i - d_{AB} \geq 2 \\
1 & \text{if } d_i = d_{AB} \\
 a_i \times R(d_i - d_{AB}) & \text{if } d_i > d_{AB} \text{ and } d_i - d_{AB} < 2
\end{cases}
\]

• Localization: after obtaining the probabilistic ranging results, compute the most plausible location using trilateration
Reduce Computation Cost

• Computationally costly for all possible cases
  – In total $K^H$ cases for $H$ RSSI measurements per transmission, give that each maps to $K$ Rs

• Reduce computation cost by
  – Narrowing down distances by applying geometric constraints
  – Utilizing the known distances between anchors
Localization Accuracy

• Evaluate the localization accuracy in a 4m x 4m square field defined by $A_0, A_1, A_2, A_3$
  - Localization error $e = \sqrt{(x' - x)^2 + (y' - y)^2}$

• Results
  - 88% of localization errors within 5 meters
  - Errors for positions inside the square within 2 meters
Localization Delay

• To evaluate the localization delay by varying the distance between a control and an anchor mote inside the 4m x 4m square field

• Results
  – Overall 8-12 seconds
  – Small variation
  – Acceptable with 30-sec localizing period
Reprogramming Delay of CASN

• Reprogramming delay: command dissemination delay + physical verification delay

• Results
  – Less than 300 milliseconds with distance closer than 10 meters
  – Low enough for effective command dissemination
Summary

• We design and implement a cluster-area sensor network in a data center
  – Wireless cluster-wide command dissemination
  – Empirical localization for verification of server’s physical presence

• Future work
  – CASN with fingerprint-based localization
  – CASN in geographically distributed data centers
Q&A

Thank You!

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