# Supporting Study of High-Confidence Criticality-Aware Distributed CPHS in GENI

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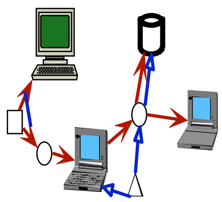
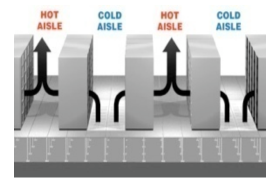
# Sandeep K. S. Gupta, IEEE Senior Member

- **Heads IMPACT @ School of Computing & Informatics ASU**

Use-inspired, Human-centric research in distributed cyber-physical systems

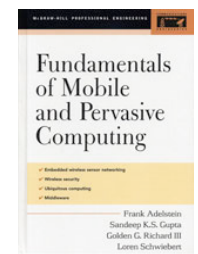





| | | | | | |
|---|---|---|---|---|---|
| **ID Assurance** | **Mobile Ad-hoc Networks** | **Pervasive Health Monitoring** | **Criticality Aware-Systems** | **Thermal Management for Data Centers** | **Intelligent Container** |

BEST PAPER AWARD: Security Solutions for Pervasive HealthCare – ICISIP 2006.

BOOK: Fundamentals of Mobile and Pervasive Computing, Publisher: McGraw-Hill Dec. 2004




- **TCP Chair**


http://www.bodynets.org

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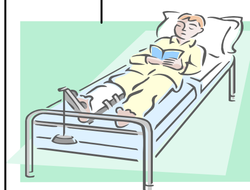
# Motivation

- Challenges – Traffic congestion, Energy Scarcity, Climate Change, Medical Cost …
- Need Smart Infrastructure – distributed CPHS (Cyber-Physical-Human System (of systems))
- **Criticality-awareness**: the ability of the system to respond to unusual situations, which may lead to disaster (with associated loss of life and/or property)
  - How to design, develop, and test criticality-aware software for CPHS systems?
- **Unifying Framework** for Safe (Energy-Efficient) Spatio-Temporal Resource Management for CPHS
  - Thermal-Aware Scheduling for Data Centers and Bio Sensor Network (within Human Body)

# Example Scenario

time

Causal Event | Detection | Response | Recovery | Mitigation



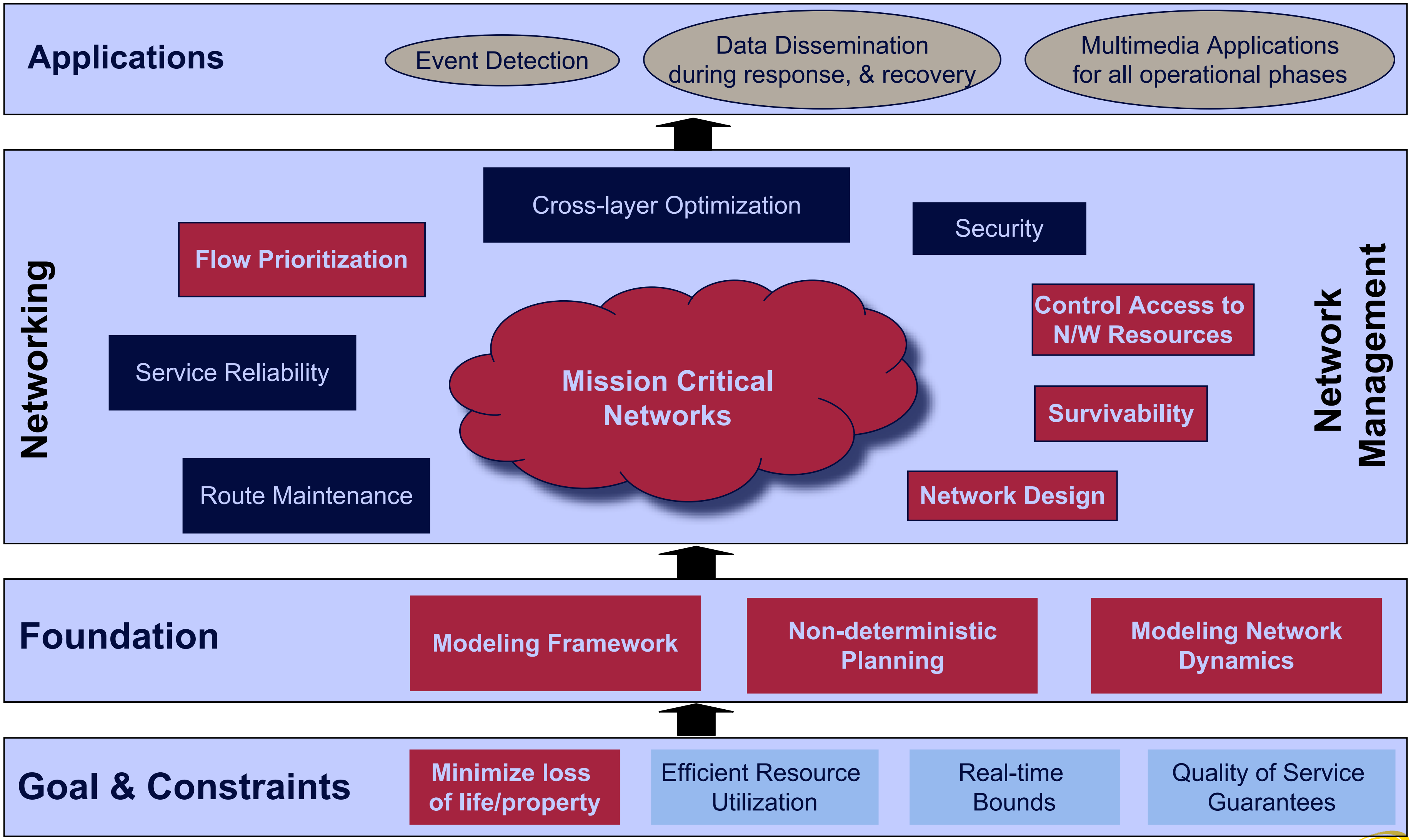
- Critical Event detected using **BSN** on the person - heart attack

- **BSN** provides patient's current health data to first responders
- Patient taken to hospital, **BSN** providing up-to-date information throughout the way.
- Information from **BSN** used by clinicians for diagnosis and treatment

- BSN helps in keeping track of patient recovery status
- Reduce hospital stay time.
- Control medicine dosage

- BSN tracks subject's health during normal times

# Grand challenges for Distributed CPS



# Recommendations from Real-time Embedded Systems GENI Workshop, Sep. 2006

- Recommendations for real-time and embedded networking infrastructure atop the GENI substrate
  - Uniform representation of time and physical location information,
  - End to end timing predictability across wired and wireless mobile networks,
  - Co-existence of guaranteed, managed and best-effort QoS services,
  - Quantified safety, reliability, availability, security and privacy,
  - Scalability across small deployments to national and world-wide deployments, and
  - Compatibility with regulatory organizations' requirements.

# Properties - Cyber Physical Human Systems

- Tight coupling between physical and cyber-world
- Human-in-the-loop
- Heterogeneous entities with order of magnitude difference in capabilities, e.g. sensors, medical devices, servers, handheld computing devices, and Humans.

