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A Cyber-Physical System for Dynamic Building Evacuation

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Outline

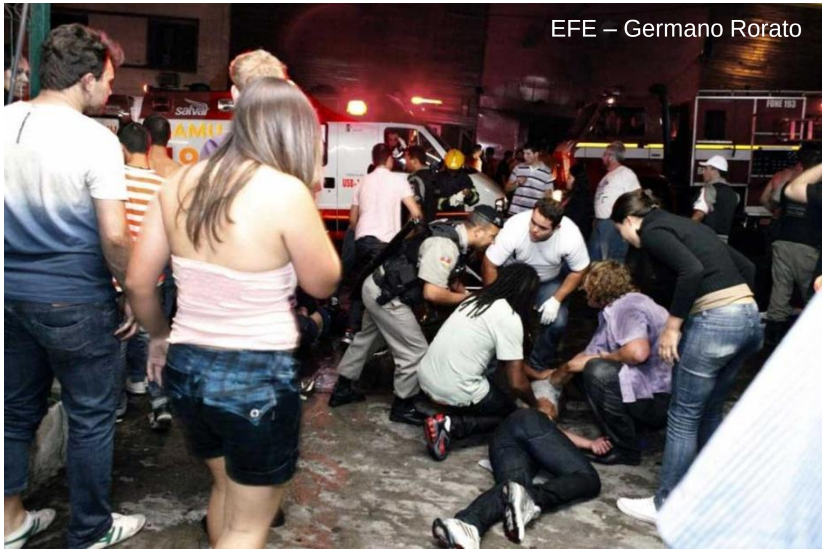
- Motivation and Challenges
- Tackling the Problem
- Proposed Solution
- Modelling the Problem
- System Operation
- Physical Setup
- Deployment
- Demonstration Video
- Conclusions

Motivation and Challenges

- Efficient building evacuation is of the utmost importance
- Current evacuation routes are static and predefined, i.e., do not change according to the hazard evolution
- **Dynamic routes** could greatly improve the outcome of such accidents

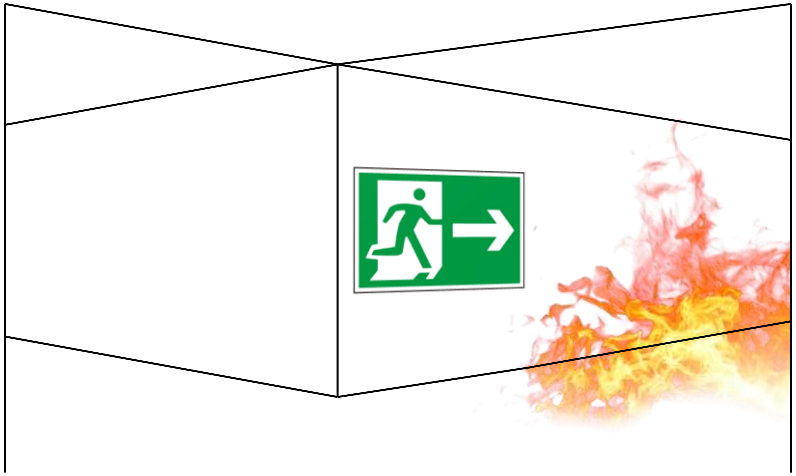
- *Problem*: to **detect on-going fires** in a building and **route people in real-time** through the safest and shortest paths.

- However, this is a challenging problem:
  - It requires environmental variables to be continuosly monitored across the entire building.
  - It requires computation of new routes on-the-fly, and providing this new information to the occupants in real-time.



“Fire rips through crowded Brazil nightclub, killing 233”

CNN.com - 28/01/2013



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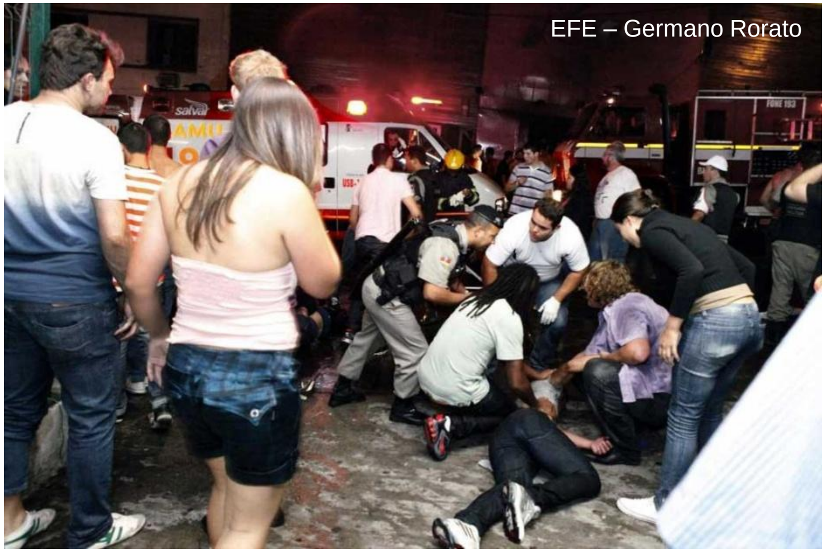

