Opportunistic Communications for Emergency Evacuation

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1. INTRODUCTION

Evacuation is an important component of emergency and disaster response. In case of emergencies, people in and near the affected area need to be quickly alerted of the emergency and evacuated along safe routes. Evacuation also needs to be fast, especially when there is a spreading hazard such as fire or flood. However, finding the best (i.e. safest and fastest) escape path is complicated due to ambiguous information and the dynamic conditions of the emergency. People may be unfamiliar with the area and the disaster might have rendered some paths unusable. Furthermore, best evacuation paths would change as the hazard spreads.

An emergency support system that aids in evacuation can prove very beneficial in these situations. However, existing communication infrastructure may be impaired due to the emergency; parts of the infrastructure may be destroyed, services may not be available due to congestion as everybody tries to communicate at the same time, or civilians may not be able to access existing networks due to prioritization of other communications. We propose the use of opportunistic communications (oppcomms) [5] among pocket devices carried by people to enable emergency support in the absence of communication infrastructure and describe the design of an emergency support system (ESS) based on oppcomms that provides alerting and navigation services to people in the emergency area for evacuation purposes. With oppcomms, devices exchange messages at a close range of a few to tens of meters with limited or no infrastructure and messages are carried over multiple-hops in a "store-carry-forward" manner by exploiting human mobility. We evaluate the performance of oppcomms and ESS using simulation experiments of indoor and outdoor urban emergencies. Our results show the degree of improvement that oppcomms can offer.

2. EMERGENCY SUPPORT SYSTEM

Our proposed ESS [4] is targeted for densely populated indoor and outdoor urban areas as node density plays an important role in the effectiveness of oppcomms. ESS consists of two types of communication devices: **mobile communication nodes (CNs)** and **fixed sensor nodes (SNs)**. CNs are small, battery-powered pocket devices carried by people, capable of short-range[1] wireless communication and having a processor and some local memory. CNs form a network in an opportunistic manner as they come into contact due to human mobility; the opportunistic network (oppnet) formed by CNs is a type of delay/disruption tolerant network (DTN), characterized by intermittent connectivity, no end-to-end paths, and long delays [2].

Each CN carries messages on behalf of others in its local storage, and forwards them to other CNs as they come into contact. Thus, a message is delivered to its destination over multiple hops via successive opportunistic contacts in a store-carry-forward manner. Because the oppnet may be disconnected for long periods of time, CNs may need to store messages for lengths of time, and the delivery of messages to destinations is not guaranteed.

We represent the emergency area as an undirected connected graph $G(V, E)$, where vertices V are locations where civilians can congregate and edges E are physical paths that civilians can use to move in the area. An edge has multiple associated costs: the length $l(i,j)$ of an edge (i,j) is the physical distance between vertices $i, j \in V$, while $h(i,j)$ represents the measured hazard intensity along this edge. We define the "effective" length $L(i,j)$ of an edge as $L(i,j) = l(i,j) \cdot h(i,j)$. This joint metric combines distance and hazard intensity to express the total cost of this edge. When there is no hazard along the edge, $L \equiv l$. As the value of h increases, the corresponding edge becomes more costly (hazardous) to traverse.

We assume that the area graph is known for the emergency area. We believe this to be a valid assumption since the topology of the area and physical distances are static and therefore the graph can be created once and stored for later use. Each CN stores in local memory the area graph, which is obtained and installed through a trusted source. All changes to the graph and edge costs due to the emergency are disseminated via oppcomms.

In indoor areas, such as buildings, we assume that there are sensor nodes (SNs) pre-deployed at fixed locations in the area, where each SN monitors its immediate environment. Each SN is a self-contained, self-powered, low-cost device with simple sensing and short-range low-rate wireless communication capability, and has enough memory and computational power to perform its sensing activities. We

[1] We assume that CNs have a communication range of up to 10m indoors and up to 100m outdoors.

assume that SNs are extremely energy-conscious. Hazard information is generated by SNs through their monitoring activities. This information (e.g. $h(i,j)$ values) is sent to any CNs that come in contact. Emergency messages (EMs) containing hazard information are disseminated among CNs via oppcomms, where each EM is destined for all CNs.