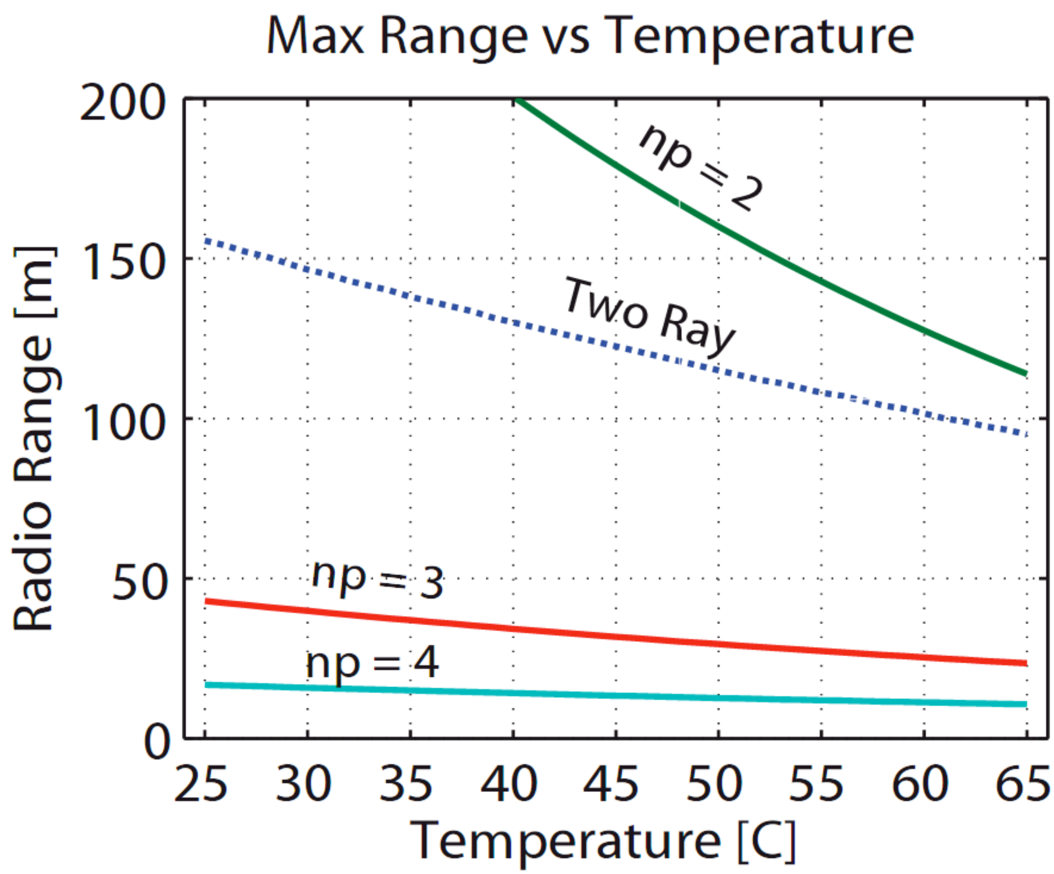
# “HOT” Mission Critical Applications – Example of Environmental Effects on Networks



- Nodes exposed to the sun might easily reach 65C and above
- Temperature at nodes in a wildfire monitoring application have reported to reach 95C.

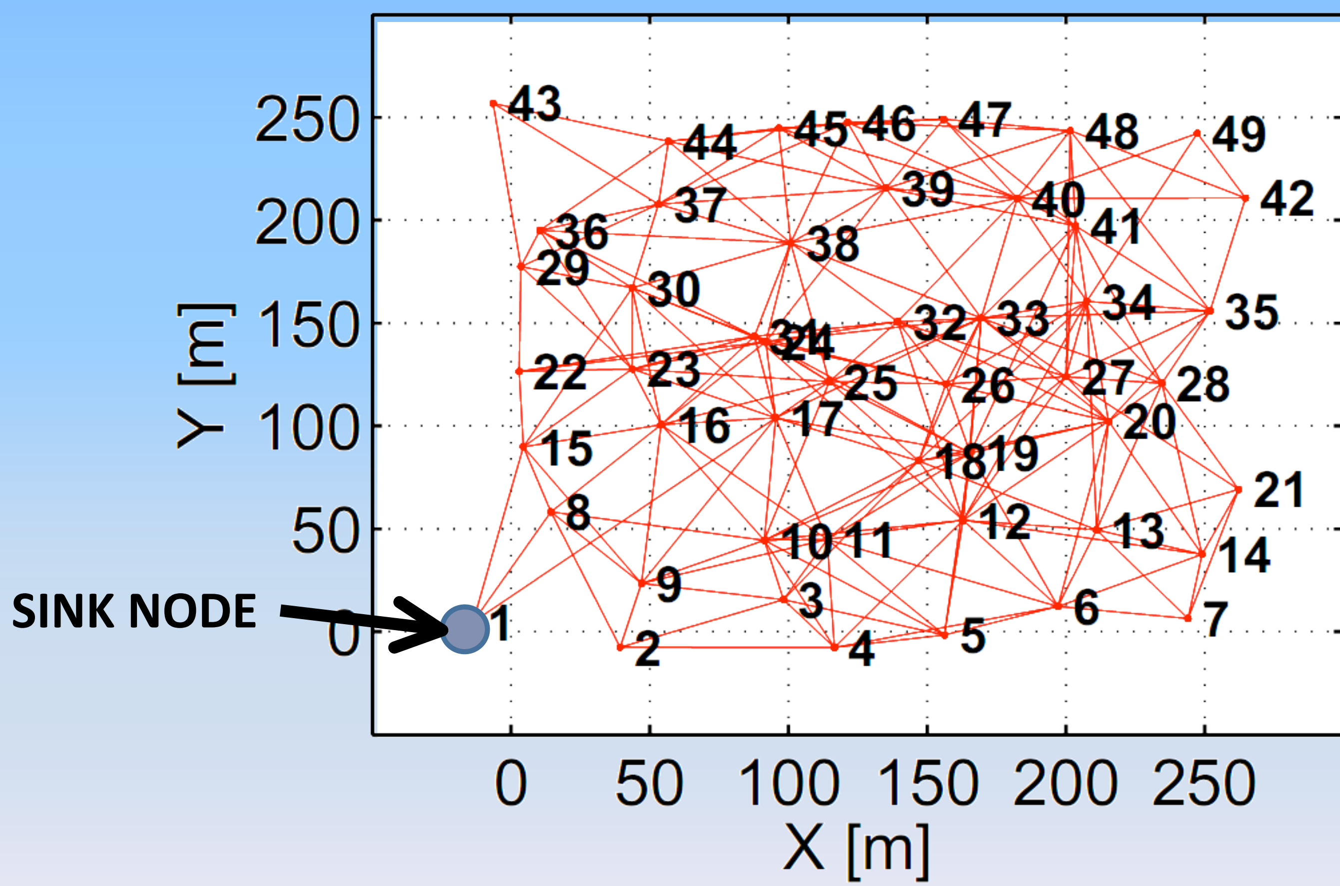
**How to compensate for temperature effects at design/runtime?**

