Activity Based Resource Allocation in IoT for Disaster Management

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Abstract. Efficient utilization of resources during disasters is a major and non-trivial problem. Improper resource allocations is due to lacking in knowledge of activity priorities. Due to disaster, in a major instances, communication networks are ruined. In this regard, Internet of Things (IoT) helps to a great extent in establishment of dynamic network for communication. Further, priority based stable matching algorithm is used for allocation of resources for the corresponding activities. This approach determines for maximum utilization of resources with complete accomplishment of activities efficiently. Also, we evaluated our approach with execution time and fairness of resource allocation for utility.

Keywords: Resource allocation · Disaster management
Internet of Things · Graph theory · Stable matching

1 Introduction

A recent survey conducted by United Nations Office for Disaster Risk Reduction (UNISDR), among the top five disaster hit countries India ranked third place [1]. During 2011–2015, 38 million people were affected with different types of disasters and total of 29 million dollars of economic damage occurred [2]. One of the major reasons for such a great loss is unavailability of real time network communication, lack of identifying the activities and improper utilization of resources. Internet of Things (IoT) is an emerging technological concept that uses rapid communications using Internet. It enables the devices to communicate any time, any place and any where [3,4]. Therefore, using IoT helps to formation of dynamic IP enabled network communication.

In the available literature of disaster management [1,2,5,6,9], majorly the challenges are divided the four phases. Namely, the mitigation [15] phase and preparedness phase that is the period before the disaster. In the mitigation phase various issues like public education, infrastructure improvement and critical infrastructure protection, information campaigns were addressed. Community preparedness, volunteer management, material management and emergency response plan were dealt in the preparedness phase. Likewise in the response phase, resource allocation, situation awareness, victim management and plan

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implementation, call_take_dispatch and etc. were covered because this period plays an important role during and shortly after the disaster. Whereas, in the recovery phase where the period long time after the disaster, issues like damage assessment, procurement, public information and insurance claim were considered. The glance of the four phases is as shown in the Fig. 1.

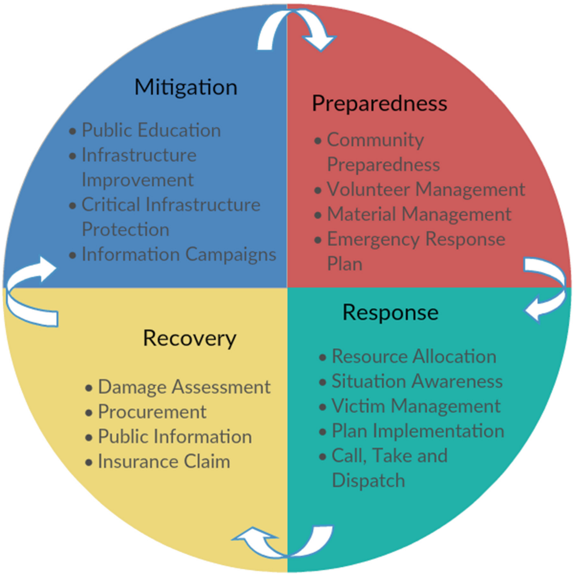

Fig. 1. Different phases of disaster management

Subsequent to the disaster, resource scheduling in the response phase is crucial that must dealt urgent based on identifying and managing tasks. Resource scheduling can be accomplished in the field level and administration level. However, on field addressing of resource scheduling is critical that directly involves in rescue, retrieve and saving lives. Hence, by studying these situations, we address the critical response for resource scheduling using Stable Matching Algorithm. Although, in the available literature for resource scheduling is applied for stable matching for paring the people for marriage [12,13] results in the safe allocation. Likewise, we further extend this approach with appropriate modifications for resource scheduling in a disaster management that results in the safe scheduling that leads to stable allocation.

Also, clustering of the devices and network, for efficient connectivity and communications in IoT is proposed in the in [8,10]. Identification of the places during disasters is handled using localization approached using IoT that is proposed in [11]. Assuming that dynamic network has been established immediately the disasters, communications in the network can be dealt efficiently real time using IoT. However, scheduling the available resources for different activity for disaster management is an non-trivial problem that we are addressing in this paper. Also, we carried out the experimental simulation results with execution time, stability in the safe schedule and fairness for the utilization of resources.

