Emergency Support System with Directional Extensions

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Emergency evacuation

- Emergency evacuation is a fundamental part of built environments (such as sport arenas, concert halls etc.)
- The technical issues it raises are related to search techniques to guide people in dangerous areas
- There has been many works related to evacuation techniques that use wireless sensor networks
- WSNs can be used for
  - sensing the hazard
  - identifying evacuees and communicating with them
  - finding safe paths
Our ESS (Emergency Support System) consists of fixed sensor nodes (SNs) and mobile communication nodes (CNs).

SNs are pre-deployed at fixed locations in the building having short range wireless communication capability and are only utilized for civilian localization and to monitor the environment.

CNs form a network in an opportunistic manner as devices come into contact and communicate each other via their radio interface.

They store the graph representation of the area, which can be used for hazard information dissemination among them.
The ESS

- Once a SN detects hazard it generates a new emergency message (EM) and forwards it to CNs in communication range.
- EM includes:
  - the location of the fire
  - the hazard intensity
  - the device ID and the observations timestamp as a unique ID
- Each civilian is guided by his/her own individual CN (e.g. smart phone).
- From the received EMs a CN can updates its own local graph and uses oppcoms to disseminate EMs to other CNs.
- The carried CN locally calculates the best evacuation path based on the obtained information (EMs).
Our goal

To provide an enhanced path finding algorithm to guide evacuees from the hazardous areas to safe exits

To provide a communication protocol to limit the number of the disseminated messages while all EMs, which can change the evacuation path are disseminated to the CNs

The main idea

Our algorithms are based on the same idea: always to maintain the direction from the hazardous area (i.e. fire area) to the exits
Our observations

Figure: An evacuation example.

- However, the "red" path is shorter than the "green" one, it leads the civilian towards the hazardous area.
- In this case the civilian should choose the "green" path instead of the "red" one.
The safety metric of a path

We can utilize directions to predict the safety metric of a path.

There are two types of direction:

- A direction vector should be determined for each exit \( \vec{v}_{ei} \), which describes its main direction.
- And another vector should be calculated, which is the optimal evacuation direction from the hazardous area \( \vec{v}_{fire} \).

\( \vec{v}_{ei} \) points from the civilian current position (obtained from the SNs) to the \( ith \) exit.

\( \vec{v}_{fire} \) is a bit more sophisticated:

- The civilian has received \( n \) different EMs.
- \( \vec{v}_{t_j} \) is a direction carried by the EM generated at \( t_j \).
- Thus, \( \vec{v}_{fire} = \sum_{j=t_0}^{t_n-1} \frac{1}{2<j>} \vec{v}_j \).
The first version of the cost function

- The algorithm tries to find a path based on the previously described vectors
- The angle between a fire vector and an exit vector can be calculated simply
- The paths with smaller angle are more likely to be safer than the paths with higher ones
- Hence, a novel cost function could be defined as follows

\[ \hat{F}(i, G) \equiv \hat{F}_i = \frac{-\cos(\phi_i) + 1}{2} \times D_i \]
The uncertainty factor

Figure: An evacuation where the first version of the cost function does find a suboptimal path.

To prevent this, the cost function should be modified with a new factor:

$$\rho_i = \frac{\Delta_i}{\min_j D_j} \ast \hat{F}_i$$
The final version of the cost function is the sum of the previous cost function and the uncertainty factor:

\[ F(i, G) \equiv F_i = \hat{F}_i + \rho_i = \frac{(-\cos(\phi_i) + 1) \cdot D_i^2}{2 \cdot \min_i D_i} \]

Our novel path finding algorithm uses this cost function to select the most appropriate evacuation path.

If a CN receives a new EM, it recalculates the direction from the hazardous area, and based on this vector it updates the cost of each path.
The protocol

- This protocol is an extended version of the Epidemic Routing Protocol
- An EM can change the path due to two reasons
  - it updates the weights in the graph ($D_i$ will be modified)
  - it changes the angles ($\phi_i$ will be modified)
- We focus on directions, therefore, the effect of the first reason is less important than the second
- Thus, only those message will be circulated among the nodes, which
  - are created later than the receiver’s latest message timestamp and
  - which determine a new direction (if $\vec{v}_{sum} \times \vec{v}_{sum'} < \cos(\alpha_t)$) for the evacuation path.
- $\alpha_t$ depends on the location of the exits, the layout of the area and other factors
Simulation parameters

- Each CN can store 100 EMs, its data transfer rate is 100Kbit/s and its communication range is 6m
- An SN is located at each vertex of the building graph
- A single-storey building was used that was created from the blueprint of a real shopping centre in London. It contains
  - 8 fire exits
  - 321 other nodes
- Each node has a maximum capacity (10)
- Two different mobility models were used
  - normal operation: moving from store to store in a random order
  - emergency case: move through the selected evacuation path
Simulation parameters II

- Fire hazard with the same intensity was used in all the simulations to achieve a consistent evaluation.
- The fire spreads along graph edges, following a Bernoulli trial model.
- Each civilian starts with an initial health of 100, which decreases based on the hazard intensity as the civilian is exposed to the hazard (i.e., fire and smoke).
- The current health of the civilian does not affect her/his movement speed.
- Fire starts 600s after the simulation begins at a predefined node.
- Four different civilian densities were used (400, 600, 800 and 1000 civilians).
Results 1.

Figure: Results of the evacuation when the fire was generated close to some fire exits.
Results II.

**Figure:** Communication results of the emergency systems.
Conclusions

- A novel path finding algorithm and a communication protocol have been presented to enhance autonomous ESSs.
- These algorithms exploit the location of the communication nodes and hazards to calculate directions.
- A real-life example of a shopping centre was used as a case study.
- The experimental results indicate that the directional path finding algorithm can offer significant improvements for the evacuees.
Thank you for your attention!
Results III.

Figure: Results of the evacuation when the fire was generated at a narrow hallway far from all exits.
Results IV.

**Figure:** Communication results of the emergency systems.