# Communication Range



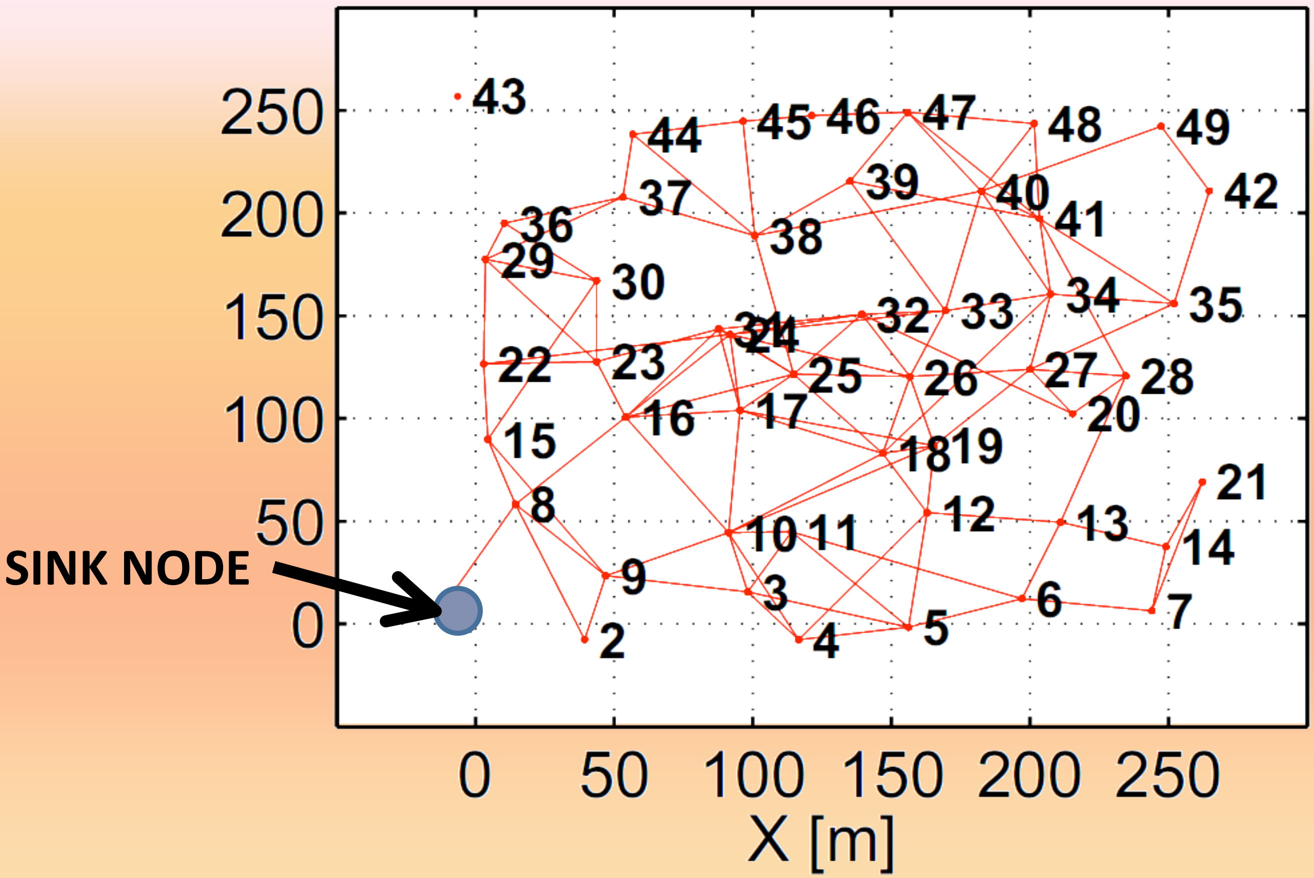

Depending on the path loss model, losses due temperature cause reduction in range comprised between **40%** and **60%** the max. value

# Network Connectivity @ 25°C




Average Connectivity = 8.94. Connected nodes = 100%.
Avg. Path Length = 2.95. **Network seems reliable.**

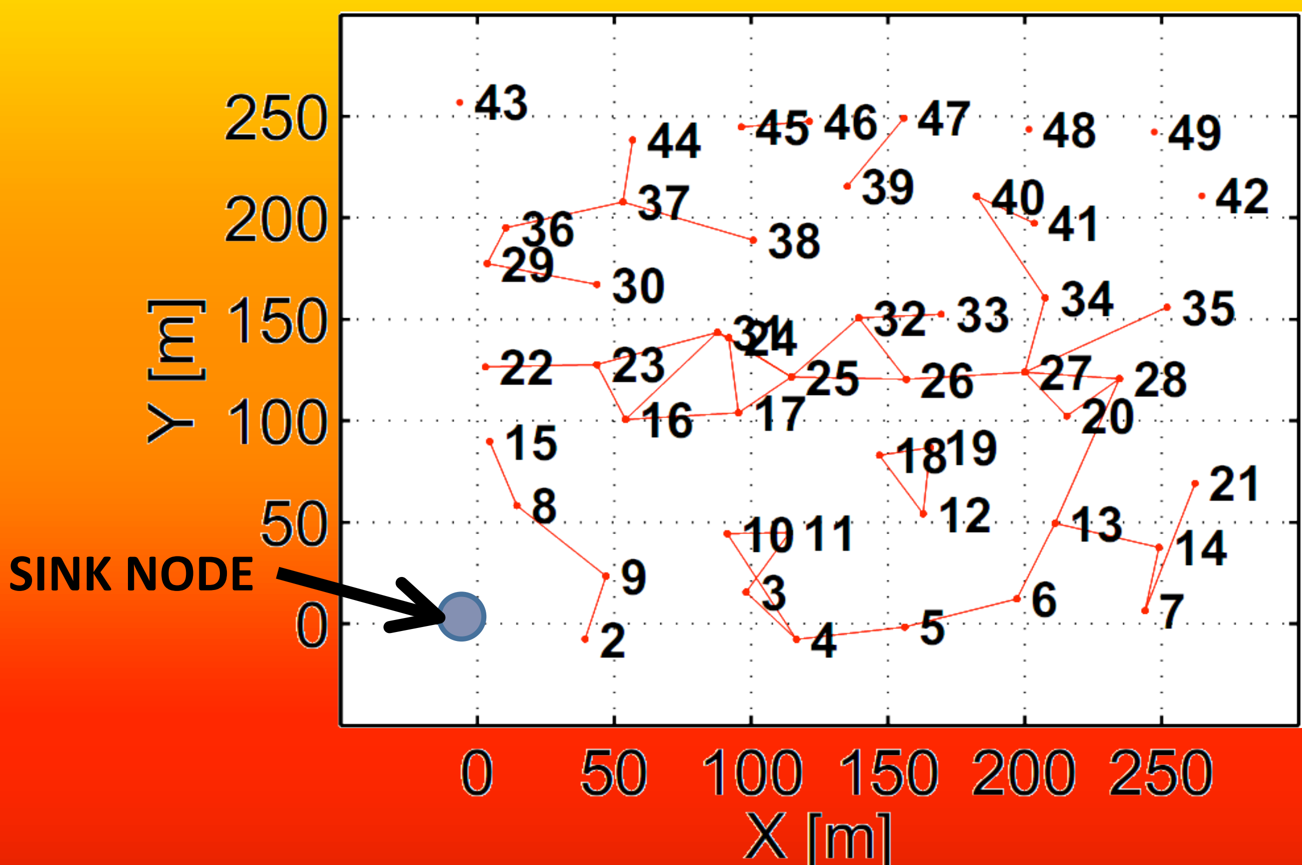
# Network Connectivity @ 45°C




Average Connectivity = 4.57. Connected nodes = 98%.

Avg. Path Length = 4.93. **Few nodes are disconnected.**

# Network Connectivity @ 65°C




Average Connectivity = 4.57. Connected nodes = 0%.

**The sink is completely disconnected from the rest of the network!**

# Physical Aspects of CPS Security

- Modifying physical environment around the CPS can cause security breach
- Example –
  - Smart-car's theft protection system fails completely if it is fooled into thinking the car is on fire by trigger specific sensors.
  - No amount of securing all the other components will help
- The problem is compounded if security solutions for CPS depend on environmental stimuli for efficiency purposes
- Example –
  - Physiological value based security (PVS) utilizes common physiological signals from the body for key agreement
  - If one of the sensors is fooled into measuring incorrect physiological signals (by breaking the sensor-body interface), the whole process breaks down

# Fundamental differences with Cyber Security

- Threat Model is fundamentally different
- The point of entry for traditional (cyber-only) is essentially cyber
  - Example – Attacker hacking a computing system through a network
- CPHS – it can be **cyber**, **environmental (physical), and human**

- CPHS system has several aspects each of which need to be secured–
  - Environment
  - Sensing
  - Communication
  - Processing
  - Feedback
  - Humans