Rest of the paper is organized as follows. The problem description is detailed in Sect. 2. Resource scheduling algorithm and corresponding complexity analysis are described in Sect. 3. In Sect. 4, simulation results are presented and conclusion in Sect. 5.

2 Problem Description

In this section, the problem description is described with appropriate notations that represent the resource allocation for the accomplishment of activities and assumptions.

Let us assume, we have m activities and n resources. The activities can be represented as a which can further defined as a set of sub activities, say $a_1, a_2 ... a_i .. a_m$. Likewise, the resources are represented as r, that can further divided into set of resources defined as $r_1, r_2 ... r_j .. r_n$. Now, the allocation is represented as a graph $G = (V, E)$, where V is a set of vertices which indicates the activities and resources, $E \subseteq \{\{a, r\} \,|a, r \in V, a \neq r\}$ defines the potential allocation edges. A state is a allocation $S \subseteq E$ such that for each $r \in V$, we have $|\,\{e|e \in S, r \in e\}\,| \leq 1$. An edge $e = \{a, r\} \in S$ provides utilities $l_a(e) = l_r(e) > 0$ for a and r respectively. If for every $e \in E$ we have some $l_a(e) = l_r(e) = l(e) > 0$, then it is correlated preferences. If no explicit values are given, we will assume that each vertices has an order of priorities over its possible allocation because for every vertex the utility of allocating edges is given according to their priorities. Then it is called as general preferences. In general preferences, the priority is allowed to be an incomplete list or to have ties. But, we define $P(S, a)$ to be $l_a(e)$ if $a \in e \in S$ and 0 otherwise. A blocking pair for allocation S is a pair of vertices $a, r \notin S$ such that each vertex a and r is either unallocated or strictly prefers the other over its current allocation. A stable allocation S is a allocation without blocking pair.

For instance, let us assume, we have three activities say $a1, a2, a3$ need to be addressed during disaster. Also, let us assume we have three resources say $r1, r2, r3$ are available. An illustrative example is depicted as shown in the Figs. 2 and 3. Each activity can be assigned priorities to utilize the resources to accomplish and vice-verse for the resources to address the activities. Now, $a3$ priorities to utilize the resources is in the order of $r1, r2$ and $r3$. Likewise, $a2$ priorities are in the order of $r2, r3$ and $r1$ and $a1$ needs $r1, r2$ and $r3$. Similarly the resource priorities for $r3$ is in the order of $a1, a2$ and $a3$, for $r2$ is $a1, a3$ and $a2$ and $r1$ is $a2, a3$ and $a1$.

To be precise, in the context of disaster, the activities can be classified as to established a communication network, to provide medical treatment to the critical, rescue and recovery. Suppose, these activities should be addressed in all the disaster places and to accomplish them, resources such as military force, fire engines, volunteers, ambulance and medical help are required. However, the