The first EM received by a CN acts as an alarm, indicating that there is a hazard and the user of the CN should evacuate the building. Received hazard information is used by CNs to update edge costs on their local graphs. An update triggers the calculation of shortest paths from the current CN location to all exits, and the path with the lowest cost is used as an evacuation path. CNs employ Dijkstra's shortest path algorithm. Since effective edge lengths ($L(i,j)$ values) are used in SP calculation, the "shortest" path minimizes exposure to the hazard while also minimizing travel distance. The current evacuation path calculated by a CN is used to provide step-by-step navigation directions to its user. In order to do this, the CN needs to know its location in the area. Indoor localization is achieved using the fixed SNs. Each SN knows its location in the building and they are used by CNs to approximate their locations in the building based on the graph.

The ESS employs epidemic routing [7] since the flooding-based nature of epidemic routing is a good fit for the one-to-all dissemination of EMs. Epidemic routing is known to have high message delivery ratios and low message latencies at the cost of high communication overhead [6]. However, the communication overhead is not applicable in ESS since each message is targeted for all CNs, and epidemic routing provides good communication performance, which is desirable for emergency communications. Timestamp-based priority queues are used to manage message storage in CNs, where newer EMs have higher priority. This is because EMs relating to recent events are generally more important than those of past events, since old EMs have already had some time to be disseminated and their data may have become stale. A CN sends its messages in timestamp-priority order during contacts. In a similar fashion, when the queue is full, the oldest messages are dropped first.

We assume that there are no SNs located in outdoor areas; in this case, information on the hazard is generated either by sensors embedded in the CNs (full autonomous operation), or by manual input by the users (semi-autonomous operation). Outdoor localization is achieved via satellite-based navigation systems.

3. EVALUATION

We implement ESS in the multi-agent distributed building evacuation simulator (DBES) [1], which is designed to support the simulation of emergency systems and scenarios. We evaluate ESS in two urban areas: (i) a three-floor large office building, modeled based on a real-life building at Imperial, and (ii) a 5km^2 area of the Fulham district of London. Our results (e.g. Figs. 1 and 2) show that oppcomms can effectively enable evacuation services, performing better than uninformed shortest path routing and a static-node based distributed evacuation system (DES) [3]. However, we also observe that parameters such as communication range and the number of CNs play an important role in the performance of oppcomms by affecting connectivity, and in certain low-connectivity conditions oppcomms may not perform well. We also consider issues of resilience to failures and security

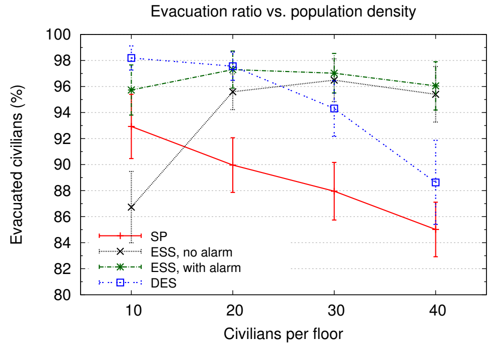

Figure 1: Ratio of successfully evacuated civilians vs. number of people (per floor), building scenario.

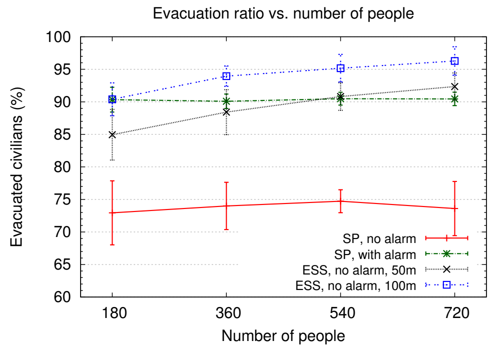

Figure 2: Ratio of successfully evacuated civilians vs. number of people, outdoor scenario.

of oppcomms for emergency support in our work.

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