Securing the environment and its interaction with other following unique to CPHS

Securing these addressed in traditional cyber security

# GENI and CPHS Security Solutions

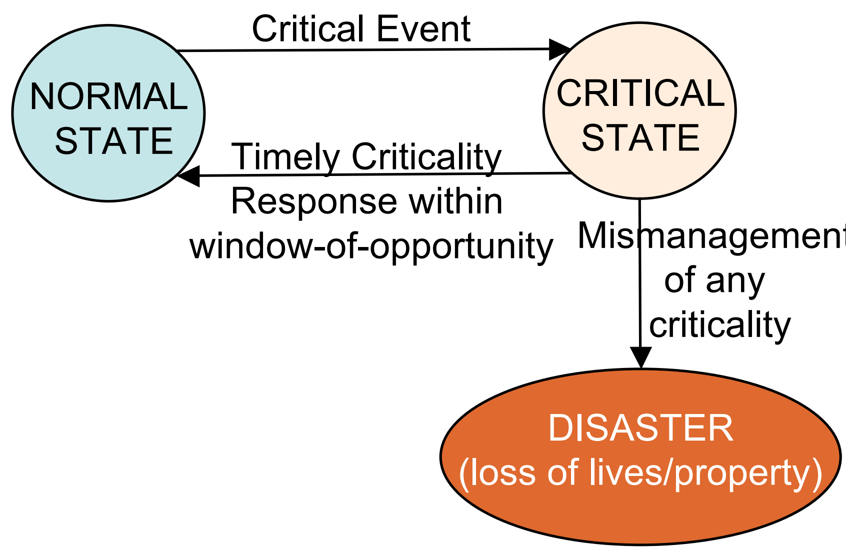
- GENI therefore needs to provide the ability –
  - To simulate/emulate diverse situations in which CPHS are deployed in real situations
  - To program the CPHS components to behave maliciously based on both cyber and environmental attacks.
  - Ability to sand-box cyber and physical components of the CPHS for evaluation various aspects of the attacks and defense mechanisms.
  - Collect feedback on security solutions' performance.

# Some Results from IMPACT Lab

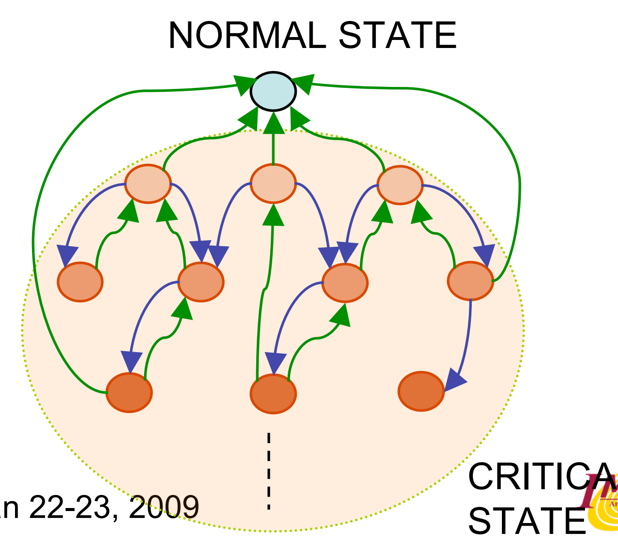
- Analytical model to minimize energy overhead of pro-active protocols for wireless networks
  - Classifies pro-active protocols based on periodic updates performed
  - Minimizes update overhead for all classes by finding optimum update periods based on link dynamics, network size, traffic intensity, and end-to-end reliability requirements
- Theory of *criticality* capturing effects of critical events, which can lead to loss of lives/property.
- Probabilistic planning of response actions for fire emergencies in off-shore oil & gas production platforms.
- Criticality-aware access control policies for mission critical systems.
- Physiological Value based security for Body Sensor Networks
- Environment-aware Communication Modeling & Network Design

# Our Approaches to Enable Criticality-Aware CPHS Study in GENI

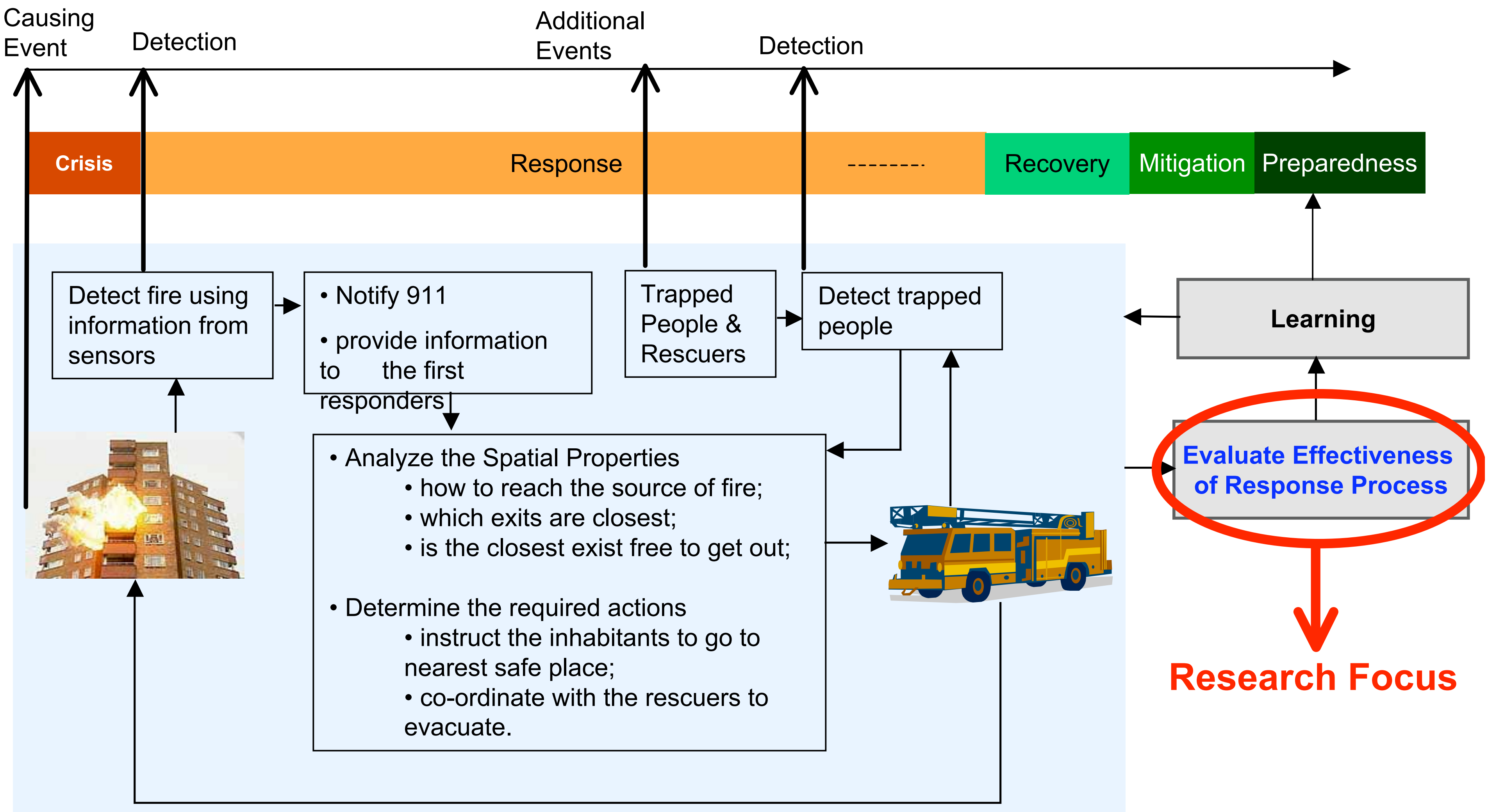
# Theory of Criticality & Probabilistic Planning



