International Journal of Advances in Computer Networks and Its Security– IJCNS
Volume 4: Issue 2 *[ISSN: 2250-3757]*
Publication Date : 25 June 2014

Post-Disaster Resource Management using Peer-to-Peer Opportunistic Networks

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Abstract— **During large-scale disasters, it is often found that services that are relied for everyday communications become non-functional. This becomes a barrier and a key challenge in effective transmission of information related to the disaster through electronic media in executing relief operations. In these situations, portable devices like the smart phones come in handy and are effective in storing offline information during post disaster management operations. Effective utilization of these mobile databases through coordination will provide a platform for executing disaster relief operations. In this paper, we have proposed a scheme in which a virtual opportunistic network is formed by these mobile agents, that effectively addresses the resource management and post disaster relief operations. Through direct and indirect coordination between agents in those situations, different static nodes in an area will become aware of the geographical location of other nodes. Aggregation of such structured data from various parts of the region at a centralized point gives a realistic picture of the situation, and thus sending resources and medical aid to a node becomes far more effective. Furthermore, even if network connectivity is detected in a region, structured information stored in the smart phone can easily be updated to the internet which adds to the advantage of the scheme as well. To achieve this we have simulated the working environment of a post disaster scenario with static nodes (where affected victims take shelter) and volunteers which performs different tasks. The performance evaluation results establish the effectiveness of the proposed scheme.**

Key words — **Opportunistic Networks, Resource Management**

I. Introduction

Any large-scale natural disasters like flood and cyclone have severe impact on communication infrastructure. Services that are relied on for everyday communications (e.g., cell phone / internet) immediately become non-functional in emergency situations due to the failure of the supporting infrastructure through both system damage and system overuse [1, 2].

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In contrast to the vulnerable fixed network infrastructure, it is very likely that battery-powered wireless personal mobile communication devices (PDA, cell-phones) will survive in disasters. It is this opportunity which we are taking advantage of in building a robust-virtual-opportunistic network by utilizing the smart phones.

Opportunistic networks have drawn significant attention of researchers in the recent past. In opportunistic networks, end-to-end route connecting any two nodes usually does not exist and a source node communicates with its destination node following hop-by-hop, store-wait-forward cycle. In this type of networks, the mobility of devices is an opportunity for communication rather than a challenge [3]; any node can opportunistically be used as the next hop, if it is likely to bring the message closer to the destination node.

In this paper, we have developed a semi-centralized mechanism in order to make each node in the model aware of the geological position and status of the other nodes. It is assumed that all fixed cellular infrastructures are non-functional and relief-workers with their smart phones form an opportunistic network in the disaster affected area. The mechanism proposed in this paper is primarily based on mobile agent based framework [4]. The whole affected region is divided into a number of segments. The working of various nodes in a segment follows a distributed mechanism, whereas the resource distribution and inter-communication between segments is made centralized with the incorporation of a central station. Through direct and indirect coordination between agents in those situations, different static nodes in an area will become aware of the geographical location of other nodes. Aggregation of such structured data from various parts of the region at a centralized point gives a realistic picture of the situation, and thus sending resources and medical aid to a node becomes far more effective.

II. Model Description

The model is represented by different types of agents that have their own duties in the field of disaster management. The agents are described as follows:

Shelter: These are static nodes in the affected region which acts as relief camps or shelters to the victims affected in the disaster. These are places where victims take shelter and edical aid and resources are being supplied to the victims. For example, these include army-camps, school buildings, some high-land areas, etc.

***Relief Worker (RW) or volunteer**:* These are mobile agents that perform different types of tasks related to post disaster operations. Those include: transferring a resource packet from one place to another, looking for excess resources in neighboring places and transporting messages as well. Each of them is supplied with a smart phone and hence they form the main carriers of information between static shelters.

Meeting Point (MP): It acts as the main information hub where all model related information in the form of messages is collected. It acts as the resource pool in the whole region and centralized decisions are taken from here only. When there is a demand of resources at a shelter, this information is passed by a hop-by-hop technique to notify the MP, which then supplies the required resources to the concerned shelter in the form of resource packets with the help of the relief workers.

Central Station (CS): It serves as a medium of communication between the affected region and the outer world. Any piece of information gathered by the MPs is updated to the CS at regular intervals, so that it is available globally. The inter-communication between a MP and the CS is achieved with the help of a High Speed Vehicle (truck, for example).