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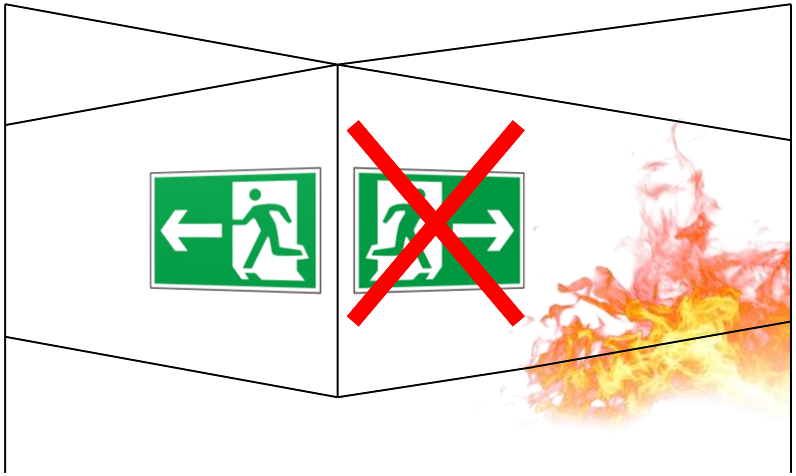
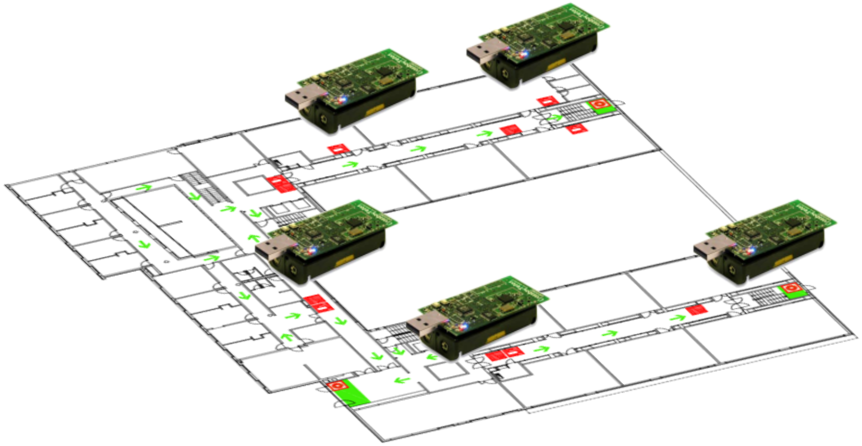


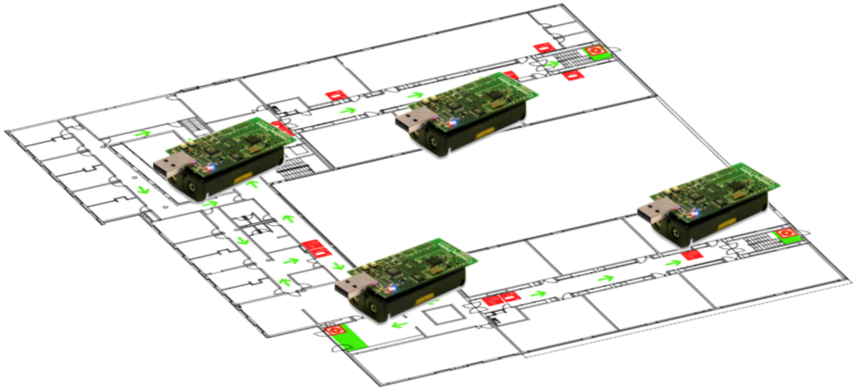
Tackling the Problem

- How to do it? A centralized solution?
  - We could disseminate fire detectors, connect them to a central server, and install dynamic lighting.
  - However, this solution is too dependent of a single node. And what about temporary venues and old buildings, where no data (or even power) infrastruture is available?



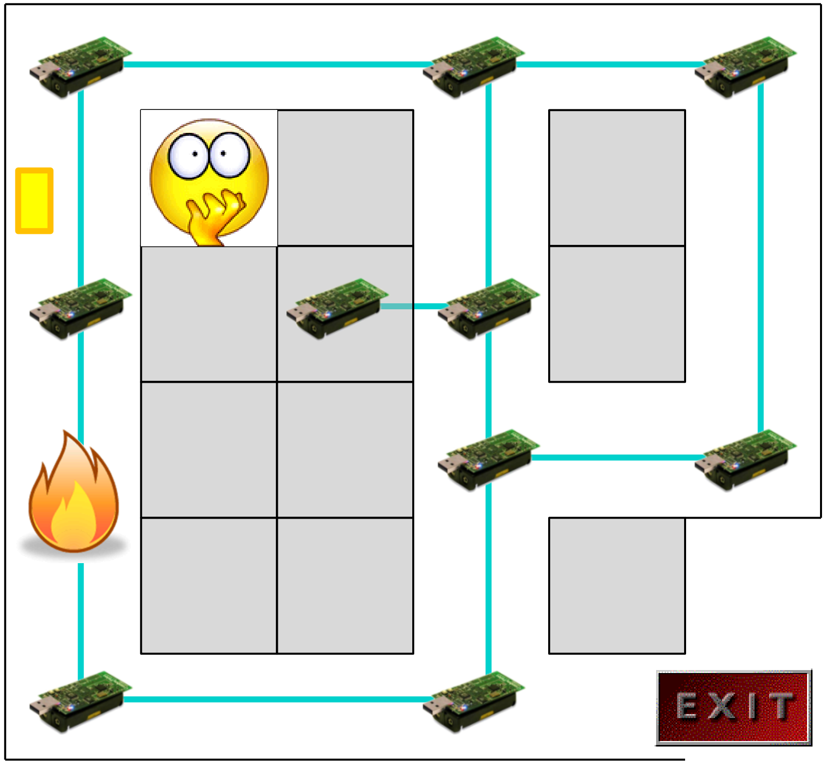
- A decentralized and autonomous solution can be achieved using a **Wireless Sensor Network**
  - Consists of a large collection of small devices called **motes**
  - Each one is equipped with a uCPU, wireless communication, sensors, I/Os, and battery for autonomous operation.
  - They have computation, communication, sensing, and actuation capabilities-

    all that we need!



Proposed Solution

- Motes are first placed in the building to monitor relevant environmental variables
- If a fire is detected by one of the motes:
  1. The mote broadcasts that information, and a dissemination process begins to get that data to all motes.
  2. Each mote computes the best way out of the building from their location
  3. Each mote actuates luminous signs to provide directions to occupants



- There are demanding system requisites:
  - **Consistency:** routes computed by a mote must be **coherent** with the routes of other motes within a **useful time frame**.
  - **Configuration:** each mote needs to learn the topology of the building, its position in it, and which actuators point to a given route.