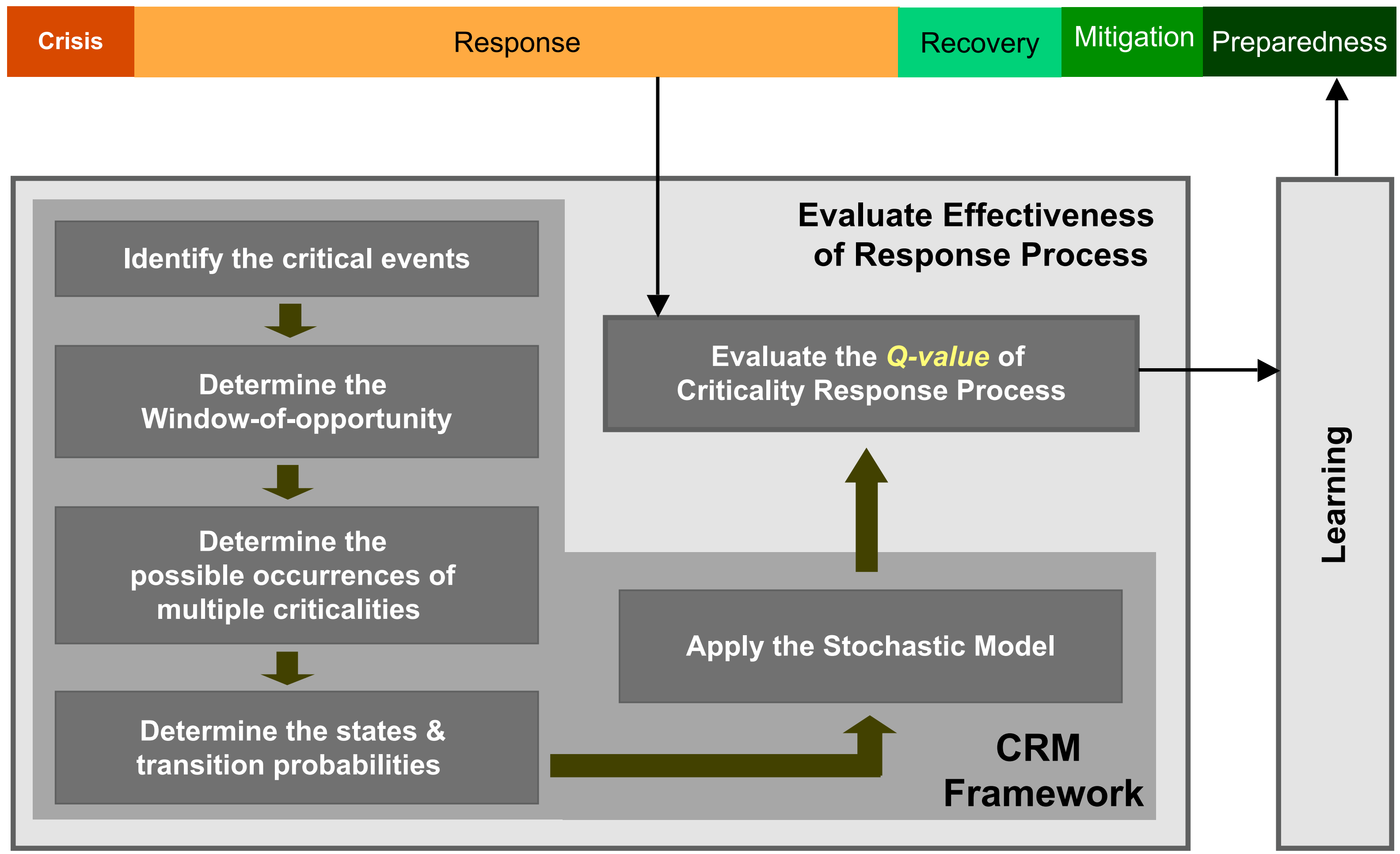

- Critical events
  - Causes emergencies/crisis.
  - Leads to loss of lives/property
- Criticality
  - Effects of critical events on the smart-infrastructure.
  - Critical State – state of the system under criticality.
  - **Window-of-opportunity** (W) – temporal constraint for criticality.
- Manageability – effectiveness of the criticality response actions to minimize loss of lives/property.
- State based stochastic model capturing *qualifiedness* of the performed actions to improve manageability of critical events.
  - Probabilistic action planning to maximize manageability



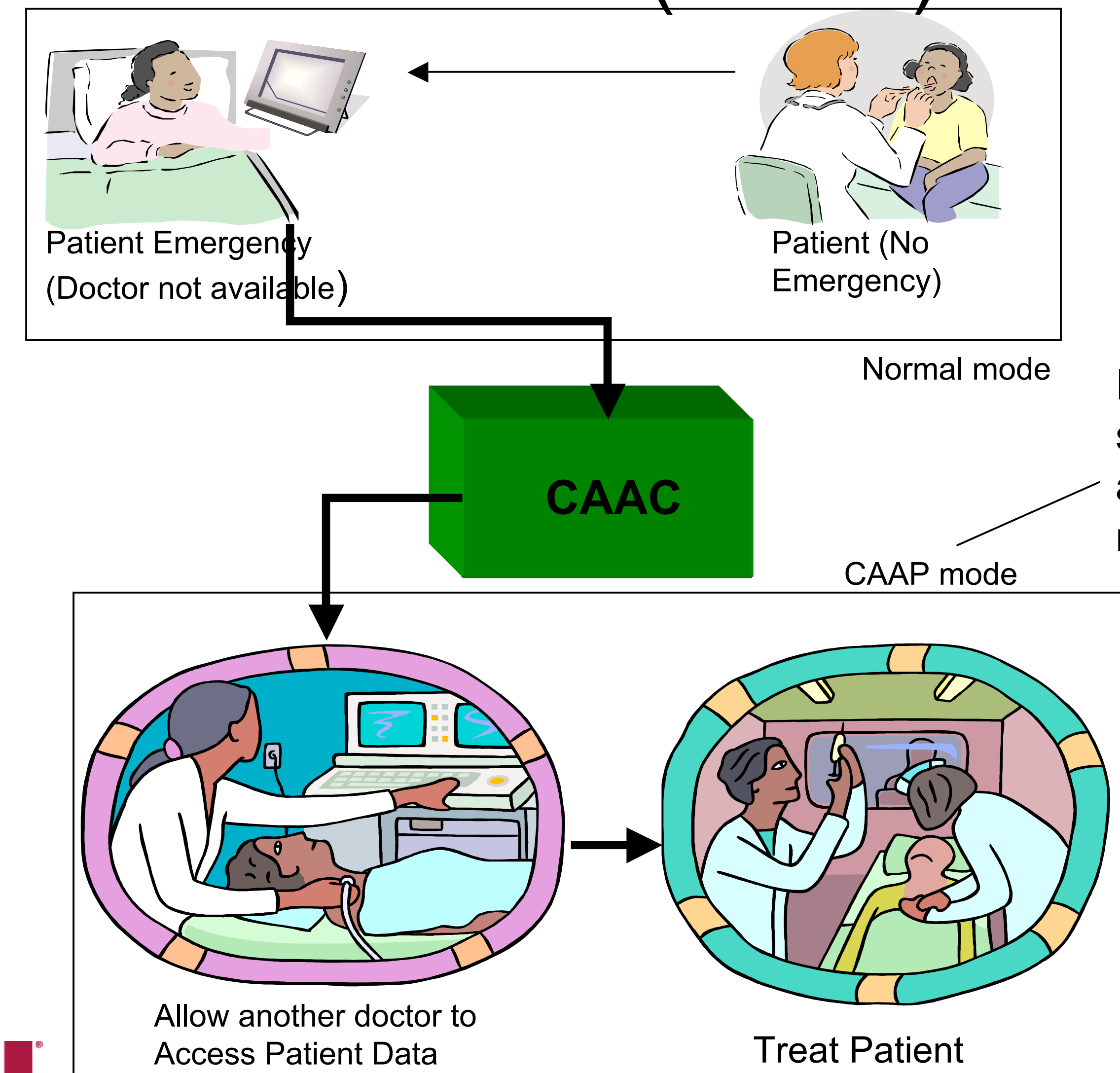
# Crises Management – Fire in Smart-Building