High Speed Vehicle (HSV): Each MP is allocated a High Speed Vehicle which acts as a carrier of resources and different agent related information to the CS. As its name specifies, it travels at a much faster speed when compared to the walking speed of the mobile workers and moves to and fro between CS and MP.

***Resource Packets*:** A resource packet also forms a part of the model, since it also acts as a carrier of data related to the model. These are the physical resources (food, cloths, etc) placed inside packets which are equipped with a blue-tooth enabled active RFID tag that can communicate with a smart-phone using Bluetooth interface. Thus, possession of a resource packet ensures an agent to read data available in it.

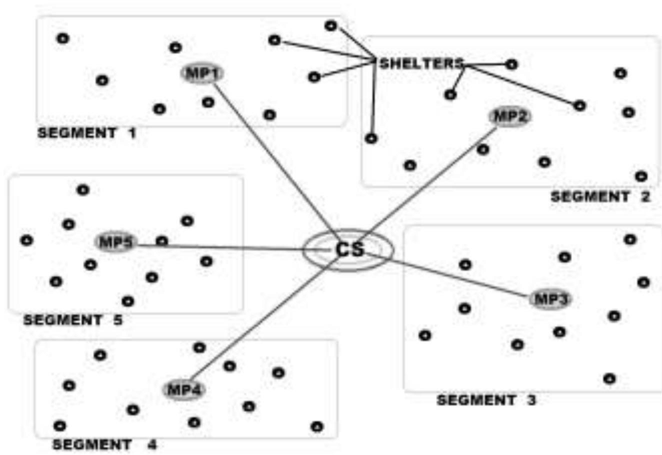

Fig. 1: The division of affected area into a number of segments. Each segment has its own MP, sharing a common CS.

The entire disaster affected region is divided into a number of segments. Each segment has only one MP and only a single CS exists in the whole region. Thus, all segments and their MP share a common CS. This is illustrated in Fig. 1. The entire model revolves around distribution of resources efficiently when required and pervading of vital information regarding different agents throughout the model. We are going to study only one of the segments involved and derive information related to the working of the model.

III. Model Overview

After a disaster occurs, a MP and the CS is set up at a suitable place which is physically accessible from all directions. Shelters are generally formed by the victims and they must be discovered first by a team of all the relief workers (RWs) in the affected area.

A. *Mobility pattern of the relief workers (RWs) and discovery of shelters*

Initially, all the RWs start off from the MP. Hence, they know the geographical location of the MP. Workers move randomly throughout the whole affected area in search of shelters. While searching for shelters, if a RW finds one, it assigns itself to that shelter. Each shelter can be assigned a maximum number of two RWs. So, when a worker visits a shelter which is new to him/her, it checks with the shelter whether the total slots are already filled in or not. If not then he assigning himself to that shelter. If the first assigned RW is busy working and is not available at the shelter, then the second RW works for that shelter. Once a shelter is discovered by a RW, it adds the geographical location and other static data related to its shelter to its smart phone manually allowing the RW using it to see the discovered shelters, MP and the CS on the available map.

B. *Information exchange*

The RWs play an important role in exchanging static information (these types include geographical location of the shelters, identities of the other RWs, number of them working in the field and corresponding shelters in which they are assigned to). The model improvises the fact that whenever two RWs are in their near vicinity, they would exchange these static information with each other. Hence, any new information unknown to the other person gets updated in its smart phone. This mechanism of passing information related to the model makes the system aware of other shelters and RWs being present in the area.

The model utilizes the well-known concept of stigmergy [4], in which agents (here the RWs) used to populate caches of nodes (shelters) with information. This mobile agent based cooperative routing protocol is suitably used for delivering messages/information in a large dense network where network performance will be increased with the increasing traffic in the network due to high degree of cooperation among the agents. The novelty of this work is the introduction of a highly cooperating agent team that can meet and exchange data with other agents carrying messages in the network. Hence, the shelters act as cache of information in the field from where *any* agent can exchange information freely. The shelter also exchanges data, and hence the pervading of information becomes efficient throughout the area.

When a RW visits a neighboring shelter or the MP to perform a task, it spends some time before leaving. This mechanism extends the chance of meeting other workers at the MP or the shelters. This, in turn, increases the degree of spatial coordination (agents must be on the same place). The temporal coordination (agents must meet at the same time) has been enhanced with the introduction of a short waiting delay offered to each RW. This waiting time will further increase the chance of meeting with other RWs. The meeting place hosted at the shelters and MP be called as the *Rendezvous Points* [5] within the network and the detainment period of the agents can be called *Rendezvous Periods*. Here, the Rendezvous periods are set to 20 time–ticks. So, before leaving the shelter, a RW achieves a good opportunity in sharing information with other RWs that might visit this shelter for performing tasks.