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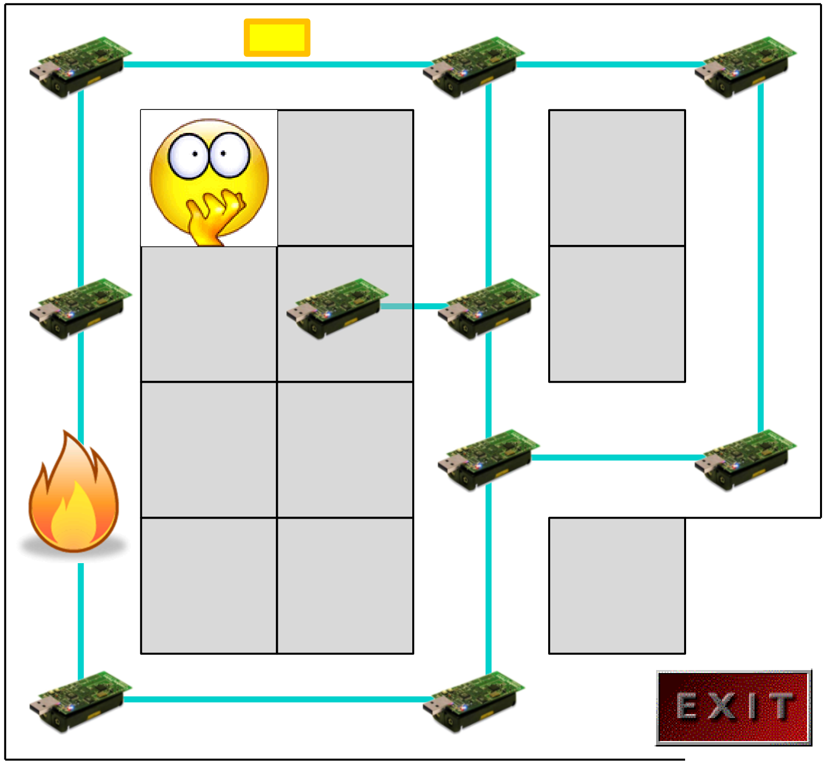

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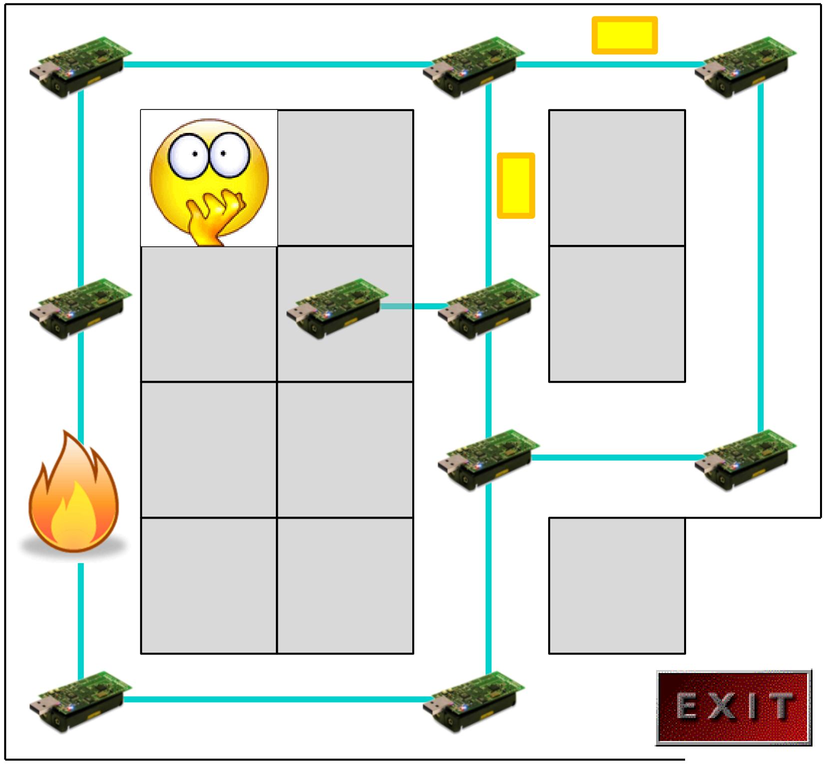

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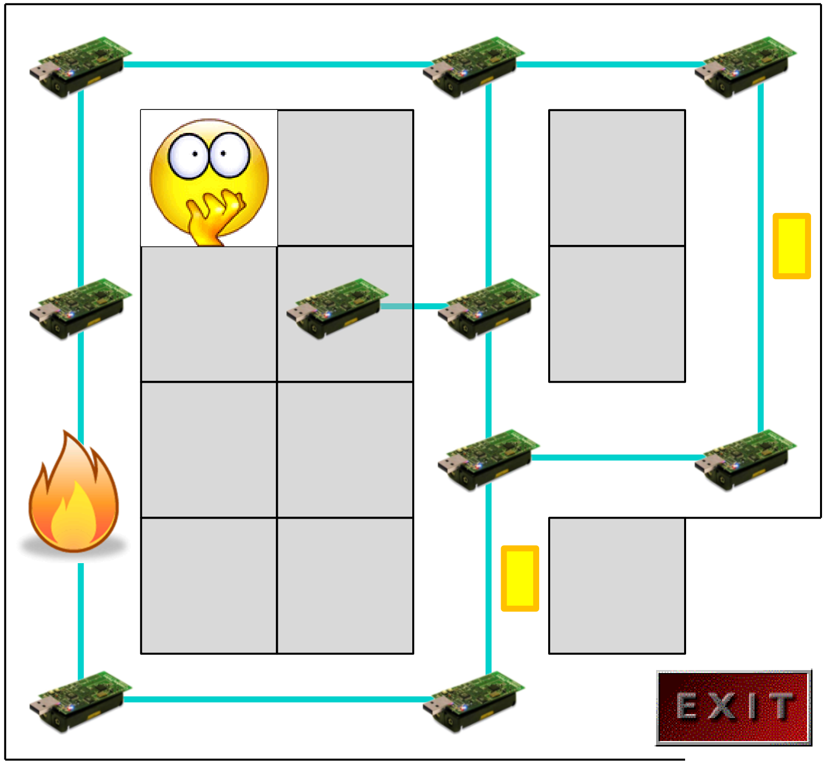