# Criticality Response Modeling (CRM) Framework



# Criticality Aware Access Control (CAAC)

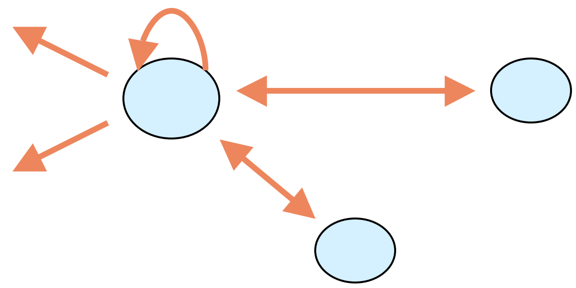


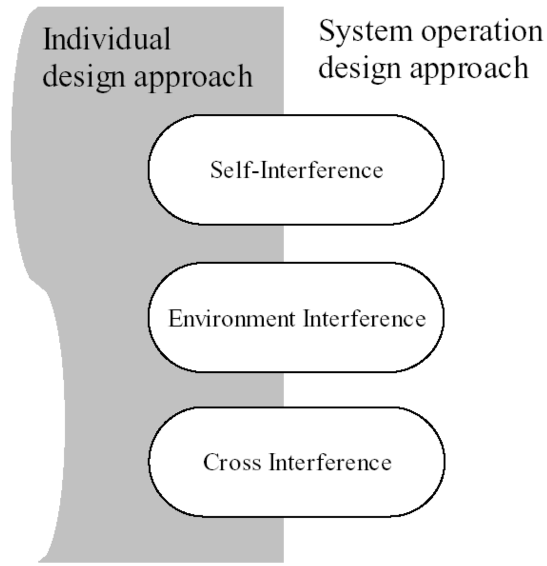

In this mode, an alternate set of access privileges are enforced for facilitating mitigative actions

# Unifying Framework for Modeling Spatio-Temporal Cyber-Physical Effects

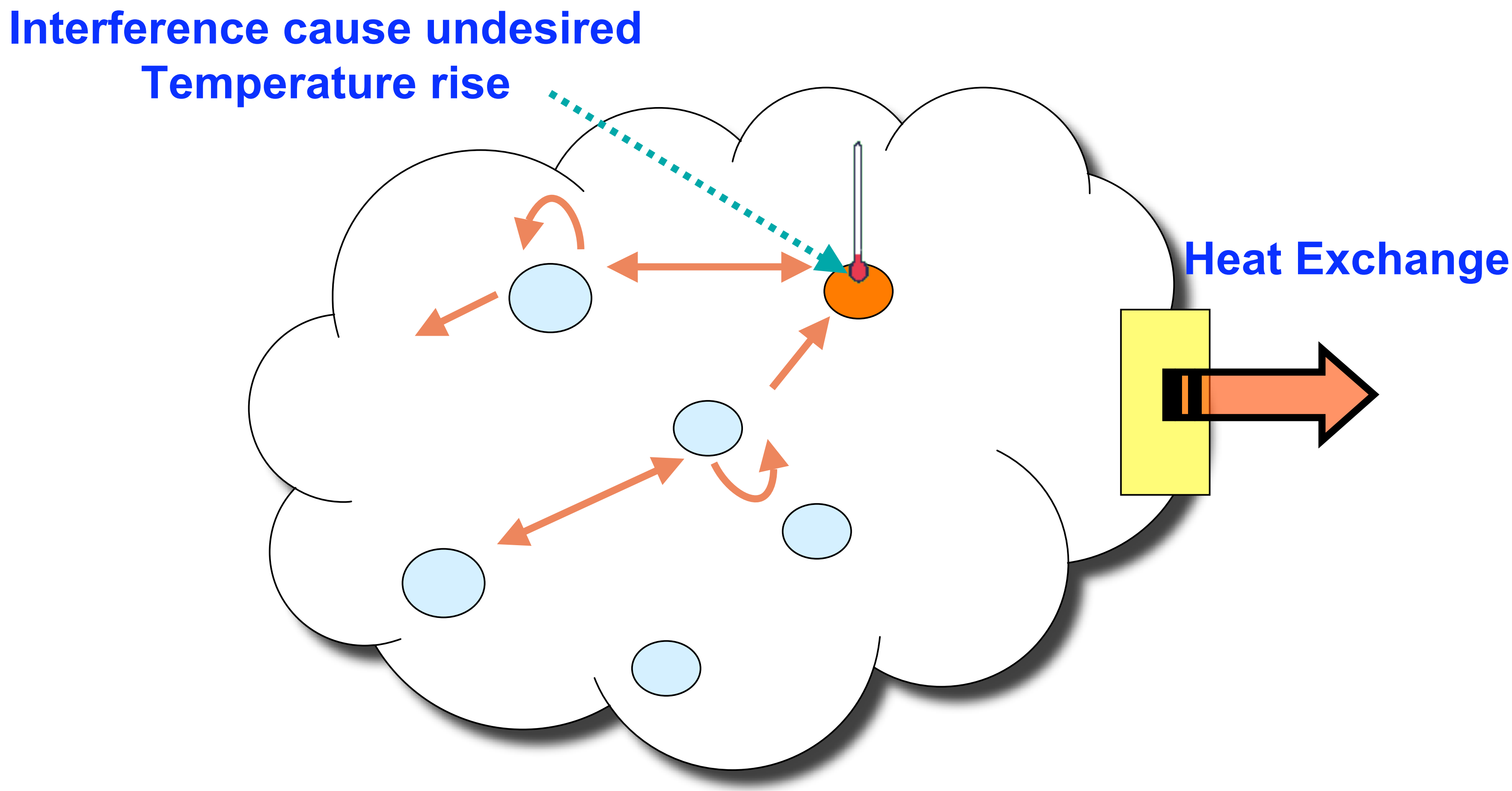
# Environmental Coupled Distributed CPS

- Terminologies
  - Self-interference
  - Environment –interference
  - Cross-interference
- Disturbance models
  - Quantitative model
  - Temporal model
  - Spatial model
  - Comprehensive model
- Individual design approach
- Network/system operation approach