C. Identification of Neighboring Shelters

As time passes by, the shelters come to know about the presence of other shelters and their locations too. Each shelter, from its own available list of shelters, finds out the best two neighboring shelters, *first* and *second* which satisfies the following criteria: the other shelter in the list should be nearer to it in respect to the MP and the shelter should fall in the path while moving towards the MP. It does so by determining an area in which it should search for the nearest neighbor.

Each shelter accesses its list at definite intervals to update the neighbors, so that the best combinations are obtained at all times. This data is also informed to its assigned RWs at that shelter, when they are physically present. Initially, when a shelter has no information about the presence of other shelters in the affected region, it is assumed that a MP is the only neighbor to that shelter. With the availability of new information, the neighbors also get modified. Each shelter has an automated system that guides the assigned RWs and it works based on the information gathered. It assigns different jobs to the workers and even decides where to send them.

D. Management of Resources

To simplify the illustration of the model, let us assume that relief resources like food, clothes, medical-aid, medicine, etc. is considered an aggregated integer quantity and is called *resource-count*. Positive resource-count indicates presence of excess resources. A negative resource-count indicates there is a demand of resources and resources are required to fulfill the demand. A zero resource-count indicates, there is neither a surplus nor a demand of resources at a shelter. In the simulation model, the shelters *self-decrement*s the resource-count, simulating the fact that victims present at the shelters consume up the resources and hence the net resource quantity at shelters decreases. The self-decrement of resources takes place after a certain time interval depending on the number of victims present.

Messages or *message packets* form an integral part of this model, since based on these messages, both static and dynamic information gets forwarded to the MP via other shelters. A message packet is used for two purposes: to denote the resources required at a shelter and to denote the resource status of a shelter throughout an entire period of time. These message packets are electronic messages that are used in smart phones. So, a message packet can be easily sent through a network when an internet or network connectivity is discovered to be functional, bringing down the delay in transferring the message physically to the MP.

Once a message packet destined for the MP is generated at a shelter stating a demand in resources, it is transferred to its *first* neighboring shelter by a RW belonging to the current shelter. Again the same process is executed for the next shelter and this goes on until the message reaches the MP. For those shelters whose first neighbor is the MP, they should directly transfer it to the MP.

When a demand is generated at a shelter, it first checks whether any one of the relief workers are present within the vicinity. If it finds any one, it automatically assigns the task of bringing resources from a neighboring shelter to the RW. All the RW has to do is physically go there and perform few checks and bring resource back to this shelter. After being assigned a task, the RW goes to the *first* neighbor in search of resources. After reaching the *first* neighbor, it checks whether any excess resource is present. If present, it takes the resources back to its own shelter to fulfill the need. If a part of the required resources is present, take it back and generate a message packet and leave it with the shelter about the extra resource needed apart from the resource that it had taken. If it finds no resources, it then moves to the *second* neighbor (if present). It just needs to give another try. It performs the same checks after reaching that shelter.

The MP regularly checks for messages that are being transferred to it. Once it gets a message related to a demand at a shelter, it executes an algorithm on its end that ensures a shortest path on a probable network that is expected to be formed by the shelters in the affected region. The point to be noted here is that the MP is unaware of the decision a shelter concerned makes in choosing a perfect neighbor. It is the MP who runs the same algorithm a shelter uses to find the neighbors in its locality and then find the shortest route in the network. MPs are supplied with five RWs that perform tasks for it. The MP then embeds this path in an active RFID tag within a physical resource packet and allocates one of its RW to transfer the resource packet to the destination. But, instead of travelling the entire path to the destination shelter, the RW transfers the packet to the nearest shelter mentioned in the path and retreats back to the MP. Again it will be the duty of a RW from that particular shelter to transfer the packet to the next shelter in the mentioned path and retreat back to its working shelter. Accordingly, hop-by-hop the mechanism is executed until the packet reaches its destined shelter which is in need of it. This technique helps a RW to travel lesser distances physically with a burden of the resource packet it is carrying. Again the model takes care of the fact that no RW that is working in the pool of relief workers at MP or at any shelter is over worked upon by taking cognizance of the average work done by each RW. With the distribution of the work equally, it helps maintain the equilibrium of energy loss and energy gained by the workers working in the field.

The High Speed Vehicle (HSV) allocated to a MP moves to the Control Station (CS) to transfer new information gathered at the MP after a definite fixed interval of time. Apart from this interval, if resource-count at the MP decreases below a certain level, it moves to the CS to fetch resources and again retreats back to the MP with the resources.