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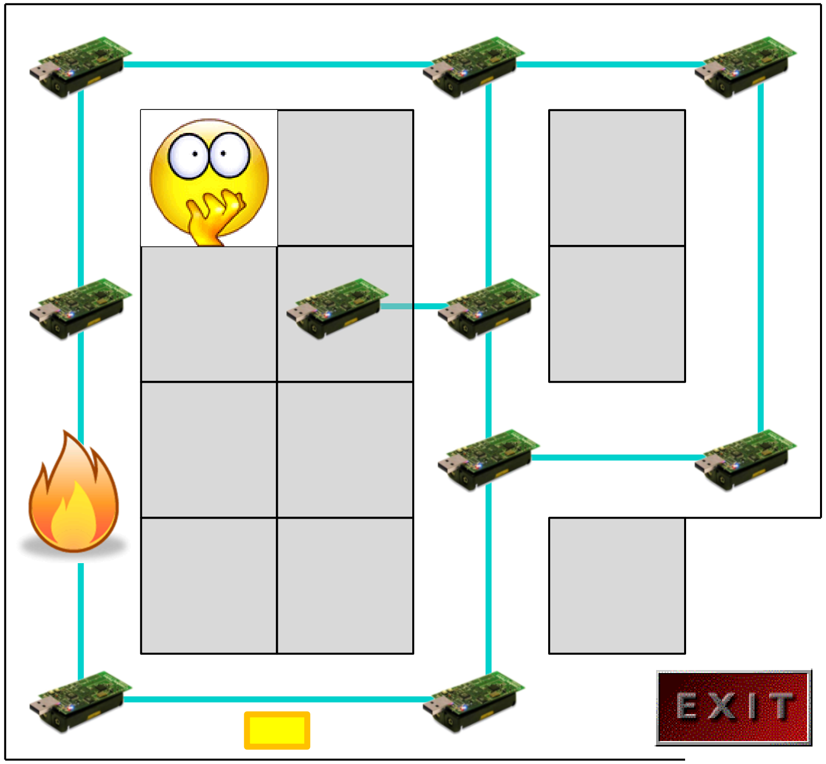

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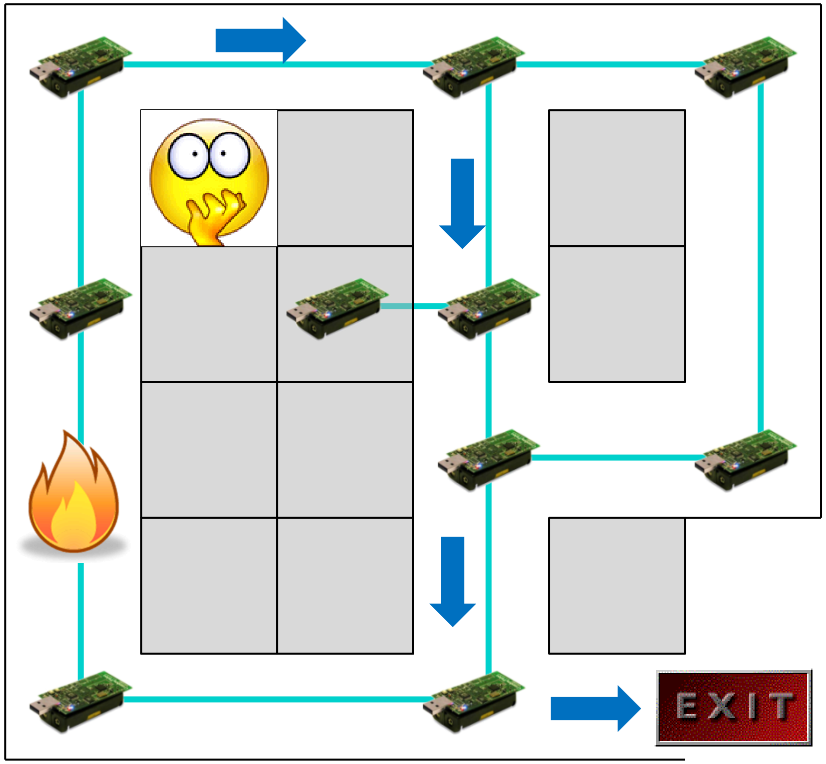
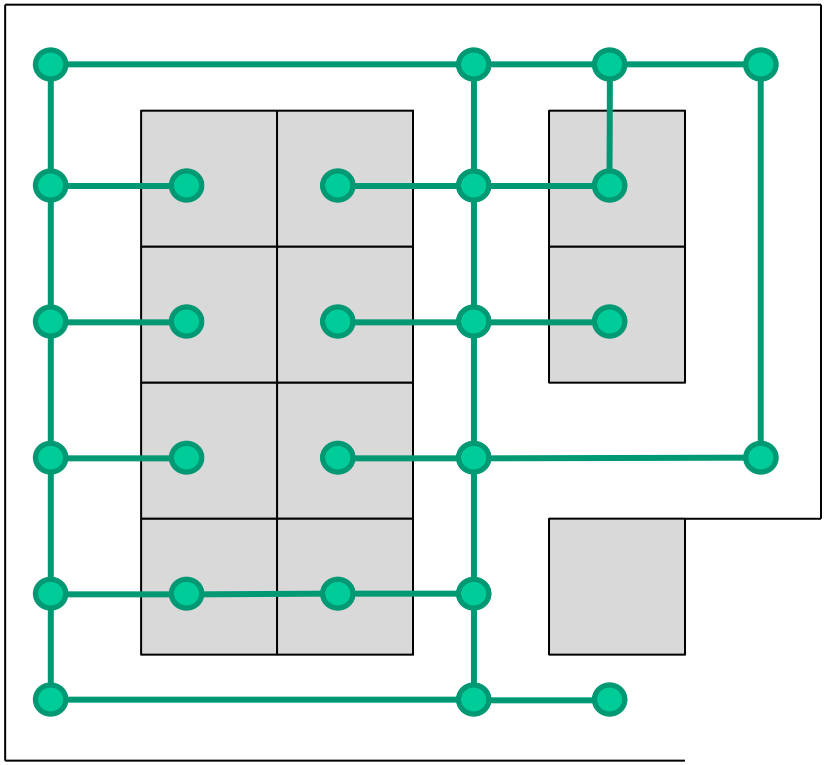


Modeling the Problem

- We used graphs to model the building and the Wireless Sensor Network
  - The building is captured by a graph whose vertices are relevant, distinct locations – *rooms, room entrances, intersections.*
  - Ideally, each one of these locations should have a mote and luminous signage – the graph of their locations would be identical.
  - However, system requirements dictate this mapping not to be that direct…
- Rules for mote placement:
  - Extra motes can be placed along corridors to ensure connectivity and sensing resolution
  - Rooms entrance motes that are close to each other maybe aggregated
  - Intersections may need more than one mote
- The vertices of the resulting graph are motes, and the links are walkable paths.