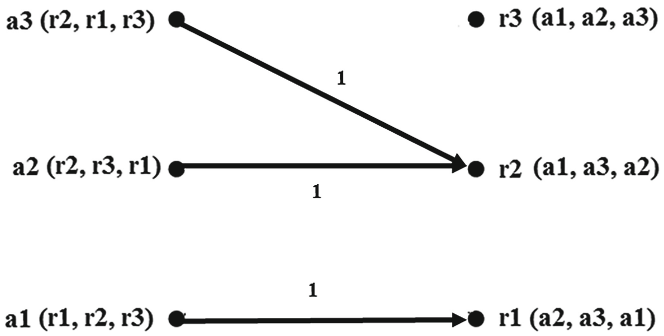

Fig. 2. Example graph with primary activity priorities

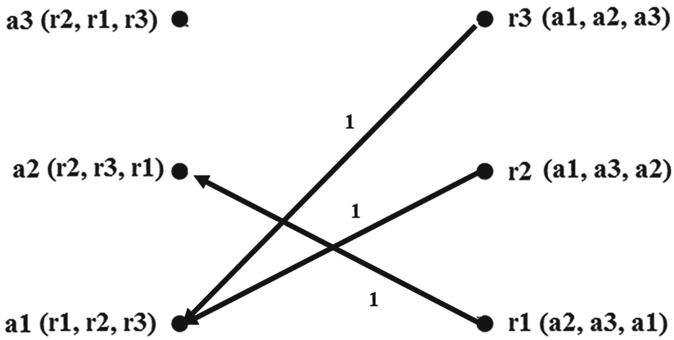

Fig. 3. Example graph with primary resource priorities

resources priorities are assigned by considering many factors such as the distance between the disaster place and resources, traffic considerations, road maintenance etc. Likewise for the activities different priorities are needed. Now, Figs. 2 and 3 depicts the demand of the same resources for different activities i.e., $a1, a2$ demands $r2$ and utility of the different resources to the same activity i.e., $r3, r2$ by $a1$ in Fig. 3. Also, few resources are not utilized properly i.e., $r3$ in Fig. 2. Hence, these kind of improper allocation leads to loss of many lives instead of saving them. Hence, to overcome them, the stable allocation of activities and resources, provided the priorities are crucial. In this regard, we propose the resource allocation algorithm that address this problem and brings the stability in the allocation which is detailed in the next section.

Since we are considering the IoT environment, we are assuming the resources has IP connectivity that by default enables to communicate any time and any where at ay place. Also, since the stable marriage allocation approach works with equal number of pairs, we assume that using clustering approach, grouping of sub activities into activities and grouping of resources can be addressed efficiently.

Further, the priorities of the activities and resources is completely depends on the context of the disaster problem. In this paper, we assume that the priorities are already defined such that we completely focused and determined to address the resource allocation efficiently. Considering these above assumptions, we propose the resource allocation algorithm that is suitable for IoT environment of addressing the resource allocation during critical disaster times.

3 Resource Allocation Algorithm

The proposed algorithm is devised in such a way that the stability in the allocation is determined efficiently. Proper utilization of all resources and proper attention to take care of all activities are considered. Having the knowledge of priorities in all the activities and resources, we utilized the stable matching concept for allocation [12,13]. In Figs. 2 and 3, since $a3$ and $a2$ are requesting the same resources $r2$, but in $r2$, the priority is given to $a1$ which leads to unstable allocation. Likewise, since $r3$ and $r2$ are requesting to be utilized by the same activity $a1$, but $a1$, needs resource $r1$ which leads to again unstable allocation.

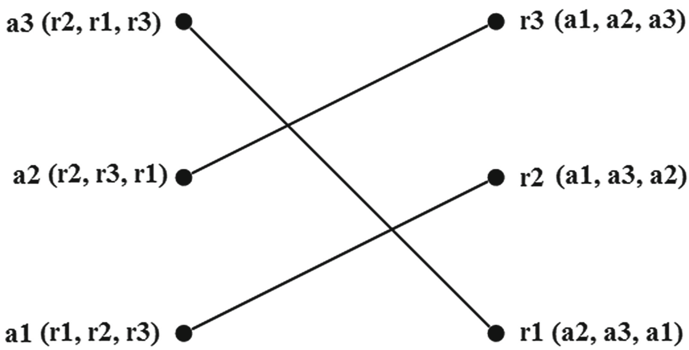

Fig. 4. Example of stable allocation of activities and resources using graph

Hence, by considering the next order priorities of both activities and resources, the allocation is been carried out in such a way that all the activities and resources got paired and none of them are left. As shown in Fig. 4, activity $a3$ is allotted with $r1$, $a2$ is allotted with $r3$ and $a1$ is allotted with $r2$ which brings the stability in the allocation. Also, complete utilization of resources and entire activities are addressed. The corresponding algorithm is devised and as shown in the pseudo code.

Algorithm 1. Resource Allocation Algorithm

```
Data: resources and activities with priorities
Result: activities with allocated resources
while there are still free resources and free activities do
    Let r be the first resource in the list of free resources ;
    Let a be the highest-ranked activity on r's preference list and r will
    try to allocate with a ;
    Let r′ be the resource with activity a is currently allotted. // (r′ can
    be -1 or some other null value if a is free);
    if a is free then
        r gets allotted with a ;
        r gets removed from the list of free resources ;
    end
    else
        a is currently allotted to a different resource r′ ;
        if a prefers r′ to r then
            r stays free //(don't alter the allocation) ;
        end
        else
            //a prefers r to r′ ;
            r and a get allocated with each other ;
            r gets removed from the list of free resources ;
            r′ get added to the list of free resources ;
        end
    end
    Update the next activity choice for r (even if r is no longer free) ;
end
return allocation between resources and activity pairs. ;
```