IV. Simulation Set -Up

Recursive Porous Agent Simulation Toolkit (REPAST) [6] is a free and open source agent-based modelling toolkit that offers users with a rich variety of features. This simulated environment is written in JAVA. The entire social simulation is achieved using agent based modeling [7] where agents are used to replicate the prime entities in the model.The proposed scheme is evaluated on a simulated environment by varying key parameters related to the model to study and estimate the efficiency and uniformity of resource distribution against time-ticks. In the Repast platform, "ticks" are considered as a unit of time; we have assumed 1 tick equals 1 minute. In the simulation, the environment to be studied is assumed to be an area of 10 km. x 10 km. However, the affected site is considered to be a rectangular area of size 10 km. x 4 km. in which all the shelters are present. In this simulation, the *self-decrement* of resources at shelters takes place at an interval of 120 time-ticks.

V. Performance Evaluation

As stated earlier, a MP act as a centralized information hub which keeps an account of all the data related to the affected area. Fig. 2, derived from a simulation illustrates the perception of the total resource-count w.r.t. the actual resources present in the affected area (total resource status of all the shelters). The shelter and volunteer-count is set to 10 and 25 respectively. The deviation of the perception graph is due to the delay induced in transferring the message of a scarcity of resource at a shelter. The main point of interest is that the MP had been able to judge the actual variation of total resource-count in the area. This is indicated from the fluctuating pattern of the perception graph (represented by the solid line) which matches the fluctuating pattern of the actual resource graph (represented by the dotted line) illustrating the fact that the information reaching the MP is correct. It is also seen from the actual resource graph that all resource demands of shelters are eventually catered by providing resources (a falling slope followed by a rising slope). At times, it touches zero, indicating all resources have been fulfilled properly. This denotes the capability of the model to cater the scarcity of resources when it is perceived at the MP.

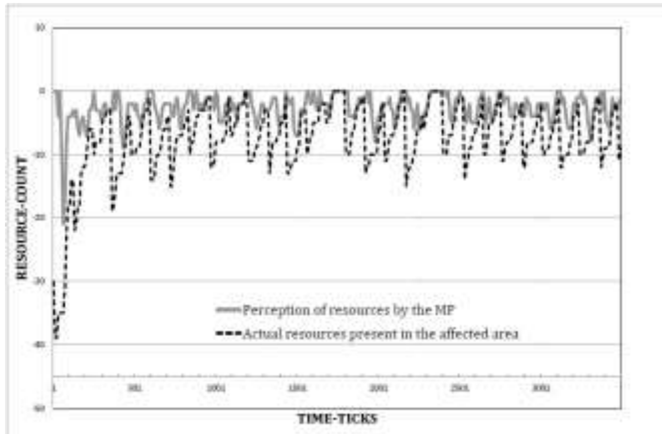

Fig. 2: Perception of resources in affected area by the MP Vs. actual resources present in the area. The number of RWs and shelters present in the affected area equals 25 and 10 respectively.

Next, we studied the convergence of static information throughout the area by varying the number of volunteers working keeping shelter-count constant in the area. By convergence it is meant what percentage of the total static information (considering only the shelter and volunteer-count) is available with each RW and shelter at different time-ticks. It is seen from Fig. 3 that with volunteer count above 25, an increase in number of volunteers does not impact the slope of convergence. However, having a more volunteer-count, for example 55, the amount of unknown information is more. It, therefore, takes a long time to achieve 100% convergence with greater volunteers.

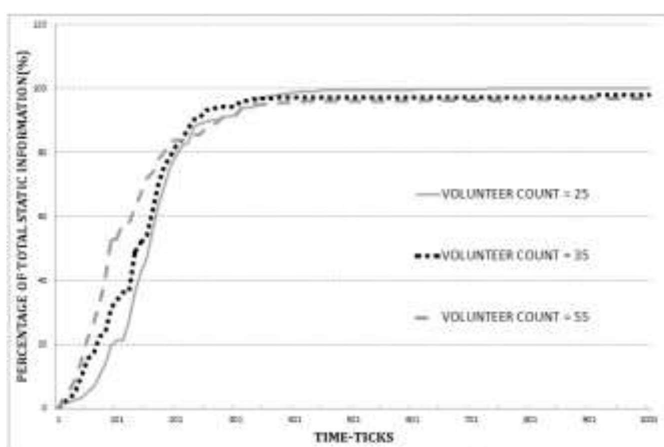

Fig. 3: Convergence of static information (shelter and volunteer-count) throughout the affected area with varying volunteer-count. The shelter-count is kept constant at 10.