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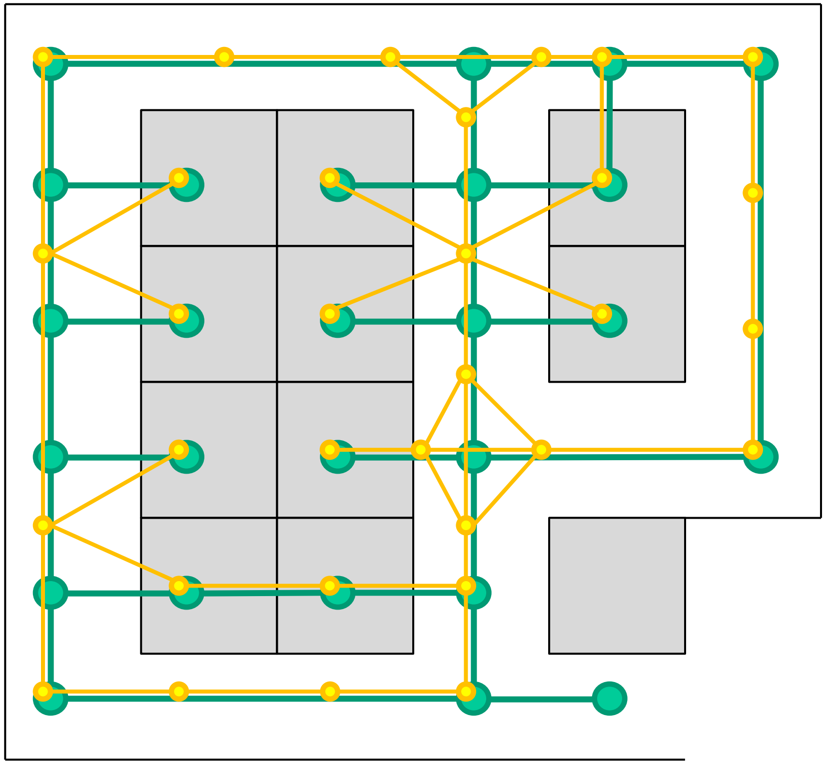

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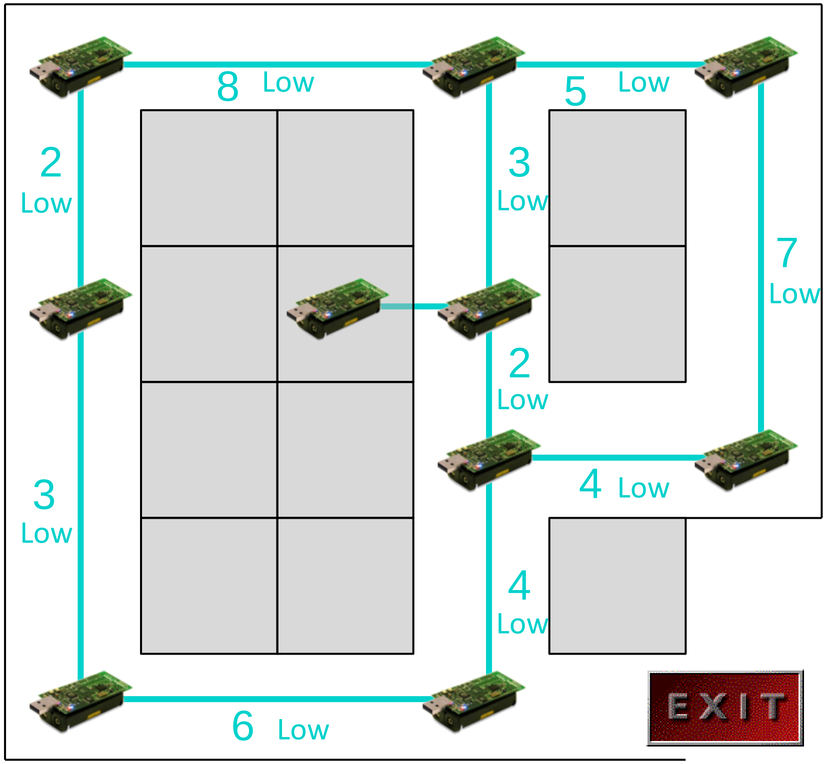
System Operation

- Route Computation:
  - Dijkstra algorithm is run at each mote.
  - At deployment, requires each mote to learn the topology and length of walkable links.
  - At run time, requires each mote to know the status of the links in real-time.
- Information Dissemination:
  - If a mote senses a change in the respective link, it broadcasts a link-status message.
  - Simple flooding is used to spread data.
  - During non-hazard periods, periodic messages are sent to detect motes that run out of battery.
- Hazard Scale:
  - The hazard level of a link is drawn from a scale: low, medium of high danger
  - This allows flexibility when computing routes.
  - During a fire, if a mote reports danger and later turns silent, that path is considered unusable.



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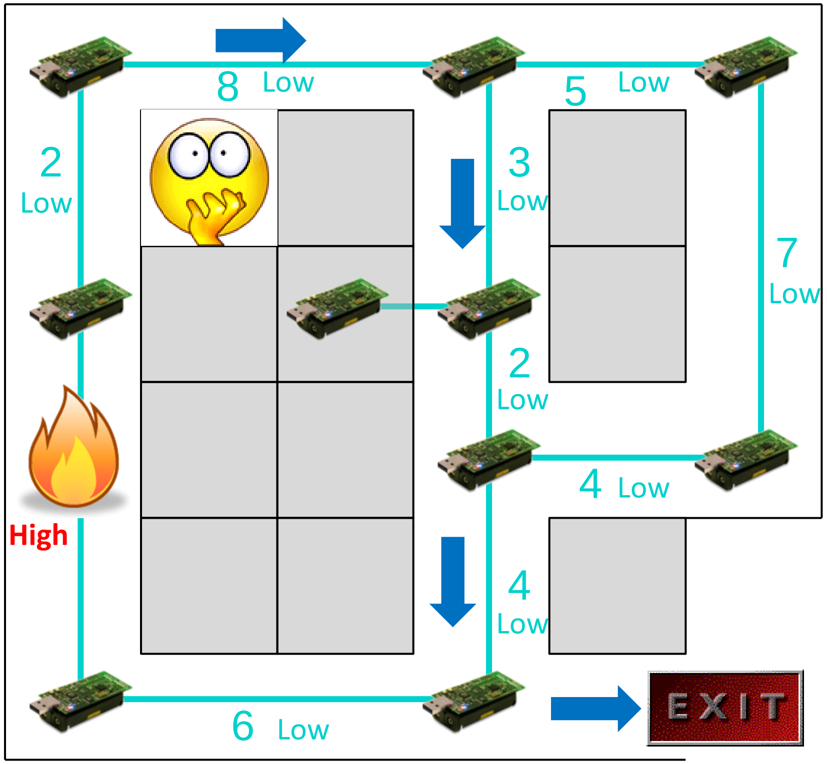