It is important to analyze the proposed algorithm in terms of computational complexity for critical time analysis and response. The proposed algorithm time complexity is $O(mn)$. There are at most mn possible allocations between activities and resources. So there at most $m \times n$ iterations. To maintain this $O(mn)$ time complexity, each iteration must therefore be of constant time due to knowledge of priorities. However, the brute force algorithm takes $O((m + n)/2!)$ since it goes through each enumeration to verify whether the allocation is stable or not. For m activities and n resources, the number of enumerations is ${}^{m}P_{n}$ which is equal to $((m + n)/2)!$.

4 Simulation Results

The simulation results for allocation of activities and resources stability is evaluated in terms execution time and fairness in the allocation resources that determines the utilization.

By First Come First Serve (FCFS) approach which works in the fashion of brute force and our proposed approach with respect to execution of time with different number of pairs are compared and is shown in Fig. 5. The proposed approach out performs the FCFS in terms of bringing stability in the allocation of resources and activities. Although till 8 pairs of resources and activities, both approaches have same execution time but as number of pairs increases the FCFS execution time rapidly grow exponentially. For larger inputs like 160, FCFS is unable execute the allocation for the resources and activities but whereas our proposed approach gives linear results even at the 1280 pairs.

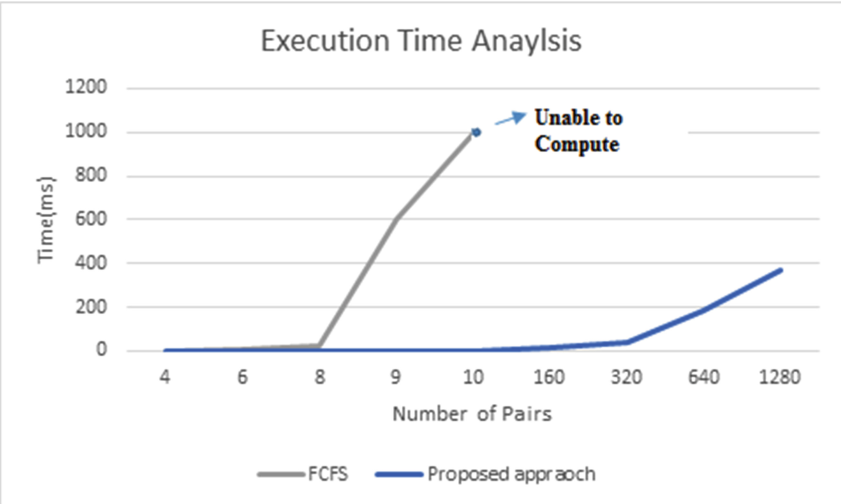

Fig. 5. Comparison of execution time analysis

The proposed approach is devised in such a way that complete utilization of the resources are carried out. For each activity the resources were allocated with complete fairness. Jain et al. [14], proposed to measure the fairness in terms of quantity which is given in the following Eq. 1.

$$f(X) = \left[\sum_{i=1}^{n} x_i\right]^2 / n \times \sum_{i=1}^{n} x_i^2 \qquad (1)$$

where $0 \leq f(X) \leq 1$ is fairness measure of resource allocation and $X = (x_1, x_2, ..., x_n)$ implies the allocated resources, n is the number of resources and activities and x_i is the amount of resource allocated to individuals $i = 1, 2, ..., n$. A large value of $f(X)$ represents fairer resource allocation from the system perspective. The corresponding results is shown in Fig. 6. Also, by deduction we can say greater the value of fairness implies better the stability, that is Fairness is directly proportion to Stability.

Hence, when compared with FCFS and our proposed approach, the allocation of the resources in FCFS is not good for the pairs from 30 onwards. But, whereas in our approach the allocation is stable even in larger pairs which is shown in Fig. 6. Since, FCFS approach couldn't able to perform the allocation under the same environment where our proposed approach is carried out, we couldn't able to compare the fairness allocation for the larger inputs i.e., from 160 pairs to 1280 pairs. Hence, our proposed approach gives better results for larger inputs which is suitable for IoT environment. Because, IoT assumes huge number of devices are going to take part, it reasons out that the proposed approach of resource allocation performs well. Also, it is well suited for the applications of disaster management where the rescue, recovery operations are critical.