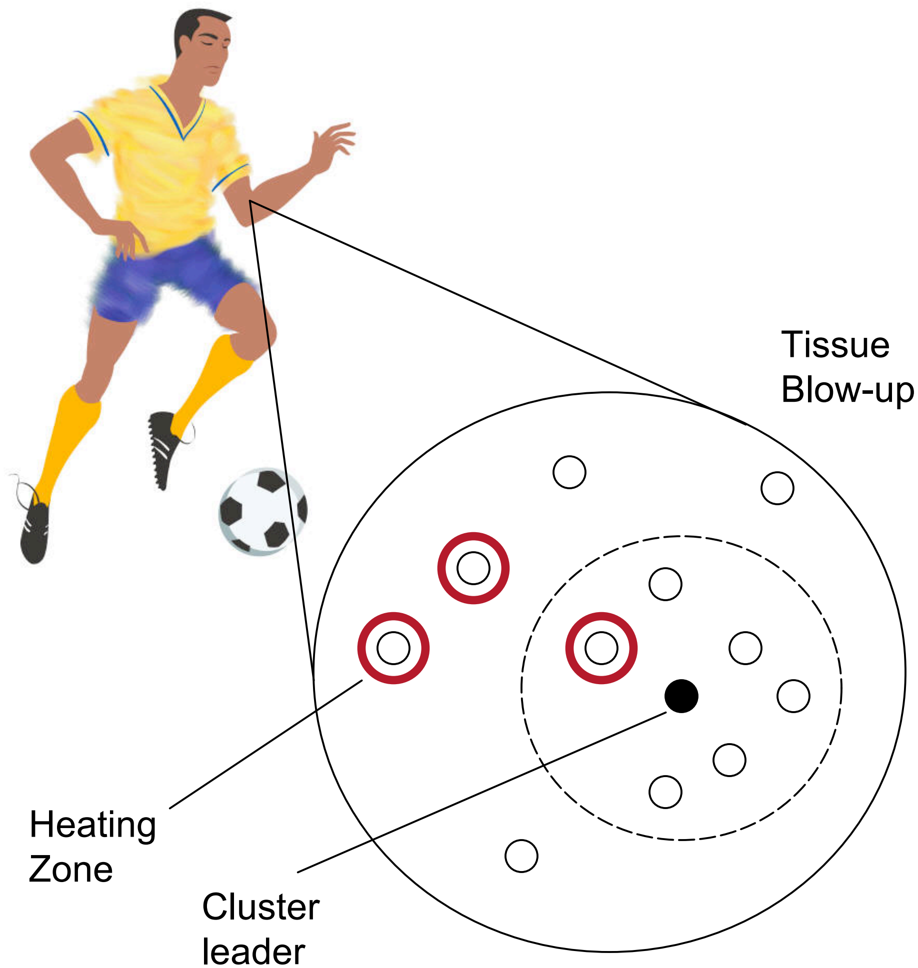
# System Model




System performance depends on the thermal distribution

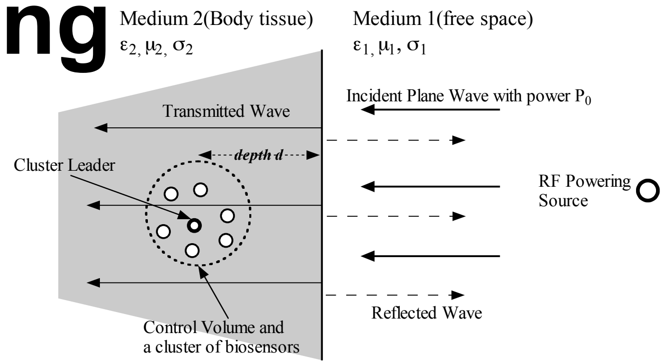
# Tissue Heating

- Medical sensors implanted/worn by human need to be safe.
- Sensor activity causes heating in the tissue.
  - Heating caused by RF inductive powering
  - Radiation from wireless communication
  - Power dissipation of circuitry
- Goal: ***minimize tissue heating.***
- Two solutions:
  - ***Communication scheduling*** for minimizing thermal effects:
    - Rotate cluster leader – balance energy usage + distribute heat dissipation
  - ***Thermal aware routing:*** *route around thermal hotspots*




**Disturbance Minimization**

# BSN Scheduling




## Requirement

- FCC Regulation

**SAR = σ E² / ρ (W/kg)**

E = induced Electric Field
P = tissue density
σ = electric conductivity of tissue

IEEE Requirement (1g Tissue)

| | | | | |
|---|---|---|---|---|
| CE | **Whole Body Average** | SAR = 0.4W/Kg | **Peak Local** | SAR = 8W/Kg |
| UCE | **Whole Body Average** | SAR = .08W/Kg | **Peak Local** | SAR = 1.6W/Kg |

## System Model

- Consider only one cluster
- 2D Model
- Rotate cluster head - dist. energy consump. reduce heating

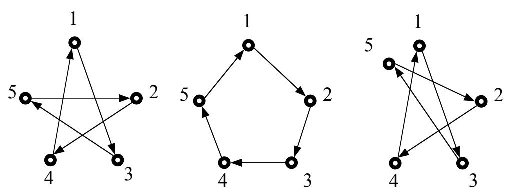
**Temperature Rise: Pennes Bio-heat Equation**

$$\rho C_p \frac{dT}{dt} = K \bigtriangledown^2 T + \rho SAR - b(T - T_b) + P_{circuitry} + Q_m$$

Heat accumulated | Heat transfer by conduction | Heat by radiation | Heat transfer by convection | Heat by power dissipation | Heat by metabolism

## Solution

- Random selection may lead to higher temperature rise
- Similar to Traveling salesman problem but with dynamic metric
- Heuristic: Leader selection based on sensor location, rotation history




(a) Ideal Rotation (b) Nearest Rotation (c) Farthest Rotation

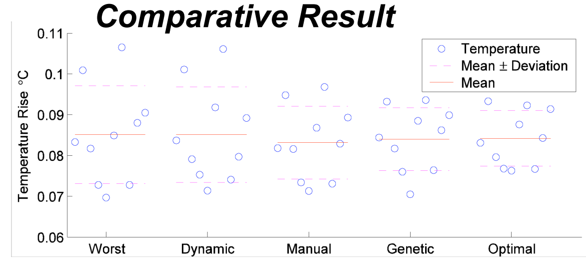
## Four Approaches

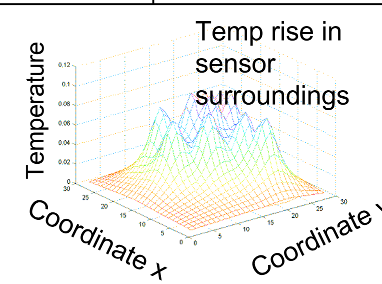
- FDTD + enumeration
- FDTD + Genetic Algorithm
- TSP + enumeration
- TSP +Genetic Algorithm

## Results

| | | |
|---|---|---|
| FDTD + enumeration | Optimal | 720960 hrs (est.) |
| FDTD + Genetic Algorithm | Near Optimal | 100 hrs (est.) |
| TSP +enumeration | Optimal | 7.6 hrs |
| TSP + Genetic Algorithm | Near Optimal | 5 min |

***Comparative Result***




Temp rise in sensor surroundings

Q. Tang, N. Tummala, S. K. S. Gupta, and L. Schwiebert, *Communication scheduling to minimize thermal effects of implanted biosensor networks in homogeneous tissue*, Proc of IEEE Transactions of Biomedical Engineering

# Data center Energy Consumption

## What are datacenters

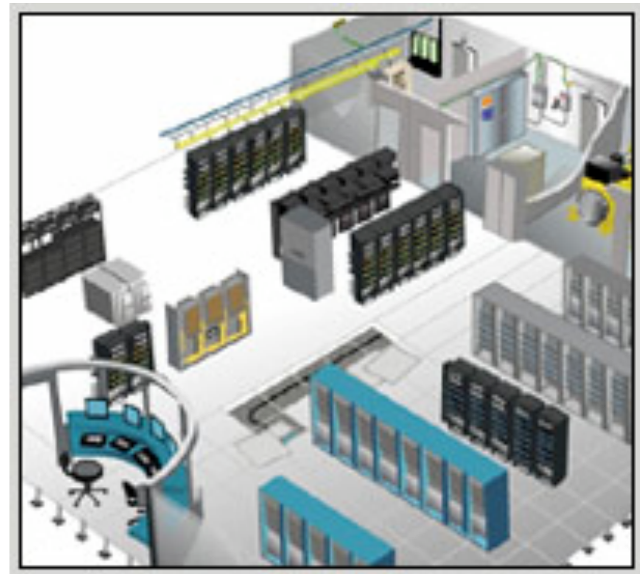
- Server farms, IT centers, computer rooms

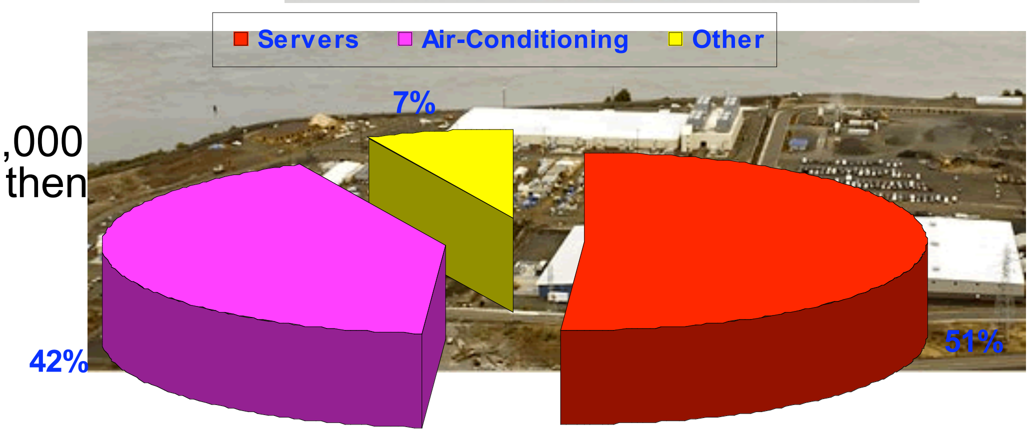
## Why they are important

- Centralized management, powerful computation capabilities
- Backbones of Internet Infrastructure