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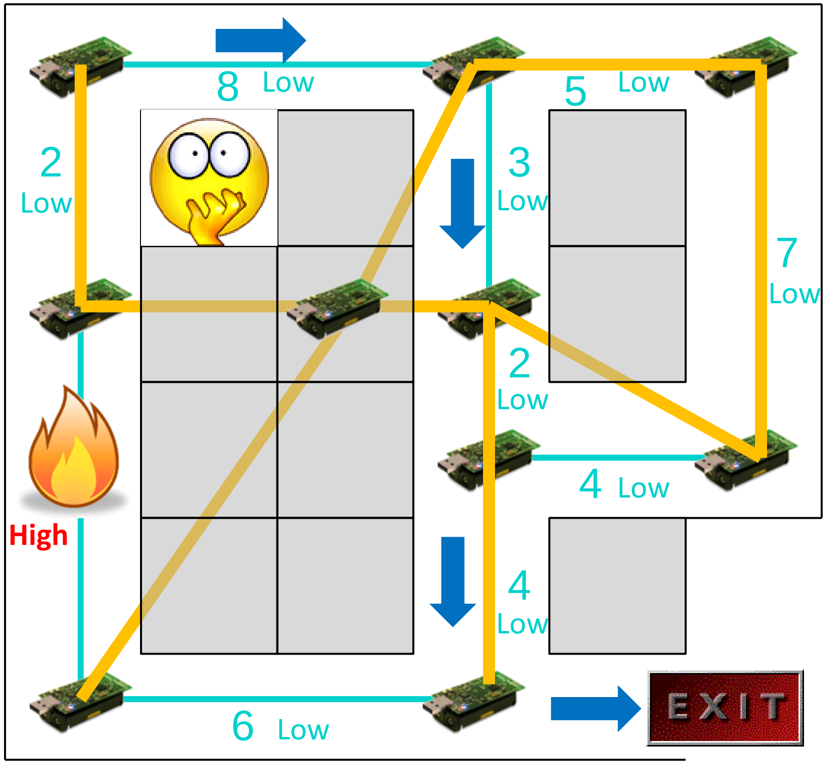

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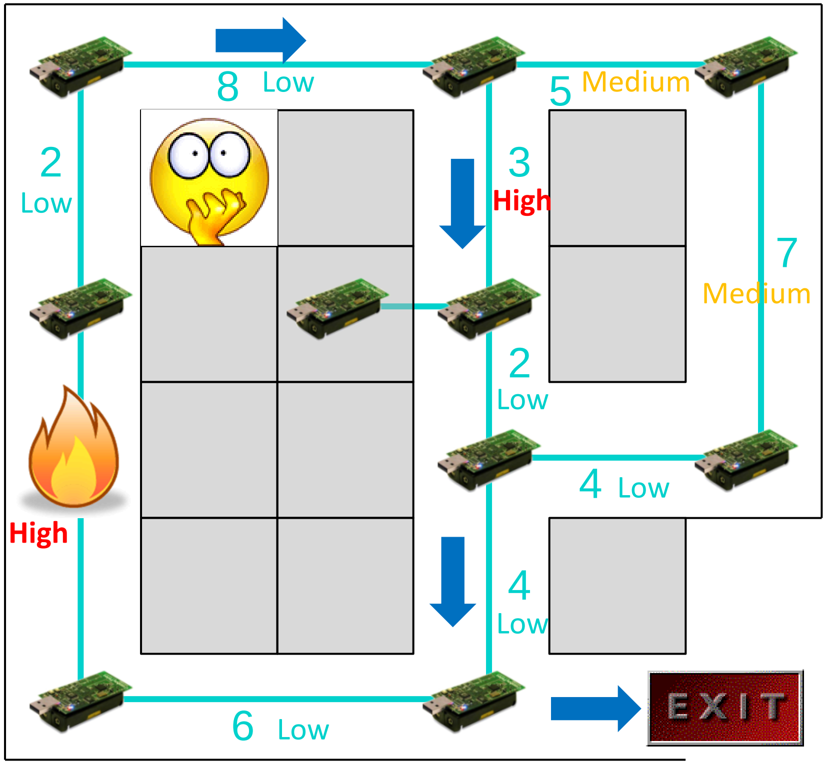

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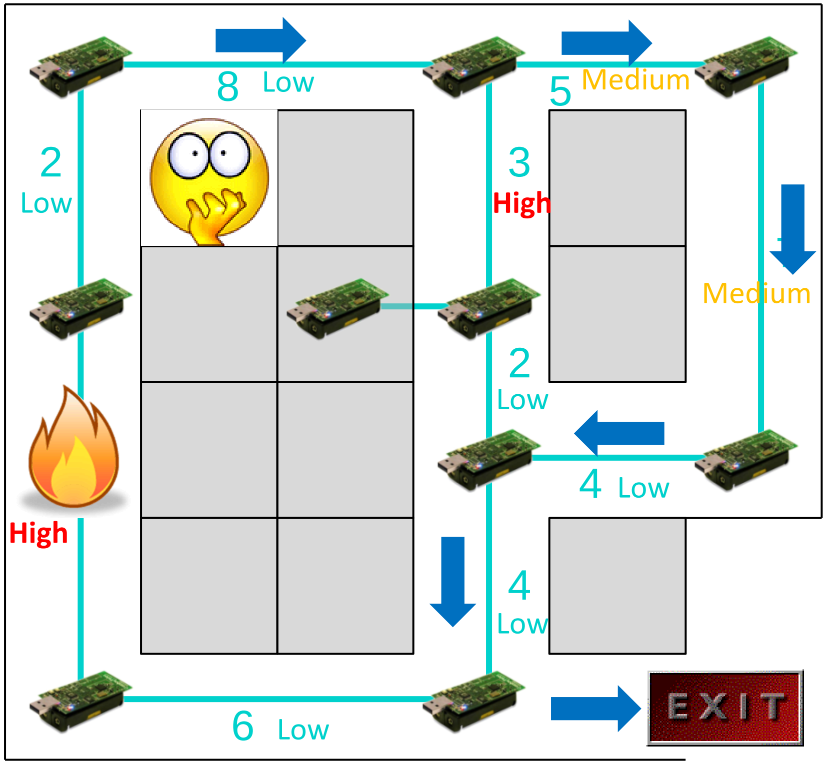
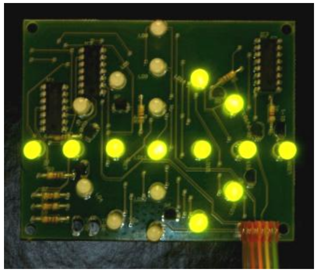
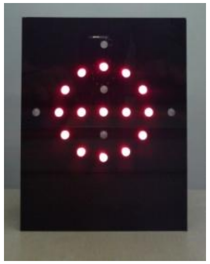