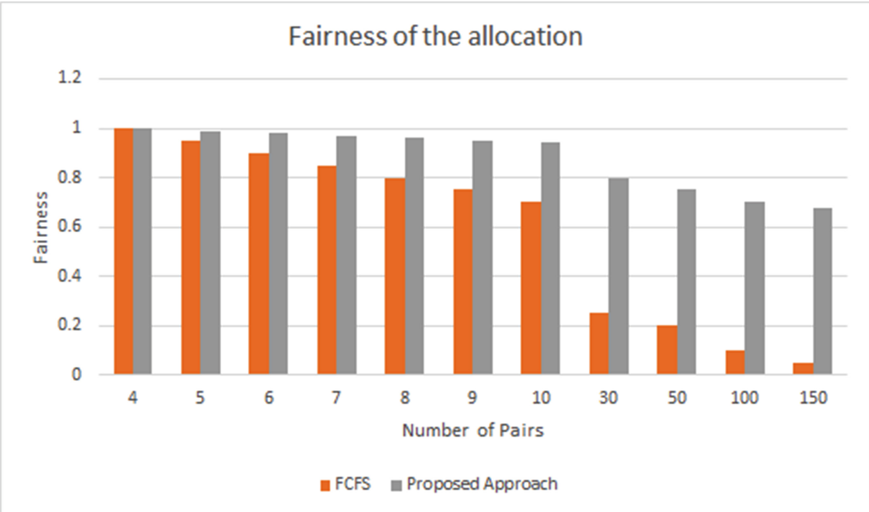

Fig. 6. Comparison of fairness analysis in allocation

Further, without proper mapping to real time environment of identifying the activities and resources, it is hard to validate our approach. Therefore, we made efforts to represent our approach in Google maps [16]. Hence, the proposed approach is shown in real time allocation using google maps as shown in Fig. 7 in which R1..R6 indicates resources and allocated with corresponding activities. The resource r_1 is allocated to activity a_1, resource r_2 is allocated to activity a_3, r_3 to a_5, r_4 to a_2, r_5 to a_6 and r_6 to a_4 respectively. Therefore, our approach assures that all the activities are addressed with proper utilization of all resources.

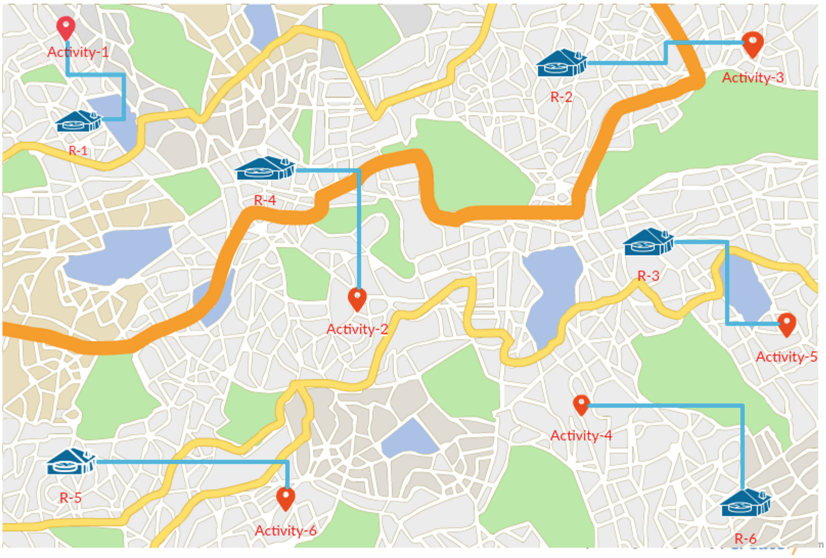

Fig. 7. Real time allocation shown in Google Maps

5 Conclusion

Resource allocation and activity management is critical during disaster scenarios. The use of IoT in the establishment of communication network in such cases helps in efficient mapping of resources to the network entities. Also, knowing the priorities in resources and activities assist to determine the allocation efficiently using stable marriage matching in order to bring the stability in the network. The proposed approach is evaluated in terms of fairness and execution time, which shows better results than FCFS brute force approach.

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