Fig. 4 shows the impact of changing the speed of the RW agents on the fulfillment of resources. Keeping the number of shelter and RWs constant at 10 and 25 respectively, we have varied the travelling speed of the RW agents to 50m/ min., 100m/min. and 200 m/min. Even if the RWs travel at slow speed of 50m/min. the demands of the shelters gets catered (represented by the dotted line) and the model is stable to react to the demands. With a speed of 100m/min. the demands gets catered at a much faster rate (with steeper rising slopes). This indicates the model's capability of perceiving and catering of the demands. Furthermore, if the speeds be increased to 200m/min. (i.e. if they are supplied with a faster moving vehicle) then it is seen that the rising slopes of the graph gets much more steeper and the graph touches the zero resource-count for the maximum period of time. Thus, an increase in speed of the RWs increases the efficiency of the model as well.

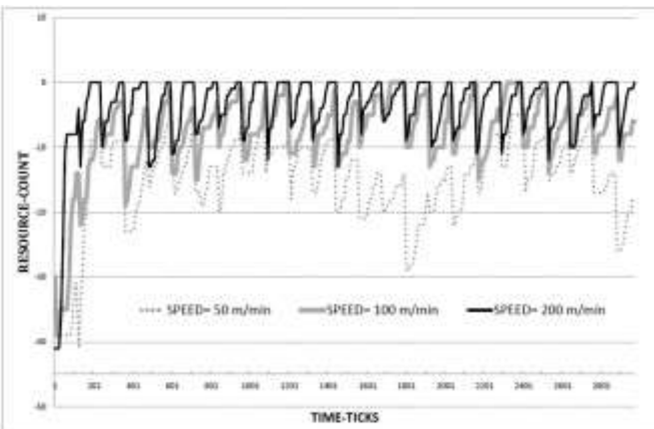

Fig. 4: Fulfillment of resource requirement with varying speed of RWs. The number of shelters and RWs were kept constant at 10 and 25 respectively.

In view of the practicality of the situation, we have simulated the environment where 6 RWs travelled at a speed of 200m/min., 10 RWs travelled at 100m/min. and 9 at the speed of 50m/min. The actual resource-count variation graph was deduced and is shown in Fig. 5.

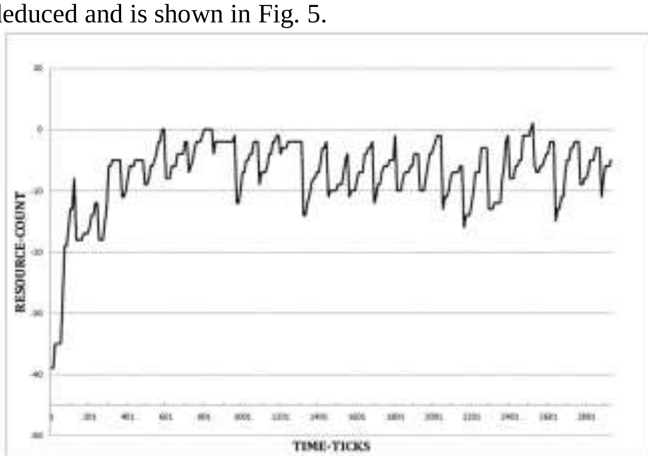

Fig. 5: Actual resource variation in the affected area with RWs travelling in different speeds of 50m/min., 100m/min. and 200 m/min. The number of shelters and RWs were kept constant at 10 and 25 respectively.

All resource demands of shelters are eventually catered by providing resources (a falling slope followed by a rising slope). At times, it touches zero, indicating all resources have been fulfilled properly.

VI. Conclusion

In this study, we have proposed and studied a scheme in which post-disaster relief operations and resource management can effectively be executed in a controlled mechanism by the formation of an opportunistic network by the RWs with pervading of vital information throughout the affected area. We have deduced from the study that with RW-count set at 25 in an area of 10 k.m. x 4 k.m. and if their travelling speed be set at 100m/min. yields the best combination in satisfying the demands generated over time at the shelters. The efficiency of the model increases if the speed of the RW agents can be increased. Though, an increase in the number of RWs provides a faster spreading of static information throughout the affected area, it takes much longer time in achieving 100% convergence of the information in comparison to the above deduced RW-count.

Acknowledgment

This study is funded by ITRA, Govt of India.

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