Physical Setup

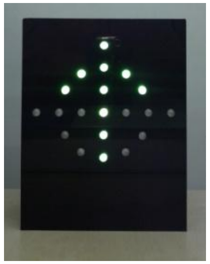
- Hardware:
  - Crossbow TelosB – performs temperature sensing, computation and actuation.
  - Custom-built PCB carries a scheme of LEDs to provide visual indications to occupants.
  - An acrylic box encapsulates both devices.



- Guiding signs:
  - Four signs are possible, but only a subset is used according to the location of the box
  - Examples:
    - Room entrance: **Forbidden** and **Go Ahead**
    - Corridors: **Left** and **Right**



Forbidden

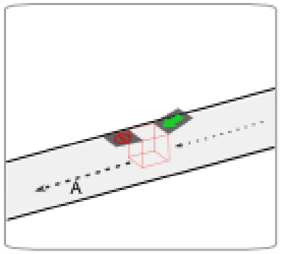


Go Ahead

Left

Right

- Aggregation of faces:
  - Several faces can be commanded by a single mote, to allow for more complex indications
  - Examples:
    - Case 1: corridors - front and back face
    - Case 2: 3-way intersection – 3 faces
    - Case 3: 4-way intersection – 4 faces



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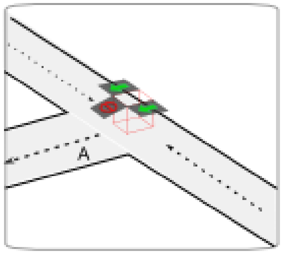
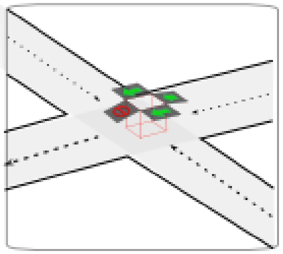


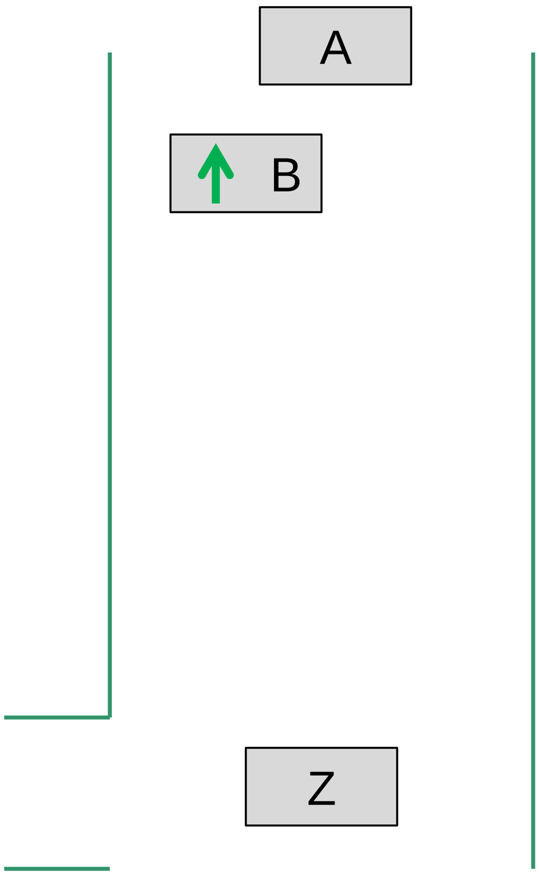
Case 2



Case 3

Deployment

- Deployment of this system is difficult due to the amount of information involved.
  - Length and topology of the walkable links
  - Assign visual signs to corresponding link
- We proposed OFD (On-the-Fly Deployment)
  - Does not require floor plans
  - Placement just needs to follow a simple set of rules
  - Configuration of visual signs happens during placement
  - Guarantees connectivity and sensing resolution
- Example – Creating a new link:
  1. The user configures mote B with the sign that points to mote A.
  2. The user then clicks button on A, which starts sending beacons.
  3. User carries B towards Z. While B is within radio range of A, it will show a sign. The walking time is the length of the new link.
  4. If pleased with the location, the user places mote B.
  5. User clicks a button on mote B to advertise the new link.



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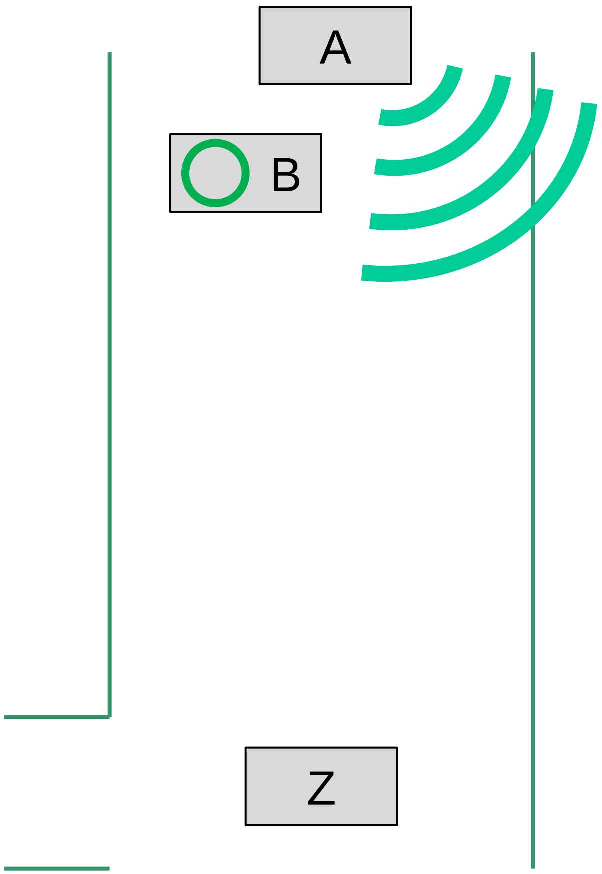

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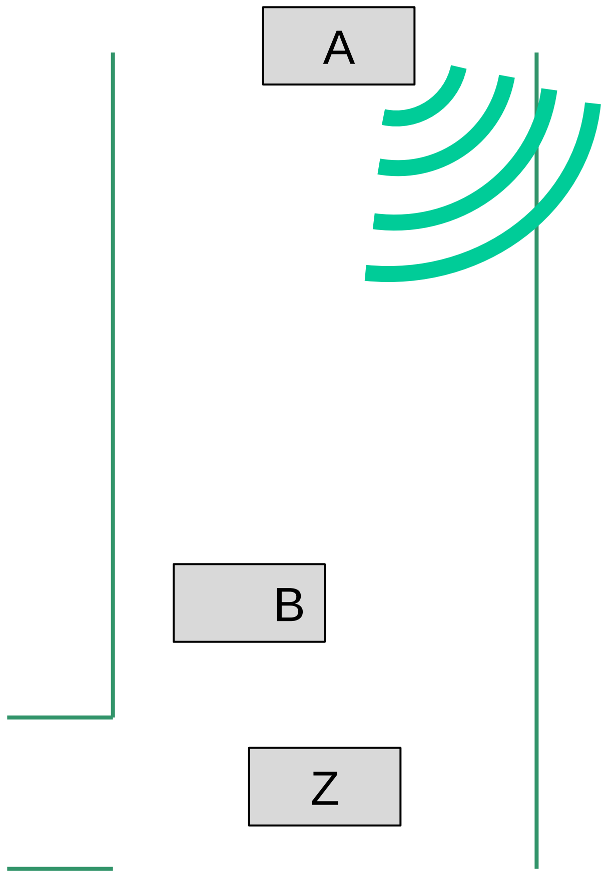

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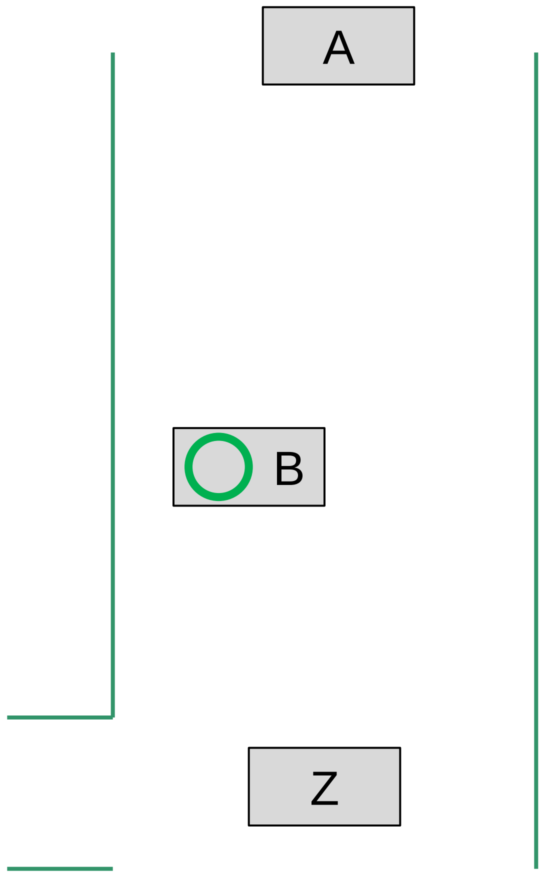

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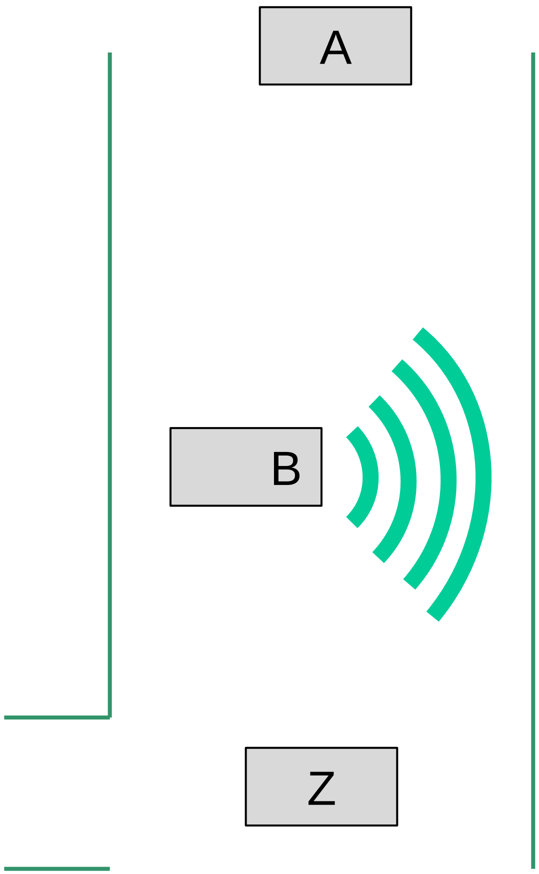

SIC Video

Carnegie Mellon Portugal Program: Vital Responder Project SIC TV Channel | April 17, 2012

http://www.youtube.com/watch?v=SSoIVYgVmzA
(seconds 2:26 to 3:07)

Conclusions

- We propose Dynamic Building Evacuation based on a Cyber-Physical System
- A **Wireless Sensor Network** is scattered through the building to sense for fires
- Motes actuate over **luminous signage** to route people towards the closest exit
- Routing options are based on **real-time information** received from the network
- We used a **graph to model the building** and the motes' location within it
- And we presented a **deployment mechanism** that saves time and is more practical because it allows configuration to happen simultaneously with placement