## Why thermal management is important

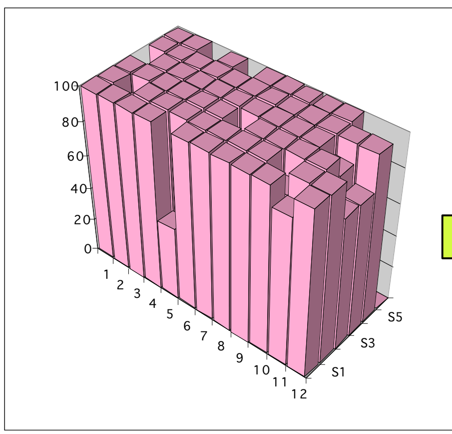
- Improve reliability
- Reduce system down time
- Save energy cost !!
  - $400,000 annually to power a 1,000 volume server-unit data center, then how much for this
- More than 40% is cooling cost



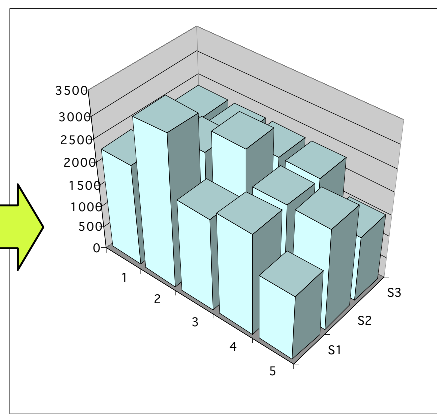


# Ecosystem of Datacenters

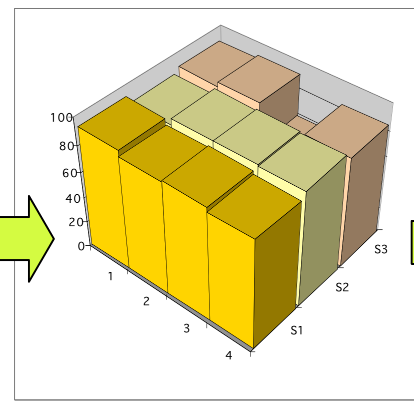
- **Different task assignments lead to different power consumption distributions**
- **Different power consumption distributions lead to different temperature distributions**
- **Different temperature distributions lead to different total energy costs**




**Server load distribution**




**Power consumption distribution**

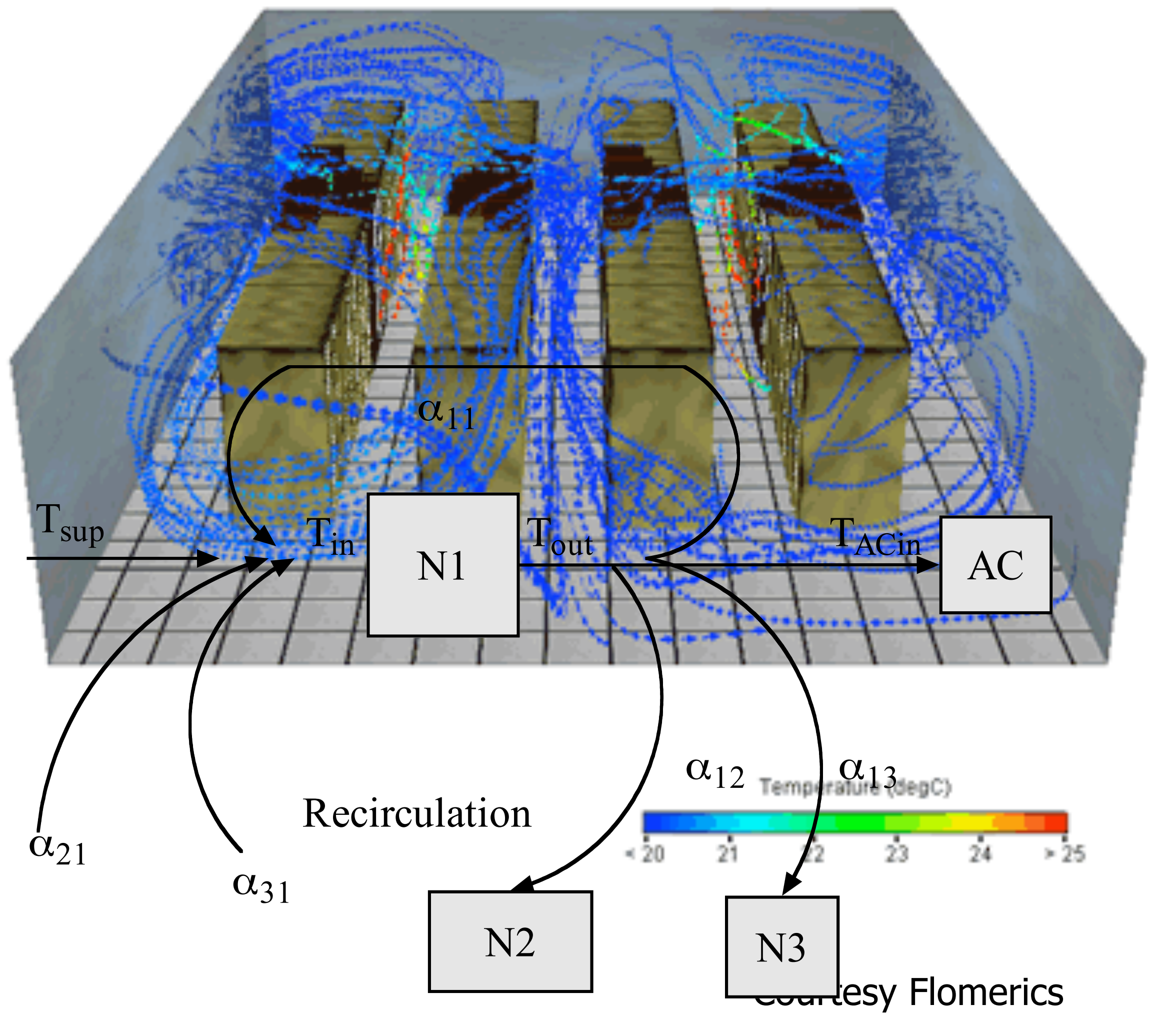



**Temperature distribution**

**Energy cost**

# Interference in Datacenters

- **Observation**
  - Airflow patterns are stable (confirmed through CFD simulations)
- **Hypothesis**
  - The amount of recirculated heat is stable, can be quantified as recirculation coefficients
  - Define $\alpha_{ij}$ as the percentage of recirculated heat from node i to node j



# Two Studied CyberPhysical Applications

| | | |
|---|---|---|
| *Application scenario* | Implanted biomedical sensor networks | Computing nodes of data center clusters |
| *Objective* | **find the best leadership sequence to minimize the temperature rise** | **find the best task assignment to minimize the energy cost** |
| *Heat transfer mechanism* | **Convection, conduction and radiation.** | **Convection** |
| *Original numerical simulation* | **Finite Difference Time Domain** | **Computational Fluid Dynamics** |
| *Abstract Model: the function F(·)* | **Time-space function** | **Cross interference coefficients** |
| *Placement or scheduling: the function H(·)* | **Temporal domain** | **Spatial domain** |

# Conclusions

- Supporting interaction of Cyber and Physical Environment in GENI – essential to study important applications such as pervasive health monitoring, remote surgery etc.
- Makes GENI itself a CPHS system
- Would enable study of important issues such as subtle (or event emergent) interactions between Security and Safety

# Questions ??

***Impact Lab (http://impact.asu.edu)***

***Creating Humane Technologies for Ever-